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MITRE PRODUCT

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Abstract

Interest in Unmanned Aerial Vehicles (UAVs) is growing worldwide and several efforts are underway to integrate UAV operations routinely and safely into civil airspace. Currently, UAV operations are confined to special-use airspace or are limited in their access, for safety reasons, by a restrictive authorization process. This document provides a context of UAV developments, describes current initiatives, and frames and assesses the issues associated with the integration of UAVs in civil airspace. Reviewed are issues related to potential safety, security, air traffic, regulatory, and socio-economic impediments. The paper concludes with recommended actions for moving forward. The intent in describing the issues and proposing recommendations is not to suggest a conclusive set of issues nor to provide a prescriptive direction, but rather to stimulate discussion, build consensus, and promote strategic planning among the organizations having a stake in the emergence of UAVs into civil airspace.

KEYWORDS: Unmanned Aerial Vehicle (UAV), integration

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Executive Summary

Military investment in unmanned aerial vehicle (UAV) research, systems, and applied technologies is increasing, and potential uses for UAVs in civil operations, particularly for homeland security, is being investigated by federal, state, and local governments. These developments, along with growing scientific interest in UAVs, are fueling commercial interest in the unmanned market. UAVs offer a unique range of features, most notably ultra long-endurance and high-risk mission acceptance, which cannot be reasonably performed by manned aircraft. These features—when coupled with advances in automation and sensor technologies, and the potential for costs savings—make a strong case for the eventual emergence of a robust civil, government, and commercial UAV market.

While UAVs hold much promise, there are numerous issues that must be overcome as a precondition to their routine and safe integration in civil airspace. Chief among these are:

- Lack of consensus on operational concepts, definitions, and classifications of UAVs
- Absence of certification standards and regulations addressing UAV systems, operations, and operator qualifications
- Lack of an effective and affordable collision avoidance system capable of detecting non-transponder equipped aircraft
- Poor reliability record of UAV systems and operations
- Lack of an available protected frequency spectrum
- High insurance liability costs
- High acquisition and operational costs

Even if these problems are resolved and UAVs are permitted full integration into the civil airspace system, there remain less tangible matters that may impede UAV developments and market potential. Such latent issues include:

- Public apprehension or rejection of UAVs
- Resistance from existing airspace users
- Poor information data exchange networks
- Lack of security controls on UAV operations
- Absence of an adequate business case for UAV operations
- Capacity limitations of the airspace

- Lack of international harmonization on standards and regulations

Based on an assessment of the issues, this document identifies ten recommended actions to achieving the goal of the safe and routine integration of UAVs in civil airspace:

1. Agree upon a concept of operations for UAV flights in civil airspace.
2. Develop a classification scheme and definitions for UAVs as they relate to operations in civil airspace.
3. Establish regulations for UAV system certification, flight operations, and ground controller qualifications.
4. Develop effective technologies and procedures to prevent collisions of UAVs with other aircraft, the ground, or other obstacles.
5. Institute security controls and approvals for UAV operations.
6. Develop and implement communications solutions for UAV systems.
7. Develop an aeronautical data exchange, processing, and synchronization network that accounts for unique UAV requirements.
8. Internationally harmonize UAV regulations, certification standards, and operational procedures.
9. Ensure interoperability with the air traffic system and assess potential impacts on the air traffic system and its regulatory and operational environment.
10. Gain public acceptance and actively communicate with all potentially affected parties.

The emergence of a commercial UAV market poses a number of challenges to the aviation system. The technologies under development and decisions under consideration today could have a profound impact on all aviation, from how airspace is used, to how the aviation market will evolve in the coming years. In this respect, UAVs present a potentially disruptive influence on the entire aviation system. Unmanned aircraft will augment some manned flight operations (adding to airspace capacity and complexity issues) while displacing others (creating labor and market disruptions). They will likewise alter existing assumptions concerning aircraft performance values, flight paths, and air services. Further, UAVs, acting as a test bed for experimentation, will act as a forcing function to the introduction of novel technologies and operational concepts. These changes, while disruptive in nature, should not be presumed to have an entirely negative influence on manned flight operations. Rather, such advances in UAV technologies will likely benefit the design and operation of manned aircraft by making them more capable, efficient, and safe. In addition, the operation of UAVs will bring benefits to the public through the provision of new services. But with these benefits will almost certainly come costs—real and perceived.

Balancing these benefits and costs will be an important part in the development of a regulatory framework for unmanned systems.

Understanding the issues, trends, and influences of UAVs will be critical in strategically planning for the future airspace system. Whatever form the UAV market takes, the airspace system—both domestic and foreign—should be prepared to accommodate its growth. This will require an effective strategy that accounts for the interactive complexities and unique properties of UAVs. Additionally, continued research is needed to better assess the potential influence of UAVs on future traffic flows, airspace capacity, infrastructure, and air traffic control procedures. These research activities will assist policy makers, manufacturers, air traffic control service providers, and regulators in building a future environment that supports *all* users of the civil airspace system while supporting the advancement of aviation.

Section 1

Introduction

In many respects, the state of the unmanned aerial vehicle (UAV) today resembles the early days of aviation. During that time, creative minds, engineering talent, and entrepreneurial spirit converged to produce new technologies and designs that spawned a new market, brought aviation to the masses, and altered forever the transportation landscape. Today that same spirit permeates the UAV industry as innovators are vying to enter and dominate in a new and potentially lucrative market.

Unmanned aircraft are a product of the military. Their success in recent conflicts has demonstrated their worth. Militaries worldwide are committing increasingly larger sums to researching and acquiring these systems. The investments and the technological advances made by military organizations have generated a growing interest in their potential use for civil government, scientific research, and commercial applications. But significant barriers to the development of these markets exist; most prominent being lack of access to civil airspace.

Integration of UAVs into civil airspace and their potential market success depends on a complex set of technical, economic, political, and legal factors. Unlike the early years of aviation, UAVs do not operate in empty skies. Rather they must contend with a mature civil aviation system—one filled with aircraft, controlled and monitored by complex systems, dominated by large commercial markets, saturated by interest groups, and governed by a voluminous regulatory structure.

This document examines the issues confronting the routine and safe integration of UAVs in civil airspace, and offers recommended actions for moving forward. The introduction provides a context for the issues.

1.1 What is a UAV?

This is a surprisingly difficult question to answer. Different organizations refer to UAVs in different ways. In the past, the FAA has termed these aircraft as "remotely piloted vehicles" and later "remotely operated aircraft," or "ROAs." The military is responsible for the current naming convention of "unmanned aerial vehicles," or "UAVs." Others have attempted variations, such as "uninhabited" or "unoccupied" to replace "unmanned." Past terms also include NASA's "remotely piloted aircraft" and the UK's "unmanned aircraft," but these terms are used less and less. For this paper, "unmanned aerial vehicle" and "UAV" will be used, as it is the most widely recognized and used international term.

Apart from the term, there are also differences concerning the definition. In its most basic sense, a UAV is any aircraft capable of being flown without a human on board. But what does this mean? What is included in the scope of this definition? Does it include balloons? Model aircraft? Airships? Missiles? Civil aviation authorities and various working groups have developed several definitions, yet none are universally accepted. Following are three examples:

- The Office of the Secretary of Defense, in its March 2003 UAV Roadmap, uses the following definition: "A powered, aerial vehicle that does not carry a human operator, uses aerodynamic forces to provide vehicle lift, can fly autonomously or be piloted remotely, can be expendable or recoverable, and can carry a lethal or non-lethal payload. Ballistic or semi-ballistic vehicles, cruise missiles, and artillery projectiles are not considered unmanned aerial vehicles."
- The British, in recently published guidance, defines a UAV as "an aircraft that is designed, or modified, to carry no human pilot and is operated under remote control or in some autonomous mode of operation."[1]
- An FAA working group formed in the 1990s defined UAVs as "an aircraft capable of flight beyond visual line of sight under remote or autonomous control for civil (non-DoD) purposes. A UAV is not operated for sport or hobby and does not transport passengers or crew."[2]

From these examples, it is clear that consensus on a definition does not exist. Because of this, no single definition is adopted for this document. The lack of a common definition is part of the current debate and presents an impediment to UAV regulatory and standards development.

1.2 Historical Perspective

The history of UAVs is one of cyclical developments often centered on military conflicts reaching back as far as the mid-eighteenth century when unmanned balloons were used in Europe and later during the American civil war to drop bombs (unsuccessfully). During WWI the U.S. developed a pilotless aircraft known as the "Kettering Bug," which flew for a predetermined time before releasing its wings and plunging to the earth. Several were built but none flew in combat. It wasn't until 1920 that the first truly remote controlled aircraft, the Sperry Messenger, was built. But peacetime interest diverted funding away from this and other remotely operated aircraft. Few, at the time, saw any practical civil use for the technology.

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[1] "Unmanned Aerial Vehicle Operations in U.K. Airspace – Guidance," CAP 722, Section 2.1, Directorate of Airspace Policy, Civil Aviation Authority, 2002.

[2] FAA Draft Advisory Circular, "Unmanned Air Vehicle Design Criteria," Section 6.j, 15 July 1994.

Then in the 1930's, with war once again looming, interest in UAVs saw a resurgence, but this time for target practice. During the 1930's, the British developed and produced more than 400 unmanned target vehicles, known as "Queen Bees", a name which eventually led to the widely used term "drone." The U.S. also began to build UAVs for target practice. In the late 1930's, a famous screen actor and remote control model enthusiast, Reginald Denny, convinced the US Army to use his remotely controlled aircraft to train anti-aircraft gunners. From 1939 through WWII, over 15,000 of these "Denny drones" were produced.

Though the U.S. and U.K. were producing small unmanned systems in volumes, it was the Germans who, during WWII, made the greatest advances to unmanned aviation technology with the advent of the V-1 bomber, an aircraft capable of autonomous control. The V-1 was significant in that it demonstrated how formidable a threat an unmanned aircraft could pose. Following the war, the U.S. learned lessons from the V-1 and applied these to new UAV designs at home.

During the Korean to Vietnam wars, several important technological advances in unmanned system controls were developed. These advances culminated in the development of the Firebee UAV, a jet powered vehicle, similar in size to a small business jet. This vehicle was unique in defining a new role for UAVs: surveillance. Surveillance was found to be the ideal mission for UAVs, one that remains today as a primary application. The Firebee flew over 3,400 sorties into North Vietnam and China throughout its years in service.[3] Also during the 1960's the U.S. deployed a highly classified vehicle known as the D-21 that was capable of speeds in excess of Mach 3 and could fly at altitudes up to 90,000 feet.[4]

While U.S. investment in UAVs receded following Vietnam, other countries began to develop UAV programs, but none more successfully than Israel. Throughout the 1970's and 1980's, the Israeli Air Force pioneered several new vehicles that were eventually integrated into the fleets of other countries in the late 1980's and early 1990's, including the U.S. It was during 1990's that UAVs gained wide acceptance as a useful military tool. The conflicts in the first Iraqi war and later in the Balkans ushered in a new era for UAVs, giving them mass media exposure. This exposure was heightened during the most recent conflicts in Afghanistan and Iraq. A variety of new UAV military systems and concepts for use evolved rapidly during this time.

It was also in the 1990s that a more peaceful role for UAV systems was conceived. Scientific endeavors, such as persistent environmental monitoring, were seen as ideal function for UAVs. The solar-powered Pathfinder and Helios aircraft, both developed by NASA and the Aerovironment Corporation in the late 1990's, exemplified the development

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3 www.sit.wisc.edu/~wrbritton/pages/evopage.htm

4 www.wpafb.af.mil/museum/annex/an11.htm

of innovative research UAVs. Other countries also began to develop UAVs for non-military applications. For example, in 1998 an Australian firm produced a 30 pound UAV, called the Aerosonde Laima, which crossed the Atlantic Ocean autonomously on only 1.5 gallons of automotive gasoline.

Achievements in the 1990's not only highlighted the value of UAVs for military and scientific missions, but also advanced prospects for their eventual use in civil government and commercial applications. Such prospective applications were, however, limited in numbers due to restrictions placed on the movements of UAVs outside of special use airspace. By the late 1990's, the need for greater access to civil airspace for UAVs became more apparent to accommodate the various missions and support a growing market.

1.3 Where are we today?

Interest in UAVs continues to grow worldwide. Recent advances in computer technology, software development, light weight materials, global navigation, advanced data links, sophisticated sensors, and component miniaturization are strengthening capabilities and fueling the demand for UAVs. Today, at least 32 countries are developing UAVs. Of these, the U.S. is leading in terms of the size, variety, and sophistication of UAV systems, seconded perhaps by Israel which has a very strong market for its military UAVs, some of which have been purchased by the U.S. for military and homeland security. Other countries having significant UAV development programs include Japan, South Korea, Australia, France, England, Italy, Germany and Sweden. Incidentally, in terms of numbers of operational UAVs, Japan leads the world with nearly 2,000 UAVs being used today for agricultural spraying and planting operations.

In addition to those countries developing UAVs, 41 countries are known to operate UAVs. There are an estimated 200 to 300 UAV models in existence worldwide (estimates range broadly due to a lack of common understanding or acceptance in defining a UAV). Of all UAV types, the vast majority (approximately 90 to 95 percent) are military, and most of those used for surveillance work.

1.3.1 Recent Initiatives and Active Organizations

In the past two years, there have been an expanding number of initiatives seeking to advance UAVs and to facilitate their integration into civil airspace. These initiatives represent national and international interests, as well as military, civil government, and commercial constituencies. Following are descriptions of the more prominent efforts by the various organizations seeking to allow greater access to UAVs in civil airspace.

1.3.1.1 Military Initiatives

The U.S. military was the earliest advocate of gaining greater access to civil airspace. This is understandable considering the vast majority of all UAVs are operated by them. In

1999, DoD, working with the FAA, developed an approval process that permitted UAVs to operate in the National Airspace System (NAS). This approval process—known as a Certificate of Authorization (COA) and contained in FAA Order 7610.4, *Military Operations*—requires a case-by-case safety evaluation of each flight. The process can take weeks to months to approve depending on the FAA region or regions where the flight will take place. A primary consideration in the approval process is the see-and-avoid capability, which usually requires primary radar coverage and/or a chase plane to accompany the UAV. The FAA will issue a time and route of the UAV flight to avoid risks to aircraft and persons on the ground. The process is cumbersome and is incapable of sustaining a high volume of UAV flight requests. This severely limits the utility and missions of UAVs.

In the fall of 2003, the DoD, in working with the FAA, developed a "national COA" specifically for the Global Hawk aircraft. This approval allows for Global Hawk flights to bypass obtaining approvals from each FAA region and instead can use one approval for national flights. The national COA has allowed the Air Force to reduce the COA approval time to approximately one week.

While the COA process works, it is neither a preferred nor a long-term solution. The military understands that its UAVs must integrate with manned aircraft and the air traffic system in a transparent manner that does not impose unwarranted safety risks or appreciable impacts on traffic flow. With the rapid increase in numbers and missions expected for military UAVs in the coming years, the DoD sought to form working groups to address these issues. Two such initiatives are summarized below.

- *Unmanned Aerial Vehicle Planning Task Force.* In October 2001, the Under Secretary of Defense (Acquisition, Technology and Logistics) established the UAV Task Force as the Defense Department's focal point responsible for assisting the military in their acquisition planning, prioritization, and execution of UAVs, and Unmanned Combat Air Vehicles (UCAVs). The goal of the Task Force is to ensure the DoD's UAV and UCAV programs proceed in a coordinated manner. In March 2003, the Task Force published the Office of the Secretary of Defense (OSD) UAV Roadmap. This roadmap outlines the direction of the U.S. military with respect to UAV research, acquisitions, and uses through 2027. The roadmap provides 49 distinct goals on matters such as platforms, sensors, communications, small UAVs, interoperability standards, airspace, and system reliability. One broad objective of the roadmap is to "promote a common vision for future UAV-related efforts by making the Roadmap widely available to industry and our Allies, and by updating it as emerging transformational concepts, such as network-centricity, are better understood." UAVs are seen as having a central role in the military's transformation. As it concerns the civil UAV community, the OSD Roadmap states as one of its top-ten goals the ability to better coordinate UAV flight activities with the FAA by revising Order 7610.4 concerning the Certificate of COA process with a method that allows for more rapid and routine access to the NAS. According to the OSD

Roadmap, the FAA and the Air Force Flight Standards Agency are engaged in establishing the air traffic infrastructure for integrating military UAVs into the NAS. The military hopes that its efforts to allow for greater access to military UAVs will establish the precedent for subsequent use by civilian UAVs domestically and to civilian and military flights in foreign airspace.[5]

- *NATO Flight in Non-Segregated Airspace (FINAS)*. In November 2003, the NATO Air Group 7 agreed to the formation of the FINAS initiative. The objective of this program is to recommend and document NATO-wide guidelines to allow for international operations of UAV in civil, or "non-segregated," airspace. The guidance will cover airworthiness, system certification, security, flight operations, maintenance, air traffic management, and legal matters. The initial focus of the group is on medium-altitude, long-endurance UAVs. The first official meeting of the FINAS working group was held in March 2004.

1.3.1.2 Government/Industry Initiatives

Even prior to the military initiatives described above, several civil government and private organizations were working to bring UAV flight operations in line with a manned operational environment. Below are descriptions of the various government and industry initiatives taking place in the U.S. as well as internationally.

- *The Technical Analysis and Applications Center (TAAC)*. The TAAC, part of the Physical Science Lab (PSL) at New Mexico State University, is one of the forerunners advocating UAV access to the NAS. In 2002, the TAAC produced a roadmap and operational concept for high altitude long-endurance (HALE) UAVs. The TAAC has also developed the UAV Systems and Operation Validation Program, which has a program for the operational and performance of UAV systems. Part of this program includes supporting tests of UAV platforms and systems in civil airspace. The TAAC has made arrangements with White Sands Missile Range to produce a joint regional UAV test and evaluation center for UAV research.
- *Joint Planning and Development Office (JPDO) UAV National Task Force (UNTF).* The JPDO was formed in the summer of 2003 as part of a multi-agency effort to transform the transportation industry. As part of this effort, a UAV working group was formed in December 2003 with chairs headed by the U.S. Transportation Security Agency (TSA) and the White House Office of Science and Technology Policy (OSTP).

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[5] OSD Roadmap, Appendix G, pg. 153.

- *UAV National Industry Team (UNITE)*. UNITE is a legal association formed by six leading U.S. aerospace firms (AeroVironment, Aurora Flight Sciences, Boeing, General Atomics Aeronautical Systems, Lockheed Martin, and Northrop Grumman) involved in the production of high-altitude, long-endurance (HALE) UAVs. This association was established with the single goal of gaining routine access of HALE UAVs into the U.S. National Airspace System (NAS). UNITE saw the need for a coordinated approach with the government to meet the many challenges involved in this goal. In 2002, UNITE approach NASA and formed a partnership which eventually led to the creation of Access 5.
- *Access 5*. The Access 5 organization was formed in 2003 in partnership with UNITE. The title "Access 5" refers to its objective of providing safe and routine *access* to high-altitude, long-endurance (HALE) UAVs in the National Airspace System (NAS) within *five* years. The project is sponsored by NASA and involves participation with the FAA, DoD, and UNITE, as well as others from industry. Planning work began in 2003 and funding for the first two years ($100 million) was approved in May 2004, with official work begun in June 2004. Access 5 intends to take an incremental approach to introducing UAVs into the NAS. HALE UAVs were chosen as the focus because they tend to be the most mature systems. The Access 5 effort intends to lay the groundwork for the future introduction of other classes of UAVs.
- *JAA/Eurocontrol UAV Task Force*. The Joint Aviation Authority (JAA) and Eurocontrol established a working group (also known as the UAV Task Force) in September 2002 to address a concept for civil UAVs regulations pertaining to safety, security, airworthiness, operational approval, maintenance, and licensing. The task force was comprised of 55 members from government and industry, including one FAA representative. The UAV Task Force produced its first publicly released report in June 2004. The intent of the report is to assist the International Civil Aviation Organization (ICAO) EUR/NAT Office in support of future ICAO UAV initiatives, and to advise the European Aviation Safety Agency in the development of future airworthiness regulations pertaining to civil UAVs. The JAA/Eurocontrol working group activities coincided with work from the UAV Safety Issues for Civil Operations (USICO) and Civil UAV Applications and Economic effectiveness of potential CONfiguration solutions (CAPECON) efforts.
- *UAV Thematic Network (UAVNET)*. The UAVNET is a 14-nation initiative started in October 2001, funded by the European Community, with the intent to stimulate growth in the civil UAV market. Designated as a "thematic network" this initiative is to act as an information exchange and to suggest policies and activities concerning critical technology research in the area of UAVs. The Israel Aircraft Industries coordinates closely with this effort. It sponsors two research programs, USICO and CAPECON.

- *Civil UAV Applications & Economic effectiveness of potential CONfiguration solutions (CAPECON)*. CAPECON is an eight-country program funded by UAVNET to investigate future civil UAV developments, applications, technologies, configurations, and economic viability. Results of the study are to conclude at the end of 2004 with a set of recommendations for the design of safe and cost-effective UAVs for civilian use.
- *UAV Safety Issues for Civil Operation (USICO)*. The USICO initiative, also funded by UAVNET, was launched in 2001 to study issues pertaining to UAV operations in civil airspace. USICO has compiled an analysis of commercial missions for UAVs. Further, this initiative is planning on a practical approach for UAV civil certification and operations regulations.
- *UAV's Concerted Actions for Regulations (UCARE)*. The UCARE initiative was formed to play a coordinating role in bringing various international interests together to help form regulations allowing for greater access of UAVs, and to create a basis for consensus on UAV policy and standards. UCARE participants include industry, Research and Development (R&D) organizations, military, and civil government bodies, including the FAA, NATO and Eurocontrol, as well as universities and associations from Europe, North America, Asia/Pacific, and South Africa. This initiative is largely being run by Unmanned Vehicle Systems (UVS) International.
- *Euro UAV Industry Consultative Body (ICB)*. The Euro UAV ICB was formed in April 2004 by seven European nations with the objective of allowing operators of qualified UAVs to fly their vehicles routinely and safely in European airspace. This group intends to act as a focal point for all European civil and military authorities involved in the development of recommendations, requirements, and procedures pertaining to this objective.

1.3.1.3 Associations and Standards Organizations

Associations have played a key role in bringing various industry and government efforts together to support the creation and expansion of a civil/commercial UAV market. Most major aviation countries today have representation from one of these associations, and some new associations have been established by several countries in the past year to assist in these efforts (e.g., Unmanned Vehicle Systems [UVS] Canada and UVS Japan). Listed here are the more prominent associations and their related activities.

- *The Association for Unmanned Vehicle Systems International (AUVSI)*. AUVSI is the world's largest association working with the UAV community. Founded in 1973, AUVSI is also the oldest association representing the unmanned systems community. The association has members from government organizations, industry, and academia. AUVSI fosters, develops, and promotes all types of unmanned systems—ground, undersea, and airborne—and related technologies. AUVSI was instrumental in forming initial contacts with the FAA concerning UAV access to civil airspace and in facilitating the initiation of the American Society for Testing and Materials (ASTM) UAV Committee in 2003.

- *American Society for Testing and Materials (ASTM) UAV Committee*. In July 2003, AUVSI coordinated the initialization of an ASTM committee (designated F38) which is to develop consensus standards that enable UAVs to be manufactured and operated in the NAS, using air traffic control rules and procedures similar to those governing general aviation. There are three subcommittees covering the areas of airworthiness certification, flight operations, and operator qualifications. A draft standard on UAV collision avoidance was published by the airworthiness subcommittee in August 2004.

- *Unmanned Vehicle Systems (UVS) International*. UVS International began as Euro UVS in 1995, but changed its name in 2004. The association seeks to promote all unmanned systems, obtain international consensus, provide an information exchange forum, identify business opportunities, give support to the establishment of standards and regulations, and promote awareness of UAVs with the general public.

- *Unmanned Aerial Vehicle Systems (UAVS) Association*. The UAVS Association, a UK-based organization, was established in 1998 and is the oldest trade association dedicated to UAVs. Their objectives are to overcome barriers to the creation of a UAV market, to facilitate the creation of an industry capability in the UAV market, and to provide advice and best practices in supporting UAV industry development of its members. The association holds official positions in the UK government steering and working groups. UAVS also acts as an information exchange with other associations such as UVS International, AUVSI, and TAAC.

- *American Institute of Aeronautics and Astronautics (AIAA) Unmanned Systems Program Committee (USPC)*. The AIAA USPC was formed in 1989 to coordinate UAV constituencies in the aerospace technical community, focus science and technology on UAV needs, and to promote cultural acceptance of unmanned systems by the public. This association also organizes technical conferences and symposia on areas related to UAV technologies and operations. In 2004, the committee developed a terminology standard for UAVs and has begun working on a standard related to UAV payload integration and applications.

- *RTCA, Inc. (formerly Requirements and Technical Concepts for Aviation; and formerly Radio Technical Commission for Aeronautics) (RTCA) Special Committee 203 (SC-203) for UAV Standards Development*. The formation of RTCA SC-203 was announced in August 2004. The intent of this committee is to develop standards for UAV aircraft operators and airworthiness certification, and flight operations in the NAS. Work is expected to commence in December 2004.

Several national associations representing UAVs were also formed in the past year including UVS Canada, Japanese UAV Association, Korea UAV Association, and UAV South Africa.

1.4 Where will it go?

Despite the many advances in the past century, UAVs are still considered by many to be in their embryonic stage. Predictions of where the industry is headed remains speculative. A number of influencing elements, such as technology advances, cost containment, regulatory controls, and public acceptance will ultimately determine the direction and strength of the UAV market. But from the vantage point of today, the prospects for UAV growth looks promising.

In its broadest context, there are three major UAV market segments: military, civil government, and commercial. While market drivers and dynamics among these segments differ significantly, they share a common objective: provide a service that cannot be accomplished by manned aircraft, and/or perform an existing manned operation at a lower cost. Development of the UAV market therefore depends on the unique characteristics and costs of UAVs services relative to manned operations. This applies to each market. For the commercial market, potential UAV business ventures will require building a sufficient business case, demonstrating to investors that the potential returns outweigh the risks. These business cases will vary significantly depending on demand for the proposed service(s), the costs of system acquisition and operation, level of competition, regulatory impediments, insurance liability, etc.

Though UAVs are not a new technology, they exhibit many characteristics of a newly emerging technology market: the technology is not altogether mature, operational concepts are being formed, and emotional and political influences on the market remain strong. The following are descriptions of the prospective markets for the military UAVs as well as civil government and commercial UAVs.

1.4.1 The Military Market

Since the 1950's, the U.S. military has spent more than $25 billion on UAV development but has had difficultly in setting priorities, determining missions, and developing standards for UAVs. This has resulted in programs being repeatedly modified, replaced, or scrapped. It seems that today, however, the U.S. defense establishment and other foreign militaries have committed to ensuring more stability in the development and fielding of these systems and view UAVs as a vital component of their military arsenal.

The military is setting the pace for UAV funding, research, and applications; consequently, they make up the largest market for UAVs today. According to one account, 90 percent of all funding for UAV systems worldwide is directed to military and defense programs.[6] In the past two years alone, U.S. military spending on UAVs has gone from $300M-400M a year to over $1 billion, as shown in Figure 1-1, and the Department of Defense expects to spend at least $16 billion through 2010, placing robotic systems among the Defense Department's top buying priorities.[7] This is backed up by a 2004 study by the Teal Group, which indicates that the U.S. market for military UAVs is "the most dynamic sector of the aerospace industry" and it estimates the market "will more than double in the next decade."[8] The 2003 OSD Roadmap provides the annual funding profile for UAVs in the following graphic.

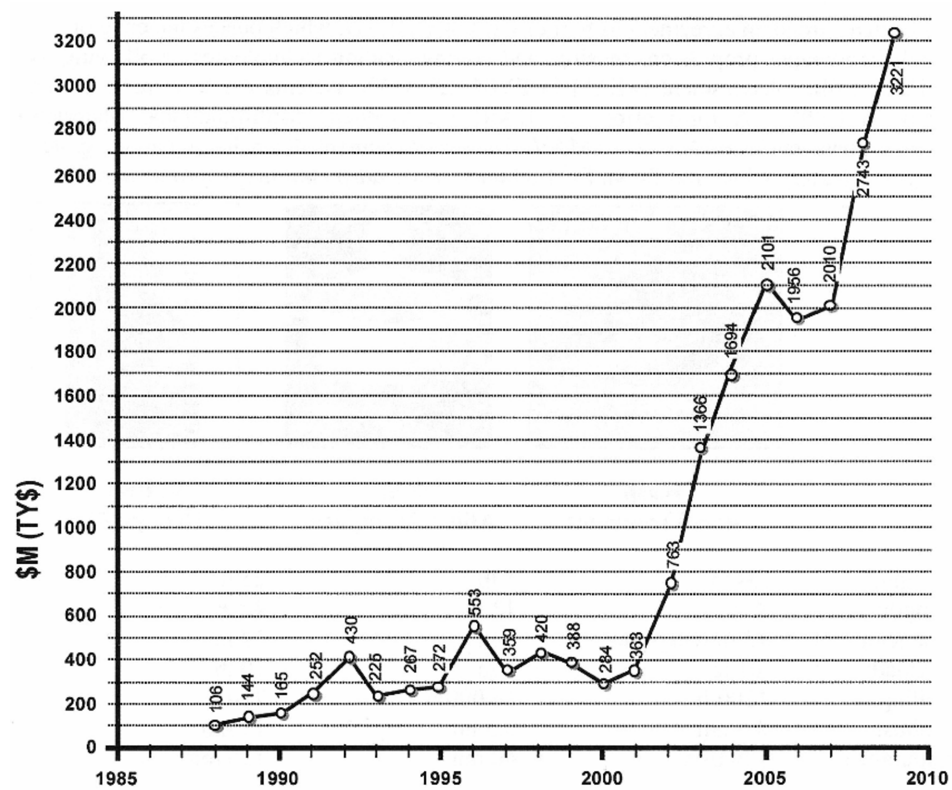

Figure 1-1. DoD Annual Funding Profile for UAVs

[6] Kuke, Dr. Reimund, "Unmanned Aerial Vehicle Safety Issues for Civil Operations (USICO)," Briefing to the European Union, 26 January 2004.

[7] Megan Sully, "U.S. Pours Millions Into UAV Acquisitions," Defense News, 9 August 2004.

[8] Presentation of a UAV market study by the Teal Group at the AUVSI Unmanned Systems Symposium in August 2004.

The OSD roadmap also shows the new UAV systems expected to come on line in the coming decades (see Figure 1-2). The roadmap also indicates that a growing share of military UAVs will be combat vehicles (UCAVs).

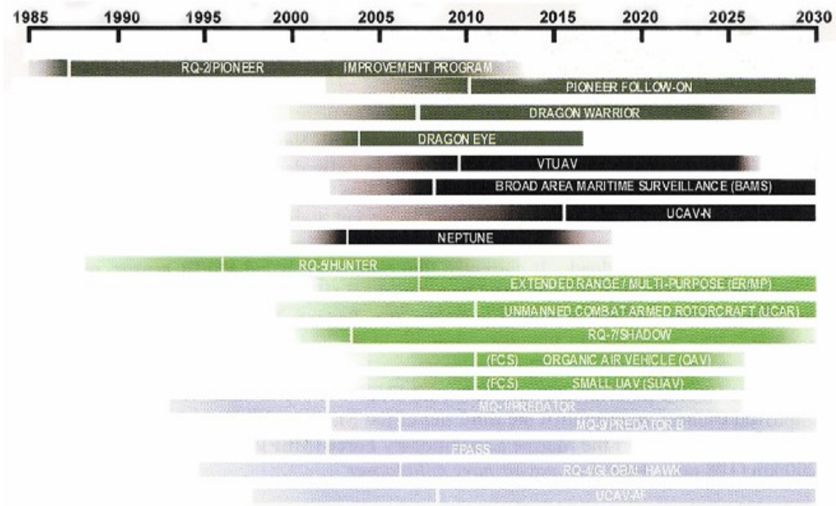

Figure 1-2. Timeline of Current and Planned DoD UAV Systems

While the U.S. makes up the lions share of the UAV military market—particularly with respect to the larger HALE and more sophisticated UCAV segments—other countries are beginning to make significant contributions. Following is a brief summary of select individual country programs:

- France is studying UCAVs as a replacement for its Rafal fighter aircraft. It has a $350 million program to produce a UCAV by 2015 that are capable of delivering two 500 lbs guided bombs. France is also interested in developing or acquiring HALE and Medium Altitude Long Endurance (MALE) systems.
- The British Royal Air Force is set to acquire MALE and tactical UAV Tactical Unmanned Aerial Vehicle (TUAV) systems under its $1.3 billion Watchkeeper program.
- The Italian Air Force is seeking the development of a UCAV system and could be flying a precision strike capable aircraft by 2008.
- Sweden has developed and flown a small scale UCAV, but will likely contribute its efforts to the French UCAV program and could contribute between $70 and $90 million to the effort.
- Germany is seeking to acquire the U.S. Global Hawk. Successful tests of the Global Hawk were demonstrated in Europe in the spring of 2004.

- Israeli industries are developing a number of MALE systems, primarily for intelligence gathering. Israel is also contracted to produce a number of TUAV systems for foreign clients.
- The Russian military has evaluated several TUAVs from Russian manufacturers. Yakolev is studying the development of UCAVs; Tupolev is projected to work on a MALE; and Sukhoi is collaborating with France's Dassault on the development of a UAV.
- Australia is undertaking a comprehensive review of its UAV needs. They have expressed interest in Boeing's UCAV and the Global Hawk. The military has used their indigenous Aerosonde UAV for surveillance and communications relay during military operations in the South Pacific.
- Singapore has a HALE UAV requirement as a replacement for a manned surveillance aircraft. They are also looking into a ship-based VTOL UAV, possibly the U.S. Fire Scout.
- The South Korean government is seeking to develop a "smart" Vertical Take-Off and Landing (VTOL) UAV and is discussing the development of an improved version of the U.S. Eagle Eye tiltrotor UAV. [9]

According to one European estimate, the worldwide aggregate UAV expenditure for military UAVs from 2003-2012 is expected to be 25 billion Euros (approximately 30 billion USD), with 84 percent of the spending on HALE, MALE and UCAV applications.[10] In addition to the usual roles of intelligence gathering, surveillance, and reconnaissance, these future vehicles will be used in applications including mine detection, combat, air defense suppression, and electronic warfare.

1.4.2 The Civil Government and Scientific Research Market

The military has developed the technological foundation and created an environment fertile for the widespread introduction of UAVs into the civil government, scientific research, and commercial market. But making the transition from a military to a civil/commercial market will involve some difficulty. Most UAVs produced today were engineered for military use. Cost efficiency, reliability, and ease of operations—each a primary consideration for commercial use—often took a distant second to the military function required of the vehicle.

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[9] Pustam, Anil, R., "The World Market for UAVs," Unmanned Systems, Nov/Dec 2003, pgs. 16-21.

[10] A presentation at the 2004 Bristol UAV conference by Shai Shammai, UAV Research Analyst, Frost and Sullivan.

According to a 2003 Frost and Sullivan briefing, the primary drivers for the civil government market will be homeland security; demand for maritime surveillance; surveillance and reconnaissance needs; exhaustive coverage (persistence); and low-cost and flexible solutions. Restraints to the market are cited as initial implementation cost; absence of airspace regulation and airworthiness requirements; financial risk; political acceptability; and lack of sufficiently long track record.[11]

Homeland Security Applications

Demand for homeland security will be the primary market for civil government use of UAVs. The Department of Homeland Security (DHS) has requested $10 million in FY05 to test UAVs.[12] The Coast Guard is set to acquire 69 Eagle Eye UAVs as part of its Deep Water program with the first vehicle is scheduled for delivery in 2007. HALE UAVs may also be acquired within 12 years depending on evolving operational requirements and priorities. Potential applications for homeland security missions include:

- Border patrol
- Monitoring of sensitive sites
- Drug surveillance and interdiction
- Domestic traffic surveillance
- Pipeline patrol
- Port security

Other Civil Government Applications

Other civil government applications would address many of the functions provided for by manned aircraft, but offer greater endurance and potentially lower cost to operate. There will also be missions in the proximity dangerous areas, such as chemical spills or radiation releases. Such civil government applications may include:

- Emergency response
- Law enforcement surveillance
- Search and rescue

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[11] "The European UAV Market and Its Global Opportunities," presentation for UAVNET, Frost and Sullivan, September 2003.

[12] Tiboni, Frank, "Army, Homeland Security Plan for Unmanned Aerial Vehicles," Federal Computer Week, www.fcw.com, 25 February 2004.

- Forest fire monitoring
- Communications relay
- Flood mapping
- High altitude imaging
- Nuclear, biological, chemical (NBC) sensing/tracking
- Traffic monitoring
- Humanitarian aid
- Land use mapping
- Chemical and petroleum spill monitoring

Scientific Applications

Other civil applications would involve scientific missions, mostly for imaging and data collection. Such applications include:

- Natural hazards research and monitoring
- Environmental monitoring and mapping
- In-situ atmospheric monitoring
- Hyperspectral imaging
- Sea ice flow observations
- Plume dispersion and tracking
- Soil moisture imaging
- Aerosol source determinations

1.4.3 Commercial Market

According to a 2003 Frost and Sullivan report, key drivers for the commercial UAV market include increasing client awareness of UAVs; low-cost and flexible solutions; pay-per-use business model; operational simplicity; potential short payback time; and provision of new services. Barriers to the market include: lack of cost/benefit studies, initial implementation costs; lack of airspace regulations and airworthiness requirements; safety; accessibility to UAV applications; and availability of dedicated sensors.[13]

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[13] Shammai, Frost and Sullivan, September 2003.

The greatest challenge facing commercial growth remains the establishment of standards and regulatory framework that applies to unmanned aircraft. The absence of standards and regulations make it difficult for investors to justify funding the development of the UAV market, and hard for insurers to determine a reasonable liability cost for their operations.

Depending on the requirements imposed on a UAV system, the costs associated with building a system to certain standards may make the unit costs of UAVs non-competitive to manned aircraft. For example, expectations for demonstrated high reliability levels or a requirement that all mission and flight critical code be deterministic as a condition of certification, could drive the development, testing, and production costs beyond those of a comparable manned vehicle.

Commercial Applications

Many of the commercial applications currently being sought for civil use involve large UAVs that are capable of mimicking the performance values and equipage of manned aircraft. But a new and perhaps more influential market will emerge for small aircraft. Interest in small UAVs has grown significantly in recent years in part due to improvements in micro-electronics, the widespread application of Global Positioning System (GPS) navigation, and the development of affordable wireless communications technologies. A list of potential commercial applications for both large and small UAVs include:

- Crop monitoring
- Agricultural application
- Motion picture
- Communications relay
- Utility inspection
- Multi-sensor station-keeping
- News and media support
- Aerial advertising
- Fish spotting
- Surveying and mapping
- Commercial imaging
- Cargo
- Commercial security

A research analyst from Frost and Sullivan predicts the following applications to emerge within the indicated timeframes:

2004-2007: border and coastal patrol; digital mapping and planning; firefighting; and energy infrastructure monitoring

2008-2012: law enforcement; search and rescue; maritime traffic control; hazardous materials monitoring; and crisis management

2013 onwards: surrogate satellites; communication and broadcast services; transportation; and urban law enforcement.[14]

Market forecasts to date, such as those produced by Frost and Sullivan, have been limited in scope primarily due to the lack of maturity in the existing UAV market and the number of unresolved factors that could significantly influence developments. However, getting a more accurate range in terms of vehicle types, frequency of operations, mission characteristics, and flight environments would assist in modeling and simulation activities and in strategic planning for the airspace system.

1.4.4 Moving Forward

The technologies being employed in UAV systems today are evolving rapidly and show great promise. Autonomous systems are becoming more sophisticated and reliable. UAVs, by virtue of their ability to take on high-risk missions and their potential for low-cost operations relative to manned aircraft, make them an ideal test bed for new aviation technology development. Absent many of the constraints associated with manned aircraft, researchers are exploring a wide array of technologies that can be applied to the unique qualities of a UAV. Research in areas such as self-healing materials; fuel cells, adaptive software; shape memory alloys; film and spray on antennas; and laser communications could reshape the aviation market and create new applications.

However, for the UAV market to truly advance, more access to the civil airspace and full integration and acceptance with the air traffic system will be needed. Consequently, UAVs will require regulatory and technical mechanisms to ensure a sufficient level of safety and security exists. To accomplish this, a litany of issues must first be identified, analyzed, and resolved. These issues, many interrelated, vary in complexity, schedules, costs, and risks. The following section seeks to examine these issues in order to gain a better understanding of the barriers to successful development and integration of UAVs, and to assess strategies for moving the process forward.

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[14]UAVworld.com news article on a presentation at the 2004 Bristol Conference by Shai Shammai, UAV Research Analyst, Frost and Sullivan, July 2004

Section 2

Issues

Allowing routine and safe access of UAVs to civil airspace involves numerous issues that touch on nearly every aspect of the aviation technical, operational, and legal system. Presented here is a framing of those issues organized into five major groupings: safety, security, air traffic, regulatory, and socio-economic. Within these groupings are specific issues. Each contains a discussion of the issue, potential mitigating factors (i.e., research), and an assessment of the issue relative to the overarching goal of full integration into civil airspace. At the end of each assessment is a table containing a summary of the safety criticality, technical complexity, socio-political risk, and economic cost, rated on a scale of high, medium and low.

2.1 Safety

Successful integration of UAVs in civil airspace will require assurances that they can safely operate within the constructs of a commonly shared aviation system and environment. As such, UAVs must demonstrate that they do not pose an undue hazard to other aircraft or persons on the ground. They must, in short, provide for an equivalent level of safety to manned aircraft. But defining this equivalency in terms of requirements is difficult. UAVs operate differently from manned aircraft. And because the pilot is no longer at risk in a UAV accident, the question arises as whether UAV systems can or should be held to the same safety standard as manned aircraft.

Safety risks are pervasive in the design and operations of any complex system. UAVs are no exception. Sorting out and defining the numerous individual safety risk factors and their interrelationships is a difficult task and one that is beyond the scope of this paper. Instead, this document seeks to address four high-level safety issues of particular concern: collision avoidance, system reliability, human factors, and weather. Collision avoidance is chosen for its *potential* to result in catastrophic accidents, while system reliability, human factors, and weather hazards are *existing* weak links.

U.S. Military UAV Safety Record

Many in the aviation community have expressed concern over the safety of UAVs operating routinely in civil airspace. This concern is not wholly unfounded. Based on the military's experience, UAVs indeed have a poor safety record. An April 2003 Congressional Research Service report noted that "the current UAV accident rate is 100 times that of manned aircraft."[15] According to a 2002 Air Force study, the current accident rate for UAVs is 50 times greater than that of an F-16. Another disturbing statistic compares an accident rate of 0.06 per million flying hours for U.S. commercial airplane in U.S. airspace to a rate of 1,600 per million flying hours for the Global Hawk.[16] Despite the high accident rates, few have resulted in third-party losses. [17]

Figure 2-1, below, taken from a 2002 OSD study shows a breakdown of U.S. UAV military accidents by type.

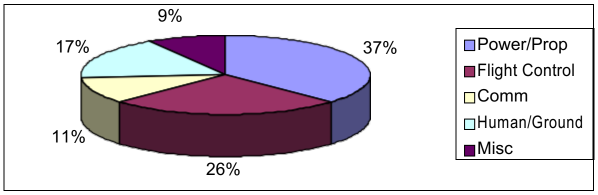

Figure 2-1. Average Sources of System Failures for U.S. Military UAV Fleet (based on 100,000 hours)

UAV Community Perspective on Safety

The UAV community is keenly aware of the safety concerns, especially concerning the poor reliability track record of UAV systems, and has moved aggressively to improve this record. They understand that any public trust and political support for UAVs that exists today will rapidly erode should a UAV be involved in a fatal accident in the air or on the ground—regardless of fault. Therefore, safety remains foremost on the minds of manufacturers, operators, airspace users, and regulators.

While much attention focuses on safety risks posed by UAVs, considerably less attention is given to potential safety benefits. Many of the new technologies and procedures being researched for UAVs have the potential to improve safety for both manned and unmanned aircraft. Advances in UAV automation, sensor detection systems, communications, data exchange networks, and monitoring systems will have direct and positive influences on all

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[15] "Unmanned Aerial Vehicles: Background and Issues for Congress", Elizabeth Bone and Christopher Bolkcom, Report to Congress, Congressional Research Service, Library of Congress, pg. 2, April 25, 2003.

[16] "Fasten your seatbelts, this could get scary," New Scientist Magazine, 13 December 2003.

[17] A Heron UAV collided with a MiG-21 aircraft in October 2003. The accident was caused during the landing phase of the MiG aircraft near the airfield. After the collision, the Heron lost control and crashed into a house, injuring several people. The MiG was also seriously damaged but it managed to land safely.

aircraft. Another counterpoint to the perception that UAVs are inherently more dangerous than manned aircraft is provided by the DoD's UAV Roadmap, reduced here for brevity:

- A UAV will never be lost due to pilot vertigo.
- Accidents resulting from pilot fatigue and indecision will not occur in UAVs, which do not tire and are not programmed to take chances.
- No UAV is likely to be lost due to aircrew urgency to return to base or family.
- Accidents from failed life support systems will not occur.
- Smoke in the cockpit can distract pilots and obscure vision, but similar circumstances in a UAV are inconsequential to the ground-based pilot.
- Automated take-offs and landings eliminate pattern work, reducing exposure to pattern-related accidents.

2.1.1 Collision Avoidance

Because of its potential for catastrophic impacts, collision avoidance has arguably become the most pressing safety concern, and, consequently, the focus of numerous studies by government, industry, universities, and research institutions worldwide. The problem of detecting and avoiding aircraft and other objects for UAVs is a difficult challenge.

To avoid collisions, UAVs must have a "see and avoid" capability (often referred to a "sense-and-avoid" or "detect-and-avoid" in the UAV community) that allows them to detect and safely steer clear of aircraft or other obstructions. The pilot's responsibilities in see-and-avoid activities in manned aircraft are spelled out in FAA advisory circular 90-48C, *Pilot's Role in Collision Avoidance*. For UAVs, FAA Directive 7610.4J, entitled *Special Military Operations*, states that UAV (referred to as "ROAs" in the directive) operations require "the proponent to provide the ROA with a method that provides an equivalent level of safety, comparable to see-and-avoid requirements for manned aircraft." This, in essence, ties it to AC 90-48C. Further, FAR Part 91.113, *Right of Way Rules*, states that: "regardless of whether an operation is conducted under instrument flight rules or visual flight rules, vigilance shall be maintained by each person operating an aircraft so as to see and avoid other aircraft." To satisfy the requirements, all UAVs must therefore be able to reliably avoid collisions with *all* aircraft—cooperative and non-cooperative[18]—at *all* times. This capability will fall to sensors that can effectively detect aircraft that do not explicitly or actively make their presence know. For the purpose of this paper, this sense-and-avoid

[18] A "cooperative aircraft" refers to those aircraft possessing systems that self annunciate their position to aircraft and/or the air traffic system. Transponders and ADS-B systems are representative of cooperative systems. "Non-cooperative aircraft" refer those not possessing or using cooperative systems.

requirement will extend to other collision hazards such as birds, ultralights, radio towers, and terrain.

Safety Metrics

While the requirements of FAA Order 7610.4J and U.S. FAR 91.113 seem straightforward, defining "equivalent level of safety" for see-and-avoid is a challenge. Part of the difficultly stems from differences in human skills, abilities, and habits. Not all pilots have the same visual acuity or depth perception, they do not spend equal time looking out the window, nor do they follow consistent scanning techniques. In addition to these human variations, the aircraft and operational environments also vary. A flight on a hazy day does not offer the same see-and-avoid advantage as a clear day, and not all aircraft have the same viewing ranges.

Research conducted by Lincoln Labs into the effectiveness of human see-and-avoid capabilities indicates that pilots are poor at identifying potential collisions, especially if not warned of air traffic in their vicinity.[19] Also, given that most of today's mid-air collisions overwhelmingly occur during clear daylight, typically near uncontrolled airports, points out the human failings of see-and-avoid.[20] If true, would basing a standard on such a poor "detection system" be desirable?

Another solution offered for an equivalency standard is based on U.S. FAR Part 23 and 25 aircraft certification requirements that specify a manned viewing field having an azimuth of +/- 110 degrees and elevation of +/- 30 degrees. But this, too, would stand as an insufficient standard. FAA data indicates that most of midair collisions occur in clear daylight conditions when an aircraft is overtaken by a faster aircraft. Limitations in rear visibility of the slower aircraft are part of the cause. In a UAV, visibility need not be restricted to forward looking capabilities but can have 360 degree viewing range depending on sensor type and placement. Considering this capability, is it appropriate to set the bar to the more limited field-of-view requirements of manned aircraft?

There is another issue to consider. If UAVs are allowed to fly in visual flight rules, pilots of manned aircraft would be expected to detect them as well. But many UAVs are small, making them more difficult to see. Even when seen, pilots may not be able to adequately judge the distance and closure rate to the vehicle, presuming it is farther away than it really is. How will this be accounted for in a see-and-avoid standard?

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[19] Informed of this study during a Lincoln Lab briefing on TCAS and UAVs held at NASA in February 2004.

[20] Newcome, Lawerence R., "FAA-Type Regulations Will Allow UAVs to Grow," www.AviatonNow.com, Aviation Week's Next Century of Flight, 28 January 2004.

Current Initiatives

Work on sense-and-avoid standards has already begun. Late in 2003 an ASTM committee was formed to address certification issues concerning UAV integration. Sense-and-avoid systems were first on the agenda. In August 2004, the ASTM F38 committee on UAV standards developed its first draft standard titled *Standard Specification for Design and Performance of an Airborne Sense-And-Avoid System* (designated F2411-04). This standard leverages existing standards for cooperative collision avoidance and avionics systems. It draws heavily from the U.S. Air Force Air Command's white paper on sense-and-avoid requirements.[21] The issue of sense and avoid standards may also be taken up by an RTCA special committee, slated to begin work in December 2004.

Existing Technologies

Beyond the difficulty of developing a standard is the challenge of finding a sensor that could meet that standard. Most UAV optical systems in use today require good weather and are susceptible to obscurants such as smog and smoke. Also, search rates of these optical systems tend to be slow and may not be sufficient for traffic detection. Other alternatives, such as radar, typically do not scale well with small UAVs due to restricted payload and unit cost.

In addition to having an active detection sensor, UAVs, if they are to operate in instrument meteorological conditions or positive control airspace, will likely be required to equip with a cooperative surveillance system, such as a transponder or ADS-B. These technologies, though designed for manned aircraft, will likely work with larger UAVs but may present problems to the smaller UAVs which have limited payloads and low electrical generation capabilities. Today's transponders are heavy and require a lot of power. Cost is another issue. In some instances, the surveillance system alone may exceed the cost of the vehicle and surpass its weight limitations.

The Traffic Collision Avoidance Systems (TCAS) is another cooperative system that has been proposed as a potential collision avoidance system for UAVs. But its performance, even in large UAVs, has been called into question. A MITRE study conducted in 1998 in support of the Air Force UAV Battlelab found that low-performance UAVs, such as the Predator, should not be equipped with TCAS II, whereas high-performance UAVs, such as the Global Hawk, could.[22] Another 2002 study conducted by a working group for the

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[21] UVOnline article, http://www.shephard.co.uk/UVOnline/Default.aspx?Action=-187126550&ID=f64f0eab-b261-464d-899b-f331c6ca5edc, 17 August 2004.

[22] Lubkowski, David J., and McLaughlin, Micheal P., "Traffic Alert and Collision Avoidance System (TCAS II) on Unmanned Aerial Vehicles," Safety Assessment, MITRE CAASD, WN 98W0000130, December 1998.

Surveillance and Conflict Resolution Systems Panel concluded that further safety analyses and studies need to be conducted to better understand the impacts of TCAS-equipped UAVs.[23] Lincoln Labs is currently conducting studies for TCAS UAV equipage for the Global Hawk. Results are to be published in the Fall of 2004. There is another concern that, even if TCAS does work in some UAVs, the slow cruise speeds and maneuvering capabilities may lead to an increase in nuisance alarms in manned aircraft.

Technologies in Development

There are numerous technology solutions being explored for sense-and-avoid systems. Some researchers continue to work with existing sensors and surveillance technologies (electro-optical, infrared, transponders, radio, Automated Dependent Surveillance-Broadcast (ADS-B), etc.) to see how they may work in a UAV context. Some of these efforts have already been discussed. While many of these technologies have been discounted due to size and power consumption requirements, others hold promise due to advances being made in miniaturization and subsystem capability improvements. Recent Defense Advance Research Project Agency (DARPA) research indicates, for example, that with the advent of high performing digital processors, field programmable gate-arrays, and radio frequency and baseband analog electronics; small, low-cost, low-power radars may be on the market soon.[24]

There are others seeking novel ways to fuse information from these sensors as well as to develop new sensor/surveillance technologies specifically designed for UAVs. The Air Force Research Lab (AFRL) has been a key contributor in this area. In 2003, the AFRL's Sensors Directorate, in conjunction with Defense Research Associates, developed a model that calculates the detection range required to avoid a collision for both manned and unmanned aircraft to meet the FAA see-and-avoid requirement. The model allows variation in sensor and target velocities; initial separation and look angle; latencies associated with communications, decisions, and maneuvers; a safety factor (final miss distance); and specific UAV maneuvering capabilities (flight speeds, climb rates, and turn rates as a function of altitude). Directorate engineers applied this model to the Global Hawk and Predator UAVs to determine the detection requirements for a see-and-avoid system placed on each of these platforms. After completing the requirements definition phase and flight demonstration of an

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[23] Drumm, A. C., "TCAS on Unmanned Aerial Vehicles: Defining a Safety Analysis Plan," Surveillance and Conflict Resolution Systems Panel: Airborne Surveillance and Conflict Resolution Systems, Working Group A, SCRSP/WGA, WP/A/4-145, November 2002.

[24] www.uavworld.com, "Low power radars needed for small UAVs," posted on members-only reference site, May 2004

aircraft detection system, directorate engineers compared the results of both. The UAV air traffic detection system performance exceeded that of a trained human pilot.[25]

In 2004, AFRL and Northrop Grumman teamed to study attributes of a see-and-avoid sensing architecture to define the way data is collected from various sensors and how these data could be fused to create an integrated view of the airborne environment.[26] They are also working collaboratively with various government, associations, and industry organizations to address civil sensing requirements under a newly formed Autonomous Flight Control Sensing Technology program. This initiative will examine past mid-air accidents and compare them to airspace tasks for UAV operations in the NAS. Sensor designs and hardware will be developed with the goal of minimizing hardware and software by making use of multifunction sensors and common image processing software while addressing reliability, field-of-view coverage, failure rates and exposure rates.[27]

Also in 2004, the AFRL formed a partnership with the Swedish government to flight test an advanced Automated Collision Avoidance System (ACAS) for UAVs.[28] A description of the test states: The auto ACAS uses Situational Awareness Data Link (SADL) data to determine if a collision is imminent and, if so, temporarily takes control of the aircraft away from the pilot for a very short time and steers each aircraft into an optimal escape maneuver. As soon as each aircraft begins to diverge, the system returns control to the pilot. If one of the aircraft involved is an UAV, then the UAV will always give ground unless otherwise necessary. In all cases, the F-16 and the virtual target aircraft established the necessary data link and transmitted data between the two aircraft, and overall SADL performance actually improved over the course of the two sessions. Both U.S. and Swedish pilots who have flown the auto ACAS simulations agree that the system has potential as a valuable tool because it activates at the right time, not before. They find it most beneficial during times when pilots lose sight of each other and don't realize a collision may be imminent. [29]

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[25] Air Force Research Lab (AFRL) Digest, December 2003, news alert.

[26] Shepard's UVonline.com update, "UAV Collision-Avoidance System Development," 29 June 2004.

[27] Molnar, Tom, Clough, Bruce, and Chen, Won-Zen, "Sensing Requirements for Unmanned Air Vehicles," Air Force Research Lab Horizons Air Vehicles Directorate, Control Sciences Division, Systems Development Branch, Wright-Patterson Air Force Base, VA-03-06, June 2004.

[28] Article posted on UAVworld.com titled, "Cracking the nut of collision avoidance for UAVs," July 2004.

[29] "Automatic Air Collision Avoidance System Test Successful," www.afrlhorizons.com/0001/t.html, 8 April 2004.

In addition to AFRL efforts, other government agencies and research organizations are investigating solutions and experimenting with new technologies. NASA Dryden, during the Summer of 2003, conducted research into a relatively low-cost radar affixed to a Proteus optionally piloted vehicle. Several scenarios were run where other aircraft were placed on various collision paths with the radar equipped vehicle. Results of the experiment show that the ground operator had greater collision awareness than the observing airborne pilot.[30] [31]

Other possibilities exist as well. One approach to the cooperative surveillance system would be to use location information provided by location telemetry provided by UAVs to the ground control station (similar to ADS-B concept) and port this information into a traffic information broadcast (TIS-B) system.[32] Just such a concept has been explored by Eurocontrol using a traffic information service in contract mode (TIS-C) to support Airborne Separation Assurance System (ASAS) applications.[33] Another approach is to use the nascent field of computer vision. One thesis contends that the higher resolution coming to market for digital video systems will make a computer vision-based see-and-avoid system for UAVs a viable technology in the not too distant future.[34]

Assuming that conflicts can be detected, whether by optical or electronic means, there remains the issue of how the ground operator or vehicle itself reacts to avoid that conflict. Should, for example, the UAV act autonomously or should the ground operator (or even the air traffic controller) redirect the vehicle? Latencies associated with the air/ground communications link may also present a problem.

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[30] "Flight Demonstrations Evaluate UAV Collision-avoidance Technology," NASA Dryden Flight Research Center, Press Release, 3 April 2003.

[31] Lopez, Ramon, "Avoiding Close Encounters of a UAV Kind," Unmanned Systems magazine, May/June 2003, pg 31.

[32] This concept, at least in terms of its application to ADS-B equipped aircraft, is explained in an IEEE paper written by Andy Zeitlin and Rob Strain titled "Augmenting ADS-B with Traffic Information Service-Broadcast", MITRE CAASD, 2002.

[33] Ehrmanntraut, Rudi, "Enabling Air-Ground Integration: Concept Definition for Traffic Information Service in Contract Mode (TIS-C)," Eurocontrol Experimental Centre, TALIS Project, IEEE 0-7803-7844-X/03, 2003

[34] Driessen, Johan, "Object Tracking in a Computer Vision Based Autonomous See-and-Avoid System for Unmanned Aerial Vehicles, Master Thesis, Department of Numerical Analysis and Computer Science, Royal Institute of Technology, Sweden, TRITA-NA-EO4017.

Further illustrating the complexity of the issue, those certifying sense and avoid systems will need to consider a number of interrelated factors such as the type of mission to be flown; the airspace classifications where missions will be flown; physical characteristics of the UAV; flight performance values; controllability and maneuverability of vehicles; the sensing technology capabilities and limitations; and levels of autonomy used by the vehicle.

Assessment

Collision avoidance remains foremost in the agendas of regulators, researchers, and the UAV community. But what is the actual danger posed by mid-air collision and ground impacts resulting from an increase in UAV activities? Could it be overstated? According to FAA statistics, fatalities resulting from mid-air collisions and falling aircraft/aircraft parts account for only 3.6 percent and 2.2 percent of all aviation fatalities, respectively. And in the case of UAVs falling to earth and causing injury, consider that 544 UAVs crashed over densely populated Southeast Asia during the Vietnam War, yet no one was ever killed as a result of those crashes.[35] Other parallels can be drawn concerning the odds of a midair collision. Take, for example, the launching of weather balloon radiosondes worldwide over many decades. According to one source, in North America alone there are 150 radiosonde launch sites, most of which launch small packages twice daily, for some 100,000 launches each year. Yet in decades of launching at this rate, with millions of total launches, there has not been a single reported incident of a mid-air collision with a balloon package, either on ascent or descent (some have, however, been spotted by airline pilots).[36] These examples are not meant to imply that a risk is not present and should not be mitigated, but rather that the threat may not be as great as perceived. Much, of course, depends on the type of UAV (size and speed), where flights occur (traffic and population densities), and the frequency of those flights. A detailed hazard analysis of these factors is provided in a recently published paper by the Massachusetts Institute of Technology (MIT) International Center for Air Transport (ICAT).[37]

Yet despite the statistical rationale indicating low probabilities, numbers mean little when it comes to public perception and political acceptance. Cleary work will and should continue in this area. One of the first steps needed is to develop a sensible baseline measure for a see-and-avoid requirement that can be translated into a Minimum Performance Standard (MPS). This MPS should be sensitive to and flexible enough to account for the range of UAV types,

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35 Newcome.

36 http://members.shaw.ca/sonde/risks.htm

37 Weibel, Roland and Hansman, John, "Safety Considerations for Operation of Different Classes of UAVs in the NAS," MIT ICAT, paper presented at the American Institute of Aeronautics and Astronautics (AIAA) 4th Annual Aviation Technology, Integration and Operations Forum, AIAA-2004-6421, September 2004.

missions, and operating environments. Any requirement evolving from an MPS should not be technology specific, nor should the requirement expect a near-perfect system where none exists today. And because future UAV operations will involve international boundary crossings, the requirement should be internationally adopted in ICAO Standards and Recommended Practices (SARPs) and manuals. Encounter scenarios should be detailed to validate the requirement, and costs and complexity must be factored in. The key issue preventing acceptance any collision avoidance requirement will probably not be technical in nature, but rather involve issues of cost and implementation feasibility.

Another major challenge in developing a reasonable see-and-avoid requirement will be to address the unique issues associated with small UAVs. Because pilots of manned aircraft will have a greater difficulty in seeing these small vehicles, there may be an argument for the development of a cooperative sensor/surveillance system that can assist both manned aircraft pilots and UAV vehicles/operators in identifying and avoiding proximate traffic. Such a solution would need to be sensitive to cost, weight, and power consumption so as to be acceptable to small aircraft—manned and unmanned.

There is reason for optimism that see-and-avoid solutions will be found for all UAV types. Research being conducted and advances in existing technologies indicate that detection devices will continue to diminish both in size and power requirements while concurrently increasing in capability and affordability. New technologies being explored will not only benefit the UAV community, but will migrate to manned aircraft and may eventually reduce the risk of collisions for all aircraft.

Safety Criticality	Technical Complexity	Legal Complexity	Socio-political Risk	Economic Cost
High	High	Low	Low	Low to High (depends on technology and system requirements)

2.1.2 System Reliability

The poor reliability record of UAV systems is frequently cited as a principal inhibitor to the integration and wide-spread acceptance of UAVs. If no improvements are made, this issue will probably stand as the greatest impediment. However, there is a lot of industry effort being put into addressing this issue. Just how reliable UAVs must be will likely vary depending on the vehicle size, speed, airspace usage, and intended mission.

As noted earlier in the introduction to the safety section, UAVs have a high accident rate when compared to manned aircraft. Table 2-1, taken from the 2002 OSD Reliability Study illustrates the differences.

Table 2-1. Examples of Manned Aircraft Reliability

<table>
<tr><th>Aircraft</th><th>Mishap Rate (per 100,000 hrs)</th><th>MTBF (hours)</th><th>Availability</th><th>Reliability</th></tr>
<tr><td>General Aviation</td><td>1.22</td><td colspan="3">Data proprietary or otherwise unavailable</td></tr>
<tr><td>AV-8B</td><td>10.7</td><td></td><td rowspan="4">Data unavailable</td><td></td></tr>
<tr><td>U-2</td><td>3</td><td>105.0</td><td>96.1%</td></tr>
<tr><td>F-16</td><td>3.5</td><td>51.3</td><td>96.6%</td></tr>
<tr><td>F-18</td><td>3.2</td><td></td><td></td></tr>
<tr><td>Boeing 747</td><td>.013*</td><td>532.3</td><td>98.6%</td><td>98.7%</td></tr>
<tr><td>Boeing 777</td><td>.013*</td><td>570.2</td><td>99.1%</td><td>99.2%</td></tr>
<tr><td>Predator/RQ-1</td><td>32</td><td>55.1</td><td>93%</td><td>89%</td></tr>
</table>

According to a recent Defense Science Board review, approximately 85 percent of all UAV accidents are a result of equipment failure.[38] This statistic compares well with the OSD UAV Reliability Study which shows that powerplant, flight control, and communications equipment failures accounted for 75 percent of system failures on average for its military fleet of UAVs.[39]

Despite the glaring reality these statistics present, it is in many respects unfair to compare manned aircraft with UAVs. Unlike manned aircraft, many UAVs have been developed as experimental or expendable vehicles. Cost, weight, function, and performance have traditionally been the primary concerns, not reliability. Most were designed for military applications and have purposefully been put in harms way. Naturally, given its high risk missions and experimental nature, little attention was paid to system redundancies or other design considerations aimed at increasing reliability. Further, many UAVs have not traditionally been provided the same level of maintenance and operational support given to manned aircraft. For instance, the Predators sent to Bosnia in the 1990's lacked spare parts, maintainers, and adequately trained operators. The premature deployment of the Global

[38] Cited by Bob Nesbit of MITRE to an AUVSI panel session. UAVonline.com, "AUVSI: Defense Science Board Hears from Review Panel," Shepard's News Brief, 4 August 2004.

[39] OSD UAV Reliability Study, pg. 31.

Hawk to Afghanistan, while still in its development phase, is another example.[40] A further justification for the high failure rates is that UAV manufacturers frequently use non-aviation quality components to achieve cost savings or because such parts are not available for the size, dimensions, or power requirements of the vehicle.

While justifications can be found for past UAV accidents, this does little to relieve concerns by the military and civil entities concerning their overall safety. To be permitted to operate routinely in civil airspace, these vehicles will clearly require improvements. The liability associated with potential ground fatalities resulting from a UAV system failure is very high. Insurers will not cover UAV operations that cannot be performed in a consistent, safe, and reliable manner. And, apart from liability, there is another strong motivation for improving system reliability: cost. Many UAV are expensive and their payloads, in some instances, may exceed the cost of the vehicle.

Improving Reliability

There are essentially two ways to improve reliability: 1) improve the integrity of components and systems and/or 2) build in redundancy. Each method has a price. Using highly reliable and certified aviation parts adds to acquisition and maintenance costs. Also, one needs to consider the appropriate level of safety needed, especially given the wide variations in UAV types and missions. Should, for instance, a small UAV used to spray crops be held to the same safety standard as a large and fast UAV used for urban surveillance? Since a UAV poses its greatest risk to persons on the ground, should the safety level be based on population densities of potential missions?

Improving reliability is a recognized goal of the UAV community and is being actively pursued by aircraft manufacturers. General Atomics, a primary UAV manufacturer, has developed their Predator B with reliability specifically in mind. According to one account, an extrapolation of hours flown by the Predator B as of July 2004 indicates a reliability record that exceeds that of manned aircraft.[41] NASA has contributed $100 million to develop a modified version of the Predator B, called Altair, which is intended for use by Access 5 to evaluate various technologies that are critical to enabling UAVs to fly safely in the NAS. The Altair is configured with fault-tolerant dual-architecture flight control system and triple redundant avionics to increase reliability. Incidentally, the aircraft will be integrated with an automatic collision avoidance system and air traffic control voice relay.

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[40] Peck, Michael, "Pentagon Unhappy About Drone Aircraft Reliability," National Defense Magazine, May 2003.

[41] Safety statistic cited by Steve May, a General Atomics representative, at the UVS International Conference in June 2004.

The OSD reliability study provides suggestions to manufacturers when designing UAV subsystems. These suggestions are intended to increase reliability yet keep cost low. These include:

- use of standard systems engineering and layout practices
- simplicity of design
- testability of the design to enhance prognostic and diagnostic capabilities
- ensuring future availability of replacement materials and parts
- sensitivity to human factors with respect to manufacturing, operation, and maintainability
- use of redundant or fail-safe designs based on a failure modes and effects analysis;
- producability of design
- use of preferred or proven materials and parts; and
- maintaining control over material and parts quality

The OSD reliability report points out that research is underway that will offer potential solutions to existing hardware problems. Examples include:

- shape memory alloys that could reduce or eliminate the need for servos and actuators
- biopolymers that will leverage nature's design to create strong, lightweight structures resistant to fatigue; and
- autonomic (self-repairing) materials that will mitigate structural issues that arise during a mission

Assessment

Improvements in reliability are likely as increased emphasis and funding is being dedicated to resolving this issue. This issue is primarily an engineering challenge, though costs will play a deciding role. In some cases, the costs to improve reliability may be too high relative to the overall vehicle/payload costs and/or the return on investment from a UAV mission. Because of this, it is unlikely that the smaller, low-cost UAVs will be able to attain a reliability level expected of the larger vehicles carrying more expensive payloads. It also seems reasonable to expect that level of safety requirements, and their resulting costs, will be highest for those UAVs posing the greatest hazard to other aircraft or persons on the ground (i.e., large and fast vehicles operating in populous or high traffic density areas). This leads to several questions: Should safety levels be based on the UAV size, speed, operating environment, mission, or other criteria? What should be the appropriate measure for reliability (i.e., probability of total system failure or by component failure)? Since the vast majority of aviation fatalities today occur to persons onboard an aircraft (as opposed to third party fatalities), do UAVs need to be as safe as manned aircraft given that no onboard lives are at risk?

Safety Criticality	Technical Complexity	Legal Complexity	Socio-political Risk	Economic Cost
High	Low	Low	Low	High

2.1.3 Human Factors

UAVs have long been treated as a technical engineering challenge, with emphasis placed on system design, function, and performance. The human element has more often than not been a secondary consideration. However, as UAVs become more prominent and their systems grow in complexity, the role of the human will grow in importance. Studies of human performance in UAV systems shows that human response and effectiveness depends on the amount of automation, levels of system fidelity, and information update rates associated with a particular system.[42] Because UAVs vary considerably in these respects, it is difficult to make a conclusive statement regarding human interactions with UAV systems.

Comparisons to Manned Aircraft

According to the OSD UAV Reliability Study, 17 percent of UAV accidents in the military are caused by human failures compared to 85 percent for manned aircraft. In reference to this statistic, the report notes: "This is intuitive when one considers that by reducing the influence of human control in UAVs, the percentage of human related errors would also decrease." It goes on to speculate that: "Assuming that human error is consistent over similar tasks, one could even argue that human influence in unmanned vehicles is approximately 70 percent less than that in piloted vehicles, even when the UAV has a remote pilot on the ground. This difference could be attributed to a different approach to the human factors issue as well as increased automation of tasks for UAVs. While this theory requires further investigation, a second, more likely explanation for the difference is that human error does remain constant between most UAVs and manned aircraft, and that in the case of UAVs, it is simply overshadowed by the high unreliability of the other subsystems."[43]

The OSD UAV Reliability Study also states that the human influence in UAV accidents is approximately 70 percent less on average than in manned aircraft (due to UAV automation

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[42] Tso, Kam S., Tharp, Gregory K., Tai, Ann T., Draper, Mark H., Calhoun, Gloria L., Ruff, Heath A., "A Human Factors Test bed for Command and Control of Unmanned Air Vehicles," Air Force Research Lab and IA Tech Inc., IEEE 0-7803-7844-X/03, 2003.

[43] OSD UAV Reliability Study, pg. 57.

capabilities) and therefore human/system interactions account for a proportionally higher degree of accidents. The report also states that: "Adaptation of the cockpit environment to the ground control station is more difficult than anticipated. The military experience has shown that UAVs present more challenges for pilots on the ground than pilots flying aircraft, even with highly automated UAV systems. Pilots in aircraft have visual, aural, and motion cues that add to situational awareness which occasionally leads pilots to override automation when necessary. For the ground-based pilot, however, decisions are based solely on automation or through visual contact."[44]

A 2002 Congressional Research Service report cites 70 percent of all major accidents in manned aircraft of the U.S. military are due to human error. Broadening the scope to all manned aircraft, that figure rises to 85 percent according to the independent, non-profit Flight Safety Foundation.

Skill Levels

While human factors has been a persistent safety concern, there is still no consensus on skill levels needed to pilot a UAV (or multiple UAVs simultaneously). Current U.S. military practices illustrate this point. The Air Force, for example, insists on using officers who are fully qualified Instrument Flight Rules (IFR) pilots, the Navy and Marine Corps use enlisted personnel with private pilot licenses, while the Army has no aviation rating requirement and uses enlisted personnel who undergo ground school training. Some of the distinctions within the military and elsewhere results from varying levels of UAV system sophistication and the environment in which the UAV is being flown (positive Air Traffic Control (ATC) vs. uncontrolled). Experience with UAVs operated by licensed pilots and non-pilots do not provide a definitive link as to one being better than the other. One reason is that advances in autonomous technologies are lessening the role of traditional piloting skills and shifting emphasis to monitoring and collaborative decision making skills.

Autonomous aids are being developed that simplifies control of UAVs. These technologies allow for unskilled operators with little or no piloting experience to operate a UAV. This technology is also allowing the possibility of having one pilot manage multiple vehicles at one time. This transference of roles from a single pilot operator to a multiple system monitor presents an unknown safety impact. It further brings into question the qualifications needed to operate and monitor these aircraft simultaneously. How this will affect qualification criteria is unknown.

Situational Awareness

Another factor to consider is the difference in situational awareness and relative risks applied to airborne versus ground-base pilots and how this may affect behavior. Pilots of

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[44] OSD UAV Reliability Report, pg. 57.

manned aircraft always bear the risk of system failures. This awareness leads to heightened responses to changing conditions, especially threatening ones. Even with highly automated aircraft, pilots would be likely to have an advantage in overriding errant autonomous functions based on situational awareness. While the incentives to correct a perceived threat to a vehicle is greater with a pilot in the aircraft, there is no evidence that the responses will be any more correct than if performed from the ground. One of the primary objectives in designing a UAV control station will therefore be to increase situational awareness or hand off more responsibilities to automation. This is an approach being considered by the Air Force Research Labs where they are developing logic in UAVs that will permit them to make decisions autonomously, even when instructed otherwise by a pilot if it is known by the system that an instruction will lead to an unnecessary hazard.[45] The assumption is that the vehicle will have a better awareness of itself and its environment than would a distant operator.

Controller Issues

In addition to issues pertaining to the pilot, consideration must also be given to air traffic controllers and issues associated with the management of airspace and the conduct of air traffic control. Air traffic controllers may need to interact with UAVs in ways different from manned aircraft. They will, for example, need to be able to understand and predict UAV behavior to maintain safe separation, sequence traffic, and possibly even conduct unique flight procedures. How UAVs will affect controller workload, situational awareness, and the ability to maintain focus on airspace management is unknown. Further, UAV operations may impact ATC information processing, communications, display requirements, data input tasks, and management of mixed traffic (UAV and manned aircraft).

Assessment

There are many variables unique to UAV operations that bring into question common assumptions concerning piloting skills and the relationship between air traffic controllers, pilots, and the autonomous systems on the vehicles and on the ground. Skill levels of ground based pilots (and possibly controllers) will differ depending on the autonomous level of the vehicle being operated, and perhaps the number of vehicles being operated as well. This will make for a difficult regulatory challenge. Regulations must, as a basis, have an agreed upon set of qualification criteria that considers the unique piloting skills required for UAVs. Also needed is a definition of the responsibilities assumed by UAV operators. If an operator controls multiple highly autonomous vehicles, his or her skills would likely be very different from a pilot remotely controlling a manually operated UAV (more discussions on this issue are found in the Operator Certification section of this report).

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[45] Presentation titled "Empowering UAVs with Responsibility for Own Safety," by Robert Smith of AFRL to the AUVSI conference, 17 July 2003.

Additional work is also needed on the design of ground control stations. These stations typically mimic the cockpit environment, but there may be better alternatives. Displays can be made much larger and operators should be able to reconfigure the layout of displays based on individual preferences. There are a number of research opportunities in this area. Another issue concerns not only human-in-the-loop performance and function, but a newly evolving concept being tested in the military of human-*on*-the-loop in which the vehicle operator plays only a minimal, secondary role to the autonomous system.

Beyond the focus of the individual are the more complex system issues relating to human performance and judgment when confronted with both autonomous and mixed autonomous operations. Another significant area concerns human/machine reactions to the impact of upsetting events (i.e., weather or emergency operations) on complex system interactions, such as with operations where manned aircraft, highly autonomous UAVs, air traffic decision support systems, and UAVs having limited autonomy must all decide on appropriate actions.

Safety Criticality	Technical Complexity	Legal Complexity	Socio-political Risk	Economic Cost
Moderate	Moderate	Low	Low	Low

2.1.4 Weather

While no formal statistics were found concerning the amount of UAV accidents attributed directly to weather, there are a number of anecdotal accounts of weather being the primary or contributing factor to a number of military UAV accidents. The impact of weather on a UAV, as with any aircraft, depends on the size, configuration, equipage, and powerplant of the aircraft, as well as the type of weather being encountered, exposure time, and severity. Many UAVs have configurations and characteristics that make them more vulnerable to weather than most manned aircraft.

Generally speaking, today's UAVs are lighter, slower, and more fragile than their manned counterparts and consequently are more uniquely sensitive to certain meteorological events such as surface/terrain-induced (boundary layer) winds, turbulence, icing, extreme cold, and precipitation. Small UAVs and those having a light wing load are especially sensitive. Even with the larger UAVs, weather conditions, such as turbulence, have caused lost links (signal dropout) and even loss of control where conditions exceeded the autopilot's ability to recover. Recent examples of weather related accidents include the 2003 loss of a Predator A aircraft in Afghanistan due to icing and, in a more publicized event, the loss in July 2003 of the Helios experimental UAV which lost control due in part to turbulence resulting from terrain-induced wake eddies. In most UAV weather accidents, as in the examples cited, the vehicles were not equipped with sensors and the ground control was not fully aware of the hazardous meteorological conditions that existed at the time. And there are other unique weather hazards not seen as a problem for manned aircraft that could have impacts on proposed long-endurance, high-altitude station keeping operations, such as those generated by gravity waves and rare phenomena such as sprites and blue jets.[46]

Assessment

Though weather has been a known contributor in several UAV accidents, it remains a less critical safety issue (at least concerning risk to humans) compared to the other safety issues addressed in this section. Even if lives are not at stake, UAV operators have to consider the economic and third-party liability consequences of weather-related accidents. Therefore, weather will continue to play a critical role in determining operational feasibility of UAV applications and in gaining acceptance with regulators.

Despite the many weather vulnerabilities of UAVs, they do have more real-time, ground-based weather information available to them than pilots of most manned aircraft. This suggests that improvements in ground-based weather detection and information distribution systems will improve the ability of UAV operators to forecast, detect, and avoid hazardous weather. Also, UAVs typically have much greater endurance than manned aircraft and can often sit out adverse weather conditions until they improve, and high-altitude UAVs can fly above most weather hazards.

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46 A paper by Walter A. Lyons and Russel A. Armstrong, titled "A Review of Electrical and Turbulence Effects of Convective Storms on the Overlying Stratoshpere and Mesosphere," suggests that stratospheric phenomena could significantly affect operations of UAVs currently under consideration. These include rare and poorly understood electro-dynamic disturbances associated with thunderstorms such as sprites and blue jets which occur above the storm cells.

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Safety Criticality	Technical Complexity	Legal Complexity	Socio-political Risk	Economic Cost
Moderate	Moderate	Low	Low	Moderate

2.2 Security

UAVs may present unique security issues. The wide variation in flight environments, missions, and vehicle sizes make the secure control of UAV flights a challenge. Security requirements of the ground control station, data link infrastructure, vehicle and even the data must be a fundamental consideration in system design and operational policies and procedures of UAVs. In addition to being vulnerable to security breaches, UAVs themselves are also a potential security threat. And as the cost of UAV systems fall and the capabilities

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47 A paper by Walter A. Lyons and Russel A. Armstrong, titled "A Review of Electrical and Turbulence Effects of Convective Storms on the Overlying Stratoshpere and Mesosphere," suggests that stratospheric phenomena could significantly affect operations of UAVs currently under consideration.

increase, a proliferation (or at least wide availability) of highly capable UAVs could further exacerbate security concerns.

2.2.1 Ground Infrastructure

The operation of UAVs will be conducted from ground-based facilities. These facilities can vary from small mobile units to elaborate, interconnected, global systems. Security requirements for these controlling facilities will need to be developed. This becomes a more complex issue as the control functions and infrastructure of some ground operations may be distributed in various locations within the U.S. and around the world.

The amount of security applied to the ground control facility will depend on the size of the UAV being operated, the airspace being used, and the missions being flown. For large operations that may be controlling multiple vehicles from one site and that are networked with other facilities will require a much higher degree of security than a single control station responsible for a moderate to small size vehicle.

Assessment

This is an area that has been given little attention by the UAV community. Applying appropriate security measures for large centralized operations would presumably be easier than for the small, mobile facilities. Apart from the UAV control facility, the communication infrastructure will need have redundancies and alternate paths. The risks to implementation are low because the technology needed to secure physical facilities is well known. The cost of implementing security measures will likely be the greatest obstacle.

Safety Criticality	Technical Complexity	Legal Complexity	Socio-political Risk	Economic Cost
Low	Low	Low	Low	Moderate

2.2.2 Communications Signal Security

UAVs are in essence “tethered” to ground-based links which are, in some instances, widely distributed geographically. These links are used for vehicle control, monitoring, and air traffic communications and are, to varying degrees, vulnerable to jamming, spoofing, and interference or attempts to usurp control. To prevent this, a system of high-integrity, secure data links between the aircraft, the ground control stations, and air traffic facilities will be a fundamental requirement in approving UAV operation in the NAS. Modern encryption and authentication technology tools, including augmented versions, may mitigate the issue. However, high power jamming will also pose a hazard even with modern encryption and authentication technologies.

Communications security depends on the frequency used, the communications media, the encryption technology employed, and the associative properties of the communication link.

Typically, encryption with a lower frequency and low bandwidth poses more of an issue than with higher frequencies and high bandwidths. There is also a tradeoff concerning security, performance, and cost. Generally speaking, the higher the security, the less the performance and the greater the cost.

The military has established technologies to ensure adequate encryption of Satellite Communications (SATCOM) data links for its larger UAVs. These systems tend to be expensive and may not be available for civil use. It is possible, however, that some civil variant of the military systems will be made available for UAVs.

Beyond the military systems, there are number of encryption technologies available in the civil environment to enhance datalink security, but many of these may not be available, effective, or practical for all the communication links currently being explored for UAVs. An example includes research conducted by Japan's Advanced Telecommunications Research Institute where they are working on a cryptographic key using fluctuating signal of a chaotic laser. The method promises to provide extremely secure transmission through space or over fiber-optic lines, or be used with chaotic radio signals which, it is claimed, can "lead to practical encryption systems in two to five years, and cheap, general-purpose, less expensive systems in five to ten years."[48]

Assessment

Securing mobile and wireless communication networks will be an ongoing challenge not only for UAVs but for a host of existing and planned communication technologies. Needed is an evaluation of threats to the various data link systems and of means available to protect against intentional misconduct. The extent of security applied to the communications links will likely depend on the vehicle type, potential lethality (determined by size, speed, and proximity to manned aircraft and population centers), intended operations, and flight environment. The encryption integrity level will be defined in certification requirements. Cost will be a significant factor. Further, there is a concern that too high of a security requirement can impinge on performance to the point that users bypass security controls to permit the system to operate more efficiently. The security requirements of the communication system and the components that it links should be considered at the outset. This should entail the production of a security policy that contains an evaluation of the threat to the system, security level of the communication data, an assessment of the vulnerability of the system, and requirements as to how the system should be protected.

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48 "Chaotic Lasers Lock Messages," Technology Research News, www.technologyreview.com/articles/rnb120503.asp, article based on work that appeared in the October 2003 issue of Applied Physics Letters, 5 December 2003

Safety Criticality	Technical Complexity	Legal Complexity	Socio-political Risk	Economic Cost
Low	Moderate	Moderate	Low	Moderate

2.2.3 Data Security

Aviation data will be used by UAV operations to plan flights and code autonomous systems. Dependence on data for UAV flight operations will therefore require a high level of data integrity. This may entail multiple validation stages prior to and during flight operations. Safeguards must be assured to prevent the possibility of intentional corruption of the data.

The Department of Defense has a critical growing dependence on information systems that are part of its network-centric environment. To address data security concerns, the DoD is developing a suite of technologies and programs to prevent cyber attacks, while providing managers of the information system an ability to see, counter, tolerate, and survive such attacks.[49] These programs in the military could be adopted by the aviation community to protect data that will be vital to future aviation operations.

Assessment

Data management initiatives, such as the System-Wide Information Management (SWIM), are being designed to address data security and integrity issues. These initiatives will, if successful, ensure greater accuracy, reliability, and access to current mission data. The issue of data security and control is already being addressed as it affects modern manned aircraft. Increased reliance on navigational data for onboard systems, as well as other data used for mission planning and dynamic updates, will likely be resolved. Controlling the data input process, where good data may be intentionally altered prior to downloading into a UAV flight management system, may be the greatest challenge.

Safety Criticality	Technical Complexity	Legal Complexity	Socio-political Risk	Economic Cost
Moderate	Moderate	Moderate	Low	Moderate

2.2.4 Technology and Operational Controls

UAVs, especially the small UAVs, are varied in the type of take-off and landing environments and systems they use. Some UAVs are capable of taking off vertically like a helicopter, launched from building tops, projected from vehicles, or even hand launched. This versatility gives UAVs the opportunity to operate within virtually any environment,

[49] A Compendium of DARPA Programs, Defense Advanced Research Projects Agency, August 2003, pg. 30.

including urban areas. While this operational flexibility is a plus, it also creates a security risk as surreptitious flights may be made easier. According to a U.S. Senate Committee on Governmental Affairs testimony: “UAVs could be used as a delivery system for chemical or biological weapons given UAV’s ability to disseminate aerosols in the right place at the right altitudes.”[50] This threat poses issues concerning the control of UAV operations and technologies and how this can be done without imposing unnecessary restrictions on the market.

The U.S. and other governments may seek to control UAV technologies being developed for military purposes, or restrict operations of UAVs. There is a growing concern that advanced technologies, specifically those pertaining to miniature sensors, advanced data links, and micro-miniature guidance and navigation components, will be used for nefarious activities.[51] The use of UAVs as weapons by terrorist or others may influence tighter controls that may in turn reduce or inhibit UAV capabilities and civil/commercial activities. There are indications that Washington may impose export controls on some military UAV technologies. The Government has already created assistance programs to help other UAV manufacturing countries develop export controls of their own.[52]

Dennis M. Gormely, senior fellow at the Monterey Institute’s Center for Nonproliferation Studies, sees the need to “tighten restrictions on flight control systems that could be used to modify remote-controlled UAVs or manned aircraft into unmanned, autonomous systems.”[53] In a paper commissioned by the Non-Proliferation Education Center, and co-authored by Mr. Gormely, states: “The employment of UAVs promises to make military operations more discriminating in their effects. But, as this trend establishes itself, more ominous possibilities are emerging. UAVs—both armed and unarmed—are growing larger. They are breaching the threshold for the most restrictive international non-proliferation restraints. And civilian applications for UAVs are developing. These trends—combined with the inherent capability of UAVs to deliver nuclear, biological, or chemical payloads—set the stage for a new level of proliferation threats—the very opposite of the discriminating use of force.” The report

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50 Testimony of Vann Van Diepen, Acting Deputy Assistant Secretary of State for Nonproliferation, provided to the Senate Governmental Affairs Subcommittee on International Security, Proliferation and Federal Services, 11 June 2002.

51 Robert Wall, “Closer Watch: U.S. Intends to Enhance Controls Over Missiles and UAV Technologies,” Aviation Week and Space Technology, 15 March 2004.

52 Hoskinson, Charles, “US Seeks to Block Spread of Unpiloted Aircraft Technologies,” SpaceDaily online, www.spacedaily.com/news/uav-02n.html, 11 June 2003.

53 Testimony of Vann Van Diepen, pg. 25.

goes on to add that UAVs are: “inviting loopholes in the Missile Technology Control Regime that permits aerospace firms to sell flight management systems specifically designed to turn small manned aircraft (including kit-built ones) into autonomously guided missiles…were a country or terrorist group motivated to develop a crude cruise missile or UAV either on its own or with some foreign assistance, they could readily take advantage of the last decade’s quantum leap in dual-use technologies that comprise the chief components of autonomous air vehicle development.”[54]

Assessment

Whether all operations need some type of approval needs to be considered. Is it practical to implement flight authorizations for a vehicle that can be launched undetected from virtually any site? Would such an authorization criteria prevent those not seeking an approval? The solution will ultimately reside with law enforcement and their ability to detect UAV launches and activities in areas restricted from their use. Merely imposing an authorization requirement would only penalize those who play by the rules by creating an added layer of bureaucracy and an opportunity to unintentionally violate a rule.

The issue of operational security and technology controls is, therefore, a law enforcement issue. Restricting the use of UAV activities, or trying to regulate security, will do nothing to address the issue. A person determined to use UAVs for terrorism or other criminal activities will not seek permission or obey any restrictions imposed by the government. The effect of such security controls has a greater impact on hindering market expansion possibilities than on preventing criminal acts. The issue to the UAV community is therefore one of supporting law enforcement in developing plans to assist in identifying potentially nefarious activities. The government can and should continue to prevent the proliferation of technologies that could be easily configured for terrorist use, but this will becoming increasingly difficult as many of these technologies, or close variants of them, become pervasive in the commercial markets.

Safety Criticality	Technical Complexity	Legal Complexity	Socio-political Risk	Economic Cost
Low	Low	Low	Low	Low

2.3 Air Traffic

Assuring the safe and efficient integration of UAVs into air traffic operations will require UAVs to operate within the constraints of the evolving air traffic system. Assessing the potential impact of UAVs on air traffic operations will depend on the UAV types, numbers,

[54] Gormely, Dennis and Speier, Richard, “Controlling Unmanned Air Vehicles: New Challenges,” Paper commissioned by the Non-Proliferation Education Center, 19 March 2003.

operating environments, frequency of flights, performance characteristics, and equipage levels as they relate to the air traffic infrastructure and operations—current and planned. Because operations of UAVs to date have been limited in numbers and have purposefully remained clear of air traffic, it is difficult to assess impacts other than through analysis, modeling, and simulation.

2.3.1 Air Traffic Management

Future UAV designs and capabilities will vary widely and their performance characteristics will differ significantly from those of manned aircraft. Many will fly slowly and lack maneuverability while others will operate at very high speeds with great agility. Some UAVs will be launched and recovered from virtually any location (ship, buildings, runways, etc.). Additionally, sophistication will vary among vehicles, from those having fully autonomous flight controls to those requiring more direct pilot inputs. Further, the types of missions being planned for UAVs are rarely point-to-point but typically involve some form of patterned flight or tracking activity that may include intermittent short- or long-term orbits. Endurance will last from hours to months depending on the vehicle and mission. Taken together, these variations have the potential to significantly effect air traffic operations. To accommodate UAVs, operational procedures are required to enable consistent handling by UAV pilots and ATC. The ATM system, too, will need to be adequately structured to manage the additional complexity related to the rise of UAVs.

Potential NAS-wide Impacts

The varied vehicle performance and flight characteristic of UAVs may prove challenging to air traffic service providers and their supporting systems. Because so few UAVs have interacted with the air traffic system to date, it is difficult to predict their impacts. This issue is more one of uncertainty than of a specific technical challenge. The extent of UAV impacts on air traffic management will be dictated as much by UAV performance as by market developments. Some UAVs are clearly more capable of fitting within the existing environment than others, but the market will ultimately determine the number and type that are present in the system.

Some UAVs may be unable to climb and maneuver along designated IFR departure, arrival and approach routes within the designed and approved parameters of those procedures. As a result, some UAVs—particularly the low-performance varieties—may require exclusion from particular published routes or airspace, or may require the development of specific routes or procedures that consider the unique performance characteristics of those UAVs. It is doubtful, however, that many UAVs will be using tradition flight procedures, given the unique mission and takeoff/landing sites that most will use.

Controller Impacts

Controller roles may also be affected by UAV operations though, in instances where controllers have handled UAVs to date, the procedures and communications were transparent; most not aware they were controlling a UAV. This has at least been the case with the larger, sophisticated UAVs that operate within manned aircraft performance parameters, however this may not be the case for other UAVs that are typically slower, cannot perform standard rate turns at altitude, and may be unable to climb or descend at rates familiar to controllers.

Because UAVs exhibit unique performance and capability issues, they would likely require specialized notification or treatment by a controller and therefore require a special designation in the flight plan and/or on the controller display. This may entail modifications to existing air traffic radar symbols and require changes to the En Route Automation Modernization (ERAM) system. Another characteristic that may be of interest to a controller is whether the UAV is flying autonomously or manually, or if it can accept data link messages.

Dealing with mixed UAV/manned aircraft operations will present one of the greatest challenges to the air traffic system. Many aircraft, manned and unmanned, will be employing advanced avionics to permit more accurate and predictable flights, but there will also be UAVs and manned aircraft having less capable systems. This difficulty will be made more complex as ground-based air traffic decision aids and UAV airborne systems each seek to evaluate the environment and plan for movements that may not align with the ground systems or other aircraft in the vicinity. Studies and simulations will be required to demonstrate safe operating concepts of these mixed operations.

Another issue concerns the registration number for UAVs. Because a controller is only interested in speaking with the pilot of a UAV, there will probably be a requirement for the ground control station to have a registration number (commonly referred to as an “N” number in the U.S.) separate from the vehicle (or vehicles) the pilot is controlling, which will also require an N number as required by ICAO. Incidentally, the vehicle N number is also needed for maintenance tracking.

Contingency Procedures

Contingency and emergency procedures will also need to be understood by controllers in case of lost communications or if a vehicle malfunction affects a change in the planned route. The procedures to be taken by the vehicle will need to be communicated or predictable to the controller. This is especially important if either the communications link or the command and control link to the UAV are lost.

Wake Turbulence Separation

A final issue for air traffic management and controllers is to consider the effect of wake turbulence on UAVs. This will be especially important in the reduced vertical separation minima (RVSM) environment where the vertical spacing may create unacceptable upsets to the light wing loads of the endurance UAVs. This may require special spacing or vertical separation procedures.

Assessment

UAVs flown in the next few years for test and evaluations in positive controlled airspace will be equipped with radios and transponders; and most of these flights will probably take place in airspace or at altitudes that are not frequented by manned aircraft. But as more UAVs begin accessing the system, and their sizes, capabilities, speeds and mission become increasingly varied, such conformity to the existing system cannot be assumed. As new vehicles come on line, the issue of air traffic management becomes a wildcard. A number of questions arise, such as:

- What affect will UAV performance characteristics have on system capacity?
- How will UAVs affect the spacing and speed control of air traffic? Controller workload?
- Will unique controller training be required to effectively predict the speeds and turn rates of the many varieties of UAVs?
- Can or should different separation criteria apply to UAVs? Will the irregular flight paths of UAVs create issues for ground-base conflict probes?

To answer such questions, more needs to be known about UAV capabilities and limitations, as well as the potential market for these aircraft. Which UAV operations succeed, how they are flown and equipped, and where they operate will all have a bearing on the questions being asked. Analyzing potential impacts requires simulation and modeling of future scenarios that are based on a range of market forecasts. Also needed is a more complete understanding of the UAV regulatory and technology developments as they relate to air traffic management.

Safety Criticality	Technical Complexity	Legal Complexity	Socio-political Risk	Economic Cost
Moderate	Moderate	Low	Moderate	Low

2.3.2 System Interoperability

If UAVs are to be fully integrated into civil airspace, they will be expected to interact with the various ground components that comprise the overall airspace system. UAV operations will require direct communications between ground controllers and air traffic controllers, as is expected with manned aircraft today. Additionally, UAV data links, position reporting devices (i.e., transponders, ADS-B), and software coding must be proven to work effectively and safely in conformance with ground-based air traffic control equipment and procedures. While this conformance is generally practiced with the major UAV systems, there are some UAV developers proposing or using a variety of communication, sensor, guidance, and other systems that may not be compatible with the existing airspace system. The military experience has shown the difficulties and costs associated with accommodating multiple systems. They have, therefore, called for a higher degree of commonality and integration. Conforming UAVs into a common architecture requires consensus from the FAA, DoD, industry and the international community. This architecture should spell out the interoperability requirements, and in doing so, must be flexible enough to allow for innovative and cost effective approaches to be applied.

Many UAV systems will have autonomous capabilities that allow for certain decision to be made independent of ground operator input. The actions of these systems will need to act in a manner that does not conflict with air traffic decision support tools. Operations of UAVs that having unique flight characteristics or limitations (e.g., slow ascent/descent rates) will also have to be accounted for in air traffic ground systems so that their actual performance values fall within expected ranges programmed into those systems.

It is possible that air traffic systems may require modifications to accommodate UAVs. For instance, the ERAM may need to add elements that address UAVs and controllers may need (or desire) an identifier on their displays to indicate UAVs as well as the equipment and navigational performance values of the vehicle. These changes may take time to accommodate and should be communicated as early as possible.

Assessment

Integrating UAV systems and technologies, especially those involving specialized applications not found on manned aircraft, will be challenging. Those responsible for legacy systems may be reluctant to change their equipment/software to accommodate a new architecture. While the development of standards may help in defining requirements, standards do not necessarily translate into interoperability. Accounting for and balancing capabilities with interoperability of existing and planned systems will be the key challenge. Understanding these linkages will be critical in infrastructure investment strategies.

There are several issues underway to address some of these issues. The FAA and DoD are actively working on harmonizing the DoD net-centric framework with the FAA system. The Europeans, through its UCARE program, are working with NATO to make a system that is interoperable and deployable among NATO allies. Eurocontrol/Eurocae has begun defining interoperability requirements for UAVs. And, finally, DARPA is developing a networked system between manned and unmanned aircraft to facilitate processing and exchange of data among the various onboard and ground based sensors.[55] Coordinating these efforts is key to ensuring system interoperability.

Safety Criticality	Technical Complexity	Legal Complexity	Socio-political Risk	Economic Cost
Low	Moderate	Low	Low	Low to Moderate

2.3.3 Information Networks

Most UAVs—especially those operating autonomously—are reliant on accurate and timely data for navigational guidance, vertical guidance, thrust control, and flight path optimization. In addition, data is needed by UAV ground control stations for planning, in-flight retasking, and tracking of aircraft movements, as well as for weather and traffic avoidance. Ideally, these data requirements will align with the data being processed, distributed, and communicated by the air traffic system for manned flights. Incorporating unique data requirements of UAVs early in the development of data management systems will facilitate their integration and acceptance. Such data may include the geographic locations of emergency flight recovery areas and dynamically changing airspace restrictions on UAV activities (i.e., allowance times for operations in Class B airspace). The System Wide Information Management (SWIM) system concept is being developed to acquire, process, store, and disseminate information on traffic, systems, and weather conditions. SWIM will provide an information sharing infrastructure to support enhanced situational awareness, improved collaborative decision making, and free flight.

The SWIM concept is still evolving in terms of definition and scope. It is unknown if SWIM and/or other current and future flight data management systems will be sufficiently integrated and error-free enough to ensure consistency and safety of UAV flight operations. However, attributes of SWIM's higher level functions indicate its value to UAV operations. Such proposed attributes include:

- common data standards
- acceptance of user and service provider request for data
- common GIS format
- database management

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[55] A Compendium of DARPA Projects, Defense Advanced Research Projects Agency, August 2003, pg. 16.

- classification of data security levels
- continuous updates of NAS service constraints and infrastructure status
- dynamic data exchange (i.e., weather forecasts)
- information available via data link
- validation of data against authoritative sources

Though the concept of an aeronautical information management system was first conceived in the NAS Wide Information System, the term “SWIM” originated in Europe. ICAO adopted the SWIM concept in 2002 and the RTCA NAS Concept of Operation and Future Vision in 2002 also endorses the concept. One of the goals of countries participating the development of SWIM, see it as part of a standards-based global ATM system.

Assessment

Aeronautical system data exchange, processing, and synchronization will be vital elements to the success of UAV operations in civil airspace. SWIM will be a central component. The development of an air traffic management system that links all data needed for operations into an information-sharing network would greatly facilitate the integration of UAVs into the wider aviation community. Manned aircraft will increasingly rely on available databases as well. Systems installed on modern aircraft are reliant on databases to accomplish necessary functions, such as navigation data for flying RNAV procedures. As data-dependent aeronautical application and functions grow, the importance of managing information will become more critical to system performance and, more importantly, to safety. Development of SWIM will benefit from work being undertaken by the DoD’s net-centric program and by working to ensure international harmonization. The UAV community should be active in helping to develop SWIM and other data initiatives to ensure its unique data needs and it full integration into the system.

Safety Criticality	Technical Complexity	Legal Complexity	Socio-political Risk	Economic Cost
Moderate	Moderate	Low	Low	Low

2.3.4 Communications

Successful UAV operations depend on effective and reliable communications. Most UAVs use three types of data links: flight control link, system monitoring (telemetry) link; and a task or payload link used to control, manage, or monitor various onboard sensors or other equipment. Effective and assured data link communications are absolutely essential to almost all UAV operations. Yet how UAVs will communicate with ground-based pilots and the air traffic control system—and how command and control data will be transmitted to and from the UAV to its operator—remains a fluid area for discussion.

Most UAVs flying in civil airspace today communicate with air traffic control using a Very High Frequency (VHF) radio relay aboard the UAV. This allows for transparent operations with the controller and provides situational awareness to other aircraft. This is adequate for the large military and civil UAVs, but having a requirement for a radio on smaller UAVs is problematic for two reasons. First, most UAVs have very limited payloads and power generation capabilities and; second, having to rely on both an airborne and ground based transceiver increases the odds of system failure. Another option would be to create a system that allows the air traffic controller to transmit in the same manner, but have the broadcast split between the radio and a landline network that directly routes to the ground control station. This, however, would require a significant infrastructure investment and years to achieve a certifiably safe dual communications system.

Frequency spectrum

Currently, UAV command and control communications lack a secure civil frequency approved by the FAA, and it seems unlikely that the FAA would permit a control frequency for UAVs that is not within the FAA's protected spectrum. But allotting space on this spectrum may be difficult as the current FAA air/ground band (118-137 MHz) is too congested to support existing air traffic growth, much less a new service. However, if an allocated frequency must be found, it would likely be in the 960 to 1215 MHz band, down on the low end in the vicinity of Universal Access Transceiver (970 MHz).[56]

Another option might be to continue to operate on the unregulated frequencies being used today. Perhaps these frequencies can be certified for use provided a sufficient encryption capability and backup solution exists. Or, alternatively, UAVs could operate without an allocated frequency. DARPA is researching a next generation communications system in which spectrum use is not allocated, but instead constantly changes based on availability. This approach is founded on measurements indicating that only two percent of the spectrum is actually used at any given moment, despite most of the spectrum being allocated. The intent is to develop a technology that can exploit the unused spectrum without interfering with existing users. [57] It is doubtful, however, that this alternative would even be acceptable as a control link.

Bandwidth

Another issue concerns bandwidth requirements. Where data is transmitted from multiple platforms to the ground for air traffic controller use—as would be the case in using

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[56] This analysis of the frequency spectrum was provided by Jim Chadwick, Technical Director for Spectrum Management, MITRE CAASD.

[57] A Compendium of DARPA Programs, Defense Advanced Research Projects Agency, August 2003, pg. 27.

ADS-B—issues of communication latency (data capture and processing delays), resolution limits, and compression loss will require the high-bandwidths.

Modes of Communication

There are several technologies being used or researched which may impact the radio communication and datalink technologies being evaluated. For example, Europeans have tested datalinks using the VHF digital Link (VDL)-4 mode. Others are making use of the 802.11b “WiFi.” The high bandwidth networks used by WiFi can carry command and control data along with video and other sensor data over the internet. There are even commercial applications that allow for over-the-horizon capabilities using WiFi.[58] However, there are strict regulatory power limitations placed on WiFi systems that may limit its usage. Other suggestions have been made for using the cellular tower network. Even the use of laser communications for UAVs is being researched. But one of the more viable options has been the use of the Iridium Low Earth Orbiting (LEO) satellite constellation. A study conducted in 2003 indicated that it was feasible to use the Iridium satellites as a backup for command and control of over-the-horizon UAV Air Force operations, though issues concerning latency of messages required further study.[59] The Australian Aerosonde UAV (15 kg with 26 hour endurance) is being used for meteorological reporting over the Pacific and is being controlled via an Internet interface. Recently, Aerosonde has also contracted with Iridium for communication services.

Antennas

Most antennas in use by civil manned aircraft prove problematic for the small UAVs that are incapable of carrying the relatively large antennas. Advanced antennas—such as film, spray-on, and nano-antennas—are being researched as an alternative to these traditional antennas. One advantage of these new designs, besides being small and light-weight, is that they may be used for multiple communication functions (e.g., GPS, radio relay, data link). These antennas, however, are in the early research phase and may not be practical or available for many years.

Assessment

UAV communications technologies and concepts are very dynamic. Defining a single communication solution is probably not realistic given the variations in UAV size, power generation, autonomy level, and mission needs. When considering the various options for communication modes and frequencies, there will arise issues of allocation, bandwidth,

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58 Hudson, Trammell, “A Market Indicator,” Unmanned Vehicles, Nov-Dec 2003, pg. 25.

59 Presentation at the AUVSI conference, “Iridium Performance and Testing for Use on UAVs,” Reliable Systems Service Corporation, 16 July 2003.

communication integrity, security, and interoperability with existing airborne and ground-based communication systems. Cost, power, and weight penalties will also drive decisions.

A systems approach is needed when considering a communications architecture for UAVs. The ground station, air traffic control, and manned aircraft must all be considered equally in the equation. Solutions to UAV communications will take time to design, negotiate (i.e., for frequency allocation), and implement. But before solutions are settled, requirements for communications must first be defined. That definition should not endorse a particular technology or system, nor be exclusive to a particular country or region. Requirements should be flexible enough to allow for innovative ideas and applications to be explored. The proper venue for negotiating these requirements should be through the Required Communications Performance (RCP) being developed by ICAO and civil aviation authorities. The field of wireless and networked communications is changing rapidly with the advent of new concepts, technologies, and capabilities; it would be wrong to limit future UAV communication systems to what is known and proven today.

Safety Criticality	Technical Complexity	Legal Complexity	Socio-political Risk	Economic Cost
Moderate	High	Low	Low	Low to High

2.3.5 Navigation

For UAVs to operate in the future airspace, they will likely require enhanced navigational capabilities in order to meet the Required Navigational Performance (RNP) and reduced vertical separation minima (RVSM) expected of manned aircraft. For navigational guidance, the global positioning system (GPS) and inertial blend systems will be used by most UAVs for navigation, with GPS being the preferred technology due to the small size and low-cost of the GPS chipset. As Europe's Galileo and other U.S. and foreign navigation systems and upgrades come on line, the UAV community will likely take advantage of these as well.

While GPS provides a good navigational source, there are some regulatory issues that may create untenable requirements for some UAVs. FAA Part 91, for example, requires aircraft to be equipped with navigational systems appropriate to the ground navigational systems used; and FAA Advisory Circular 90-96 requires that in the event of an Area Navigation (RNAV) system failure (for most UAVs this would again be GPS-based) the aircraft must "retain the capability to navigate relative to ground-based navigational aids." In addition, air traffic providers expect aircraft to have navigational equipment compatible to routes flown (e.g., Very High Frequency (VHF) Omnidirectional Range (VOR) airways require a VOR). Further, ICAO and EUROCONTROL also require a navigation architecture that mandates a ground-based backup system for satellite navigation.[60]

[60] UAV Roadmap, March 2003, pg. 162

UAVs can use existing ground-based navigation sources, but the avionics are typically too heavy for use on anything other than the large UAVs. Also, ground-based navigation does not have good coverage on very low altitude flights. Other alternatives to ground-based and spaced-based solutions are also being explored. For example, there have been research efforts using vision-based navigation systems, but they are still in the experimental stage.

Navigational systems for landing vary among UAV systems. The military has made use of both precision approach radar and a video camera to assist pilots in landing on manual control, such as the Predator. In fully autonomous vehicles an ILS, MLS, or transponder landing system could be used, but there is a weight penalty and cost issue that make these systems prohibitive to most UAVs. Differential GPS (DGPS) and even laser guidance placed on airports has been used to assist in landing operations by the U.K. Ministry of Defense.

Accurate altimetric and other navigational equipment aboard UAVs will be needed if they are to comply with the 4-D flights, RVSM, and other navigational standards being developed. This is largely an issue only for the larger, more sophisticated UAVs. And for these vehicles, cost will be the major consideration. Smaller UAVs will most likely be unable meet such high standards and will stay clear of such rigid navigational environments. Further, the smaller UAVs, regardless of navigational equipage accuracy, would be challenged with maintaining a precise navigation path due to their susceptibility to winds.

Assessment

Reliable navigation systems are vital to the safe operation of UAVs in civil airspace. These systems must be accurate and capable of detecting and correcting navigational errors in a manner acceptable to regulating authorities. For the foreseeable future, satellite navigation will be the primary navigation tool. As GPS become more robust, and backup systems such as Galileo come on line, the need for ground-based navigational sources may be waived. Further, many urban settings in the U.S. are acquiring a differential GPS system as part of a broader Department of Transportation GPS initiative. This capability will add accuracy and integrity to UAV navigational procedures, particularly in the low altitude environments. Also, advances in UAV inertial systems will improve to a point that they can be sufficiently relied on as a navigational backup.

Much of the applicable navigation technologies that may be employed by UAVs already exists in the civil environment and has already been put to use in the military domain, such as 4-D (time-based) Area Navigation (RNAV). Therefore the technical element of this issue is minimal. While the continued development of RNP-defined routes, Standard Instrument Departure (SID), Standard Terminal Arrivals (STARs), offsets, and other navigational procedures expand, few of these procedures will apply to UAV operations. Rather, most UAVs will perform off-airway, non point-to-point, variable, and sometimes unpredictable routes. Therefore, the navigation procedure development for UAVs is not anticipated to be a major issue. However, a more relevant challenge will be in defining containment areas (geo-fencing) for UAV operations, particularly the small UAVs that may be operating in urban areas. These areas should be defined in a digital format. Such containment areas could be structured around noise sensitive locations, areas of high aircraft traffic densities (i.e., arrival and approach paths), areas of high population density, and other sites that may result in risks or nuisances to other aircraft or persons on the ground.

Safety Criticality	Technical Complexity	Legal Complexity	Socio-political Risk	Economic Cost
Moderate	Low	Low	Low	Low

2.3.6 Equipage

A general assumption concerning UAV integration is that the aircraft and their operations will conform to existing procedures, regulations, infrastructure, airspace, and other requirements, rather than making adjustments to accommodate UAVs. If this is the case, this would necessitate carrying the same navigation, radio communication, transponder, and other equipment fitted in manned aircraft. But the relative small size, limited power generation capabilities, and low cost of many UAVs may limit the type of on-board equipment that can reasonably be installed for communicating and interacting with the air traffic system. Unless equipment required to fly in civil airspace can be engineered to accommodate such limitations, it may be impossible for many to comply with existing equipage rules.

Miniaturization of aeronautical components would help in resolving some of the size and power demands, but developments here depend on the size of the market for such devices, the cost of development, and technical challenges. But given the trend in other areas of electronic components, there is a strong case to be made that UAV equipment could become smaller, more capable, and less costly. However, some equipment, such as transponders, may be difficult to miniaturize due to the transmission power and antenna requirements.

Assessment

UAVs, like manned aircraft, have cost and size limitations that make some avionics solutions impractical for some aircraft while acceptable for others. The primary challenges in equipage standards will be accommodating the smaller UAVs. This may require the use of alternative technologies, new procedures, or restriction on movements for these vehicles.

Safety Criticality	Technical Complexity	Legal Complexity	Socio-political Risk	Economic Cost
Moderate	Moderate	Moderate	Moderate	Low to Moderate

2.3.7 Emergency Flight Recovery

Emergency flight recovery and termination systems and emergency procedures will be an essential part of operating safely in civil airspace. These systems act to avoid or minimize the consequences associated with accidents such as lost communication or on-board system failures. Emergency flight recovery systems typically involve a preprogrammed set of instructions that tell the vehicle to take a specific action based on the emergency. Examples include continuation to a designated emergency landing area, return to home, continue to destination, hold, and change altitude to attempt re-establishing contact. Flight termination systems refer to self-destructive devices. These are rarely used. Emergency recovery and termination actions can be initiated by the vehicle or the ground-based pilot (assuming control links are maintained). One consideration in the execution of a flight termination procedure is whether special airspace should be established that designates areas for emergency UAV flight recoveries and terminations. Some have proposed that emergency landing areas be designated throughout the world and coded into active databases. Such designations would assist in flight planning and in handling of emergencies. It is assumed that these areas would be sparsely populated locations that are suitable for emergency recovery or termination operations. If adopted as a practice, these areas would need to be made known to the FAA and the public, and the airspace and traffic flows configured to accommodate such operations when they occur. For legal and political reasons, such areas may be easier to implement if they are placed within special use airspace, but this may not be practical for most UAV missions.

A final issue pertains to controller training on how UAVs will react during lost links or other emergencies that result in a flight termination procedure. Ideally, this information should be included in the flight planning process and the information rapidly accessible by air traffic controllers to assist them in keeping traffic clear of the UAV during its recovery operation.

Assessment

A full understanding and agreement on what termination procedures are acceptable to air traffic controllers, the public, the legal system, and NAS users must be resolved prior to allowing UAV operations in the NAS. The actions taken by the UAV in an emergency will largely depend on the size and capabilities of UAVs as well as the varying operational missions and environments. Some UAVs may be so small and slow that such emergency procedures are unnecessary. Nonetheless, predictability of termination actions is key, especially when operated under positive air traffic control.

Safety Criticality	Technical Complexity	Legal Complexity	Socio-political Risk	Economic Cost
Moderate	Low	Moderate	Low	Low

2.3.8 Airspace

How UAV's will make use of airspace is a complex matter. Much depends on the UAV capabilities, physical attributes, its intended missions, and how it may interact with its flight environment. The goal of the UAV community is to permit UAV access to *all* airspace on an equal footing with manned aircraft. In the near term, however most in the UAV community accept that some restrictions to airspace will be necessary (e.g., flights in Class B airspace).

Creating a UAV corridor dedicated to UAV use has been practiced by the military to accommodate some UAV flights. For example, several corridors have been created in Alaska to transition the Shadow UAV to, from, and between Special Use Airspaces (SUAs).[61] While such corridors have proven practical in some instances, especially where air traffic and population densities are low, the establishment of corridors elsewhere may pose a constraining factor for air traffic operations. A more likely initial method for permitting flights in civil airspace will be through the temporary blocking of airspace. This will be especially true of the more high-value operations associated homeland security. In the long run, however, this method will strain capacity and force the issue of integration.

How exactly UAV operation will affect airspace capacity and traffic flows can only be answered through simulations of UAVs within specified airspace. Part of this simulation must account for how the vehicles will operate (speeds, altitudes, endurance), where they will operate (mission), and in what numbers. Determining the missions and numbers of vehicles should ideally be based on forecast for planned government acquisitions and commercial forecasts.

Assessment

Airspace constraints will affect UAVs in much the same way as manned aircraft. There are ways to minimize airspace usage, but none are without fault. One proposal is to reduce the separation standards between UAVs, but this may be difficult for air traffic controllers to manage. Another proposal by the Air Force is to fly formations of UAVs, which could decrease demand on airspace but would also add new complications and risks.[62]

Safety Criticality	Technical Complexity	Legal Complexity	Socio-political Risk	Economic Cost
Moderate	Moderate	Moderate	Low	Low

[61] Website www.alaska.faa.gov/at/notices/**uav**.htm illustrates some of those corridors.

[62] Lt. Col Chad Manske, "Unmanned Airlift: A New Job for UAVs?" Unmanned Systems, Sept/Oct, 2003.

2.3.9 Surface Operations

Current UAV operations in civil airspace are confined to take-offs and landings in restricted airspace, typically from military controlled airfields.[63] Some proposals suggest that civil and commercial UAV operations, if permitted access to surrounding airspace, will increasingly make use of public airports, primarily to those currently serving only general aviation. Such operations may create issues for existing manned operations, particularly at the smaller towered and uncontrolled airports, though it is anticipated that most initial UAV operations at airports will be scheduled during non-peak times to avoid mingling with manned aircraft operations.

Taxiing to and from a runway will require precise ground movements and the ability to search for other aircraft or obstacles (e.g., animals, snow banks, construction vehicles) that may be on or near the apron or taxiways. Most UAVs today operating at airports do not have this capability and therefore require being towed to the runway. However, future UAVs will likely be able to taxi via remote control or autonomously.

Consideration will be needed concerning airport infrastructure to accommodate secured communication/control and power generation backup facilities, as well as vehicle storage facilities. Further, special navaids, such as DGPS or laser guidance, may be used at airports to assist in precision landings and takeoffs, as well as for taxiing on the airport surface. And some UAVs may be unable to fly airfield pattern landings but must instead perform straight in approaches. If changes to existing airport operations are significant enough, there may be special certification requirements and/or training for UAVs operators, tower controllers, and possibly even pilots who operate into and out of airports where UAV operations take place. New airport procedures may also be needed to handle normal as well as emergency UAV operations.

Assessment

Airport and other launch operations are not anticipated to be a major deterrent to UAV operations. Nonetheless, there is still a need to define standard operating procedures for UAV surface operations—at an airport or elsewhere—to ensure the safety of others using those facilities. When operating at airports, UAVs will need to consider the possible inability of their vehicles and its operators to see or read surface marking in the same manner as manned aircraft. The Europeans have recommended the issue of UAVs on airport surfaces to be studied by the European Group of Airport Safety Regulators (GASR).[64]

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63 Reference the ADS-B demonstration flights in Kiruna, Sweden at a civil facility.

64 UAV Task Force, Final Report, June 2004, pg. 70.

Optical sensors, DGPS, ADS-B, taxiway-embedded induction sensors, and other technologies are currently being looked at as potential guidance mechanisms for both manned and unmanned aircraft to assist in situational awareness during taxi operations. These technologies may lessen any potential impacts of UAVs on airport operations.

Safety Criticality	Technical Complexity	Legal Complexity	Socio-political Risk	Economic Cost
Low	Low	Low	Low	Low

2.4 Regulation

Regulatory requirements will ultimately define the operational boundaries of UAV certification, flight operations, and operator qualifications. To date, there are only a few countries having regulations pertaining specifically to UAV operations. Whatever regulatory structure is implemented, it will be a major defining factor in the evolving UAV market and its affect on air traffic operations.

2.4.1 Definition and Classification Schemes

Regulations will require clear definitions and distinct classifications among UAV types. Currently no universally accepted definition or standard classification for UAVs exists.

Definition of a UAV

Agreeing on a regulatory definition for UAVs has been difficult in part because of the wide variety in UAV designs and capabilities. While most civil aviation authorities recognize UAVs as being aircraft, there is no agreement on what type of an aircraft a UAV is. U.S. 14 Code of Federal Regulations (CFR) Part 1 defines an aircraft as “a device that is used or intended to be for flight in the air.” This definition covers UAVs, but it also covers hang gliders and anything else that can fly. Therefore, the U.S. has attempted to distinguish between regulated aircraft (i.e., a Cessna 152), regulated “not aircraft” (i.e., ultralight), and unregulated “not aircraft” (i.e., model airplanes). Unfortunately, UAVs being so varied in type, may fit within each of these categories—or none at all.

Take for example the difficulty in making the distinction between UAVs and model aircraft. The FAA covers model aircraft under FAA Advisory Circular 91-57, but does not offer a definition nor set a size limit to such aircraft. Further, this Advisory Circular (AC) is non-regulatory, offering only suggested guidelines, and was written when model aircraft were relatively limited in range and capabilities. But today’s model aircraft are becoming more sophisticated, and in some instances are employing autonomous technologies found in advanced UAVs.[65] Some have suggested that an ICAO requirement that limits the size of model aircraft to 25 kg. (approximately 55 lbs.) serves as the delineation for UAVs. Yet several sophisticated transoceanic and fully autonomous UAVs today are under this weight limit (e.g., the Aerosonde MK 3 and Boeing's ScanEagle). Can they therefore be classified as model aircraft? In Europe and much of the world, the model aircraft industry is now regulated to some extent. This may eventually occur in the U.S. as well.

Classification Scheme

A variety of classification schemes exist for UAVs. The U.S. military generally defines UAVs based on operating altitudes and endurance (i.e., high-altitude long-endurance (HALE). The military also classifies UAVs based on operational characteristics (i.e., vertical takeoff and landing, or VUAV), the environment in which the UAV will operate (i.e., tactical, or TUAV) and the type of mission (i.e., combat, or UCAV). The Europeans are considering classifying civil and commercial UAVs based on mass and speed (kinetic energy). Eurocontrol has proposed four UAV classes based on take-off weight, range and maximum altitude.[66] New Australian UAV regulations classify UAVs based strictly on weight. The FAA, while having no clear definition of a UAV, much less a classification scheme, has traditionally classified and certified aircraft based on size and complexity. Still others have suggested that UAVs be classified based on levels of autonomy. Without an adequate classification scheme, consensus on regulations, standards and certification requirements will be made more difficult and international harmonization virtually impossible to obtain.

Assessment

How UAVs will ultimately be defined and categorized for regulatory purposes remains open to debate. Arriving at consensus on a definition and classification scheme for UAVs will be difficult, but is fundamental to progress in standards and regulatory development. The development of a classification scheme is especially important. While good reasons exist for current conventions, a single scheme should be adopted by all civil aviation authorities. A suggestion is to base UAV classifications on a combination of the class of airspace needed for operations, autonomous kinetic energy values, and navigational accuracy (ability to stay with prescribed airspace). Such a classification, while more complex than current schemes, will allow for the establishment of more refined definitions of vehicle

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[65] In August 2003 a 5 lb. model aircraft flew from Nova Scotia, Canada, to Ireland on a 38 hours flight. The aircraft, named "TAM5," was guided by GPS. More information about this flight can be found at http://tam.plannet21.com/

[66] CARE Innovative Action Preliminary Study, *Integration of Unmanned Aerial Vehicles Into Future Air Traffic Management*, Industriean-Betriebsgesellschaft mbH, December 2001.

characteristics which, in turn, will facilitate the development of system requirements, impose operational constraints, and define the level of access to the civil airspace system.

Safety Criticality	Technical Complexity	Legal Complexity	Socio-political Risk	Economic Cost
Moderate	Low	High	Low	n/a

2.4.2 Standards

There are currently no published standards specific to UAV systems, operations, or operator qualifications. Standards are a vital element in today's high tech world and often form the basis for government regulation. They do not, however, have the force of law unless specifically mandated in regulation. The U.S. and many other countries have begun moving toward the development of consensus standards as a basis for regulation as well as to facilitate market growth through the development of interchangeable formats and to ensure international harmonization. The inclusion of standards in regulations, if properly developed, has the benefit of allowing changes to be made without having to engage in the lengthy and costly process of creating a rule change. As a result, standards can be changed and regulations made consistent with the change without having to modify regulatory wording.

Regulations can and are developed without standards, but this is being discouraged. In 1998, the U.S. Office of Management and Budget revised its Circular A-119, Federal *Participation in the Development and Use of Voluntary Consensus Standards and in Conformity Assessment Activities*, directing all federal agencies to use voluntary consensus standards in lieu of government-developed standards in their procurement and regulatory activities, except where inconsistent with law or otherwise impracticable. Further, Public Law 104-113 requires agencies to use consensus-based standards unless they conflict with existing laws. This move toward requiring the use of consensus standards is important to emerging technologies, such as UAVs. The FAA, for its part, has long endorsed consensus standards, through such organizations as RTCA, and supports such a process as the precedent for UAV regulations.

There are several organizations working to develop standards for UAV systems and operations. Five are summarized here:

- Beginning in 1999, the U.S. DoD, in coordination with NATO, has developed 15 Standardized Agreements (STANAGs) that apply to UAV control, data and communications. The most recent STANAG (4586) addresses the ground control station. While STANAGs are written primarily for military operations, parts of these standards can also be applied to civil UAVs.[67]

- In September 2002, the American Institute of Aeronautics and Astronautics (AAIA) began developing UAV terminology and UAV plug-and-play payloads. The terminology standard was published in August 2004 (referenced as R-103-2004).
- In July 2003, ASTM formed a committee to look into UAV standards for airworthiness, operations, and operator qualification. The formation of this committee was facilitated by AUVSI. ASTM is usually not involved in aviation standards, but was successful in the development of standard for light-sport aircraft in 2003. A draft standard on UAV see-and-avoid was published the F38 committee in July 2004.
- In July 2004, the UK UAV Safety Subcommittee (a MoD/industry group) began work on the development of design and airworthiness standards for UAV systems. The group will be examining structures, powerplants command and control link integrity, decision-making software, accident data recorders, and human factors requirements for guidance and control of UAV termination systems. Within the next five years, the group seeks to work on a "classification scheme that will segregate UAVs according to appropriate airworthiness requirements and the harmonization of requirements with international UAV policy and standards."[68]
- In August 2004, RTCA announced the formation of a new special committee, designated SC-203, that will address UAVs, focusing initially on sense and avoid and command and control issues. This effort is endorsed by Access 5 and will involve active participation of industry associations, including the Aircraft Owners and Pilots Association. The committee is set to begin activities in December 2004.

Assessment

There is a competitive spirit in the current standards development process that precludes a unified effort. Having different standards is not necessarily a problem unless and until civil aviation authorities apply those different standards to their regulations. With aviation being a global enterprise, such action would hinder the market and likely add to the cost of system acquisitions and operations. Therefore, a primary challenge for the UAV community will be to coordinate the standards activities so that they complement rather than duplicate or contradict one another. But a first step needs to be made on reaching agreement on

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67 "NATO Standardization Agreement 4586 – Leading the Way to NATO UAV Systems Interoperability," article in www.uav.navair.navy.mil/nato/article.htm, November 2003.

68 "Priorities Defined for UK UAV Standards," New update on UAVworld News, UAVworld.com, July 2004.

definitions, terms, and classifications as they relate to UAVs. In the absence of such agreement, the job of developing consensus standards that are nationally and internationally recognized and adopted will be made more difficult.

Safety Criticality	Technical Complexity	Legal Complexity	Socio-political Risk	Economic Cost
High	Moderate	High	Low	Low to High

2.4.3 Regulation

The development of air traffic management, airworthiness, and flight operations regulations related to UAVs will be a key enabler to their successful integration in civil airspace. Today, most in the UAV community are seeking to develop regulations that parallel manned aircraft regulations. This is a position taken by the U.S. military as outlined in the 2003 OSD Roadmap where it outlines precepts for formulating a regulatory environment for UAVs:

- Do no harm—avoid enacting regulations for the military user that would later unnecessarily restrict civilian UAV flights; where feasible, leave hooks in place to facilitate the adaptation of these regulations for civilian use. This also applies to the recognition that "one sized does NOT fit all: when it comes to establishing regulations for the wide range in size and performance of DoD UAVs.
- Conform rather than create—build around the existing Title 14 Code of Federal Regulation adapting them to also cover unmanned aviation while avoiding the creation of dedicated UAV regulations. The goal is achieving transparency between unmanned and manned flight operations, not putting UAVs in a special treatment category.
- Establish the precedent—although focused on domestic use, any regulations enacted will likely lead, or certainly have to conform to, similar regulations governing UAV flight in international (ICAO) and foreign (specific countries') airspace.[69]

Premising a UAV regulatory structure based on manned aircraft makes sense, but developing such regulations to cover the vast array of UAVs will be a challenge. There are too many differences, especially concerning the small UAVs. Therefore, expectations that all UAVs can conform to existing regulatory requirement may not be realistic.

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69 OSD Roadmap, Appendix G, pg. 154.

International Conformity and Compliance

Another dimension to the issue of regulation concerns international conformity and compliance. As far back as 1944 the authors of the Chicago Convention foresaw the need to address unmanned aerial vehicles—then referred to a "pilotless aircraft"—in the context of the global environment. Article 8 of the Convention specifically addresses their operations:

> No aircraft capable of being flown without a pilot shall be flown without a pilot over the territory of a contracting State without special authorization by the State and in accordance with the terms of such authorization. Each contracting State undertakes to insure that the flight of such aircraft without a pilot in regions open to civil aircraft shall be so controlled as to obviate danger to civil aircraft.

Article 37 of the Convention instructs ICAO to adopt and amend international standards and recommended practices (SARPs) contained in the set of 18 ICAO annexes. Three of these annexes are of particular importance to UAV operations: Annex 1 (personnel licensing), Annex 6 (flight operations) and Annex 8 (airworthiness). All signatory countries to ICAO must abide by these annexes if they intend to operate there aircraft internationally. For UAV operations, the Convention and its annexes serve as the primary legal instrument governing international UAV operations and should be reflected in regulations developed by signatory nations to the Convention.

Current Work on Regulation

It is ironic that even as the U.S. leads in UAV technology developments, they lag in legislative activities relating to UAVs. Other than the COA process, the U.S. has no regulation or guidance for UAV operations. During the 1990's, the FAA did form working groups that developed draft Advisory Circulars concerning UAV airworthiness, operations, and pilot qualifications, but they were never instituted. Most regulatory action on UAVs has therefore been left to others.

The Australians and British are perhaps the most advanced in regulatory development. In 2001, Australia published an Advisory Circular (AC 101-(0)) for UAV operations, design specification, maintenance, and training of human resources. In 2002, Australia became the first country to establish a rule under its Civil Aviation Safety Regulation (CASR) Part 101, *Unmanned Aircraft and Rocket Operations*. The UK released guidance in 2002, known as CAP 722, on how UAVs can be used and licensed to fly in civil airspace. The UK has also prepared draft rules on certification of UAV airworthiness, design specifications, and operator qualifications. Other European countries are also developing new regulations. Most recently, in July 2004, the Italian parliament approved a law concerning the use of military UAVs in civil airspace. There are also pending regulations in Italy that will cover the deployment of UAVs in the air-traffic control system and the use of limited air traffic areas and corridors for UAV activities.[70]

The Europeans are also engaged in activities aimed at the development of rules that can accommodate the Joint Aviation Requirements (JARs) and satisfy member nations' concerns over UAV safety and usage. As of September 2003, the European Aviation Safety Agency (EASA) set an upper limit of 330 lbs to the size of a UAV for which national regulations apply; above which transnational EASA rules apply. Euro UVS, an association representing UAV interest, has initiated an international program to facilitate the framing of rules and regulations governing UAV's integration into managed airspace.

Analyses of regulatory changes have been published in several studies. Most notable are the 2002 NASA ERAST HALE UAV Certification and Regulatory Roadmap and the July 2004 JAA/EUROCONTROL UAV Task Force report, *A Concept of European Regulations for Civil Unmanned Aerial Vehicles*. The NASA Roadmap focuses on changes needed to U.S. 14 CFR Part 91, *General Operating and Flight Rules.* Their analysis found that most of the current regulations are "already applicable or specifically do not apply to the flight operation of UAVs." They recommend that Part 91 be modified to accommodate unique criteria applicable to HALE UAV operational requirements and limitations. The roadmap does not address the certification regulations contained in Parts 21, 23, and 25. In Europe, the UAV Task Force reviewed JAR-OPS (operations), JAR-FCL (personnel licensing), and EC 1592/2002 (airworthiness), as well as all ICAO Annexes to determine relevancy to UAVs. Various organizations were asked to identify and review in greater detail the regulatory actions needed and to provide recommended changes. Timelines and priorities were assigned to each action.[71]

So where is UAV regulation headed? Will it be harmonized? There are several international efforts under way to coordinate the development of regulations. The majority of these initiatives are taking place in Europe. The UAV-REG program, which includes participation from 18 European companies from France, Spain, Germany and the UK, developed a report in February 2004 on UAV airworthiness and Air Traffic Management (ATM) regulations. Conclusions from this report are being integrated into the program known as UCARE (UAV's Concerted Actions for Regulations) which is taking a broad international approach to regulatory development. UCARE participants include industry, R&D organizations, military and civil government bodies, including the FAA, NATO, and

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[70] "Italian Parliament Approves Law on UAV Deployment," UVOnline.com news update, www.shepards.co.uk/UAVOnline, 31 August 2004

[71] "A Concept for European Regulations for Civil Unmanned Aerial Vehicles (UAVs)," The Joint JAA/EUROCONTROL Initiative on UAVs, UAV Task Force, Final Report, July 2004.

Eurocontrol, as well as universities and associations from Europe, North America, Asia/Pacific and South Africa. A new NATO group, Air Group 7, is also seeking participation and guidance from regulatory authorities as well as coordinating with the NATO Air Traffic Management committee, the European Capabilities Action Plan (ECAP) and the European Technologies Acquisition Program (ETAP). In the U.S., UNITE and Access 5 has been seeking greater coordination with these efforts as well.[72]

Assessment

Regulations are intended to ensure that the UAV systems and their operations achieve an acceptable level of safety for people and property in other aircraft and on the surface. Existing regulations have been based on the assumption that at least one person (the pilot) is aboard an aircraft, and therefore a life is at risk in any accident. Consequently, the rules governing manned aircraft certification and flight operations are designed to meet very high safety standard. But among unmanned aircraft, this same assumption does not apply. The conventional approach of mandating specific design techniques, load cases, redundancy levels, equipment, and so forth based on manned aircraft might be unfair. An alternative would be instead to specify acceptable levels of risk while being receptive to diverse solutions for achieving those levels. In Canada [73] and Australia [74] the authorities have circulated preliminary ideas consistent with this concept.

In the past, regulatory development has been a chicken-and-egg situation: regulators have been reluctant to pursue UAV regulatory actions in the absence of an application for certification from industry, and industry has been unable to develop such applications without a regulatory structure. This is changing. Standards are being developed and regulations forming. It will be important for the UAV community, standards developers, and Civil Aviation Authorities (CAA's) worldwide to facilitate the development of reasonable regulations based on a safety case, and to ensure that regulations are reasonably harmonized so as not to impose an undue burden on the industry and, in doing so, impede the development of a new aviation market.

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72 Gilson, Charles, "UAVs Steal Spotlight as Utility Multiplies," Aviation International News, Asian Aerospace 2004, AIN Online, www.ainonline.com/Publications/asian/asian_04/d2_uavsp14.html, February 2004.

73 Minutes of Non-Piloted Aircraft meeting chaired by Arlo Speer, Chief, Recreational Aviation & Special Flight Operations, Transport Canada, Ottawa, 22 May 1998.

74 "Guidance for unmanned aerial vehicle (UAV) operations, design specification, maintenance and training of human resources," Civil Aviation Safety Authority draft, September 1998.

Safety Criticality	Technical Complexity	Legal Complexity	Socio-political Risk	Economic Cost
High	Low	High	Low	Low to High

2.4.4 Airworthiness Certification

There are no established standards for certifying the operational safety of UAV systems. The vehicle, ground control stations, communication links, flight control systems, and software all need to be considered in the certification process. Many certification requirements will be the same as for manned aircraft while others may require modified or new requirements. The existence of government/industry consensus standards and classification scheme for UAVs will assist in defining the certification requirement.

In August 2002, the UK CAA produced a study of airworthiness certification standards for UAVs. The study examined two approaches to certification: a "target safety" and a requirements-based method. The target safety approach focuses on achieving numerical levels of safety for critical features of the system by combining operational and design requirements to achieve a target. For example, uncertainty over system reliability can be overcome by restricting operations to uninhabited areas and lightly trafficked airspace. This approach has the advantages of being focused on safety critical areas, not being bound to overly restrictive requirements, and does not require development of a comprehensive set of requirements. While being a good method for UAVs not needing complex and costly requirements, it is not consistent with ICAO and most national legislation. The second approach, one that is requirements-based, was seen as more practical in that it is familiar to the aviation industry, it facilitates the development of common standards, and there are no special, type-specific, operating restrictions to address airworthiness uncertainties, therefore offering greater operational freedom. The study goes on to take the position that UAVs should be granted permission to fly by qualifying for a certificate of airworthiness that is comparable to, and derived from, those applied to manned aircraft.[75] The requirements based approach is most commonly used today and will most likely be the approach taken by the majority of CAAs.

The following subsections describe issues relating to four specific UAV certification areas: design and production; autonomous systems and software; ground control stations; and data link. A final subsection addresses a total system certification process.

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[75] D.R. Haddon and C.J. Whittaker, "Aircraft Airworthiness Certification Standards for Civil UAVs," Civil Aviation Authority, UK, August 2002.

2.4.4.1 Design and Production Certification

The design requirements for unmanned aircraft share most of the same attributes of manned aircraft concerning areas such as structural integrity, performance, reliability, stability, and control. If required to follow manned aircraft certification requirements, this means that UAVs must be built in a certified manufacturing facility, using approved methods and materials, and subject to oversight throughout the process. This production process must then be followed by a flight inspection to ensure the safety of the aircraft. These certification requirements may work for a manned aircraft, but may not be sufficient for a UAV, where the vehicle is only one component of a system. An airworthiness certification for a UAV would need to extend to the ground control station, data link facility, data link, data security, launch and recovery mechanisms (if applicable), and the autonomous systems and software integrated into the vehicle and ground elements.

Europe and Australia have made progress in developing design and production certification standards with the Netherlands being one of the first countries to certify the Sperwer UAV for civil airspace use. This certification process, the first in the world, took five years to accomplish. Political and technical impediments associated with a new technology made the certification work slow. One of the main political issues was in determining what was expected of UAVs during operational flights. [76]

In the U.S., most aircraft are certified under Federal Aviation Regulation (FAR) Parts 23 or 25. But UAVs have difficulty in meeting these requirements. For example, the most advanced UAVs, such as the Global Hawk, should be certified under Part 25 due to its size and complexity, yet this UAV would be unable to meet these requirements due to it being a single-engine aircraft. This being the case, there are only a few options left. First is to certify aircraft under Part 21.17. This regulation allows manufactures to pull regulations from both Part 23 and 25 to meet a standard of compliance acceptable to the FAA. This is typically a slow process. While this may work as a stop gap measure, it will probably not be sufficient for the long run as the number and variety of UAVs seeking certification increases. Another avenue available to UAV manufacturers is to apply for an experimental aircraft certificate using FAA form 8130.7, Special Airworthiness Certificate. Again, this has problems in that it severely limits the type of flight operations that can be conducted. Therefore, it may be necessary for the FAA to consider a new type of vehicle certification approval for UAVs.

2.4.4.2 Autonomous Systems and Software Certification

Many UAVs will employ complex, software-driven systems to sense, control, communicate, and navigate with increasing levels of autonomy. *Autonomy* refers to the

[76] Marsh, George, "Europe's Answer: UAVs in Controlled Airspace," Avionics Magazine, February 2004.

ability to act without human control, meaning that the vehicle can maintain safe flight; monitor and assess its health, status and configuration; and command and control assets onboard the vehicle within its programmed limitations.

The primary benefit of autonomy is that less human monitoring and control is needed. This capability promises to offer greater safety (i.e., intelligent reconfigurable control, prognostic health management, and automatic air collision avoidance) and increased efficiency (i.e., allowing for control of multiple vehicles by a single operator). Increased autonomy can also reduce bandwidth requirements by performing functions that would normally require data linked instructions. More advanced concepts of autonomous systems will allow UAVs to make determinations and take appropriated actions based on changing, unpredictable conditions (i.e., severe weather avoidance, traffic, system failures).

Advances in the field of aeronautical system autonomy are progressing rapidly and will continue to do so. While the potential benefits of autonomy are evident, there are also a number of technical, certification, and economic issues to be considered. Autonomous systems are complex and may pose certification challenges to certification as well as to interoperability issues with air traffic system. As complexity of software coding increases, so too does the non-deterministic nature of the programs. This is not to imply that critical functions cannot be predicted, it is just that they cannot be predicted with absolute certainty. But even a small degree of uncertainty creates issues for certification authorities. The current standard used for software certification of aircraft systems—RTCA/DO-178B, *Software Considerations in Airborne Systems and Equipment Certification*—may be too stringent for most UAVs. RTCA/DO-178B was developed by the avionics industry to establish software considerations for developers, installers, and users when aircraft equipment design is implemented using microcomputer techniques. While it is a good standard, it was written with manned aircraft in mind and may be too rigorous for the non-deterministic coding that is currently being applied to UAV systems.

2.4.4.3 Ground Control Station System Certification

The ground control station refers to any ground-based facility or device used to control a UAV. The sophistication of these stations and their physical locations and attributes vary significantly. And, there may be more than one ground control station in a particular UAV system. For example, some ground stations may separate the launch and recovery element from the en route mission operation element. Also, some ground control stations may be capable of simultaneously handling multiple UAVs. This concept is already being explored by the military.

Since this is a new area for certification, there is much research needed. What reliability levels will be required? What is the appropriate configuration? How might requirements vary depending on the vehicle, mission or flight environment? How secure must the ground station be? These are just a few of the questions that certification authorities will need to address.

2.4.4.4 Command and Control Data Link Certification

The command and control data link system is vital to the safe operation of UAVs. Like the ground control stations, these systems vary considerably. Data link systems can consist of a simple transmitter or may involve a complex networked communications system that uses a variety of communications modes (including the internet and satellite) to link information to and from a UAV. Some data link systems and providers may have no association with the aviation environment other than in the provision of this one service. These complexities will make certification of these systems a challenge. The most crucial component of the certification process will be in defining the reliability, integrity, availability, and encryption standards relative to the vehicle type and its intended mission and flight environments.

2.4.4.5 Total System Certification

Future UAV systems may include ground control stations, data link facilities, and vehicles being designed and built by different organizations, yet intended to operate as a single system. The Europeans have acknowledged that component certification will not be enough to ensure the safety of flight. They have therefore adopted a total systems approach to certifying UAVs. Much of this work is credited to work being done by the Swedish military to certify their UAV systems.

In March 2003, the Swedish military established a cooperative arrangement with the Swedish Civil Aviation Safety Agency for the introduction and certification of UAV systems in Sweden. The certification is base on a concept which views all components and systems related to the manufacturing, maintenance, and operation of a UAV as a single system. It is, in essence, a system of systems approach and calls for a system integrator function in the certification process.

The Swedish system defines aeronautical products in its broadest sense: "Aeronautical product means any technical system, sub-system, manned or unmanned aircraft, other product, parts and appliances, software product, basic data, mission data, ground materiel or consumable and expendable product that may have an influence on the level of flight safety."[77] The Swedish concept defines airworthiness in term of *system worthiness*. A system is deemed system worthy if:

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[77] Rehn, Torbjorn, "UAV Certification: The Swedish Approach," paper to the UVS International Conference, 21 May 2004, pg. 5

1. Its system integrity conforms to its system design and is assured for all anticipated conditions of the operational life of the system.
2. The safety aspects of the operational use of the system have been considered and information for safe operation has been established.
3. Organizations undertaking design, systems integration, production and maintenance of the system, are approved.[78]

The Swedish authorities have suggested that European regulations be modified to incorporate this definition. This issue is currently being taken up the JAA/Eurocontrol UAV Task Force.

Assessment

The certification of UAV systems is a fundamental step in allowing routine access to civil airspace. But fitting UAV certification requirements to those of manned aircraft may not be possible nor even desirable. UAVs are unique in many respects from manned aircraft systems. The total system certification approach, currently being considered by Europe, seems to be the most sensible given the interactive complexity of the UAV system (vehicle, ground control stations, software, and data link).

Safety Criticality	Technical Complexity	Legal Complexity	Socio-political Risk	Economic Cost
High	Moderate	Moderate	Low	Low to High (depends on vehicle type and requirements imposed)

2.4.5 Pilot Certification

Developing certification criteria for UAV pilot operations is complicated by the diversity in size, autonomy level, and potential uses of UAVs. Though variations also exist in manned aircraft and their operations, they are not as pronounced. For example, some UAVs pilots visually see and control their aircraft (much like model remote control (RC) aircraft) while others may be asked to control multiple autonomous vehicles from a sophisticated ground control facility. Further, the vehicles may be manually controlled, have flight control correction features, or operate in an autonomous mode, each requiring different skill sets.

[78] Rehn, pg.6

Manned aircraft pilots are licensed for various flight operations—private, commercial, instrument and airline—and are provided type ratings for the aircraft flown. All pilots must pass tests to prove adequate knowledge and proficiency relative to the type of operation they intend to fly. A similar model could be applied to UAV pilots, but the requirements would almost certainly be different. Knowledge concerning aerodynamic principles, general flight rules, flight critical systems, navigation, communications, meteorology, and emergency procedures will still be required of a UAV pilot whereas knowledge of physiological effects of flight and visual scanning techniques may not. Also, medical requirements need not be as strict for UAV pilots as with their manned counterparts.

The requirement for a license will depend on the operational environment and the size and complexity of the vehicle. It's fair to assume that a large UAV operating out of a major airport would likely require a pilot with extensive certification criteria similar to a commercially licensed, instrument rated pilot of a manned aircraft. However, a pilot wishing to operate a slow, electric-drive, 6 lbs. UAV to photograph wildlife, may require minimal or no licensing. This is in fact a dilemma faced by the U.S. Air Force (USAF). Some vehicles in their inventory, such as the Predator A, are designed to be flown in fully manual mode, whereas the Global Hawk can be operated in a fully autonomous mode, though each requires a similarly trained pilot-rated officer to fly. Interestingly, the Firebee UAV used in Vietnam was controlled by enlisted operators (non-pilots) and overseen by rated officers. But since 1977, the USAF has only allowed pilot-rated officers to operate their UAVs.

Then there is the issue of the small UAVs.[79] The Desert Hawk and Pointer UAV systems (hand-launched vehicles) have been successfully operated by non-license enlisted personnel, demonstrating that at least this class of vehicle need not require a pilot license to operate. However, these small military vehicles are not interacting with the air traffic system. If they are allowed to operate in an area where traffic exists, would the requirements change? (For more discussion on military UAV pilot qualifications see Section 2.1.3, *Human Factors*, on page 2-14.)

It seems clear that there are two primary requirements for a UAV pilot: he or she must be fully capable of controlling the vehicle and must be able to interact safely with air traffic in the operating environment. Drawing the line between who should or should not require a license, or what licensing levels might apply, will continue to be a challenge for standards developers and regulators.

There is another pilot certification issue as it relates to the conduct of UAV flights. Some operations may be directed by an individual that is not physically controlling the UAV but is instead responsible for monitoring or directing other people to make adjustment to the flight of the vehicle or vehicles under their command. Other complications come in determining

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[79] Bishop, Stephen, "Training for Unmanned Systems," Unmanned Systems, Sept-Oct 2003, pg. 28.

UAV pilot certification criteria when they are being asked to control multiple UAVs. In these circumstances, the skill requirement may be considerably different from those of a single vehicle/single pilot scenario, and may indeed be more akin to an air traffic controller's responsibility than that of a traditional pilot.

A final issue concerns training requirements. Some UAVs are small and designed to be very easy to operate, especially some of the very small hand-launched UAVs. These may require only a minimum of training. Producing such simple and easy to operate systems has been emphasized in some military UAV systems as means to reduce training cost and as a way to broaden the field of potential pilots. Recently training requirements may also vary depending on the UAV type, its intended flight environment, and the complexity of the system.

Assessment

There may not be a one size fits all when it comes to pilot qualification requirements. Clearly there is a need for all pilots to be knowledgeable and trained in areas relating to air traffic and airspace procedures and requirements, but specific training on the vehicle controls and systems may vary widely. Issues concerning pilot certification requirements should align closely with human factors research. It should also, at its most basic level, assure that the pilot has the proper skills and knowledge to safely operate a UAV (or multiple UAVs) within the constraints of the flight environment. If only operating a small UAV within visual sight at low altitudes in a rural setting, the certification would likely be low; whereas on the other extreme, a pilot seeking to control multiple UAVs in a complex and heavily trafficked area would need an entirely different set of knowledge and skills.

As for training requirements, it doesn't seem necessary that a UAV pilot be trained in a manned aircraft. Computer-based training may be more appropriate. Some of the new training systems and techniques being explored for pilots of Small Aircraft Transport System (SATS)-equipped aircraft could also be employed by UAV pilots.[80]

Safety Criticality	Technical Complexity	Legal Complexity	Socio-political Risk	Economic Cost
High	Low	Low	Low	Low

2.5 Socio-Economic

Economic, political, and social issues simultaneously drive and restrain the UAV market. Demand for government use of UAVs (e.g., military, homeland security, law enforcement,

80 The SATS computer training program, known as Cyber Tutor, is being developed by Embry-Riddle and the Southeast Lab Consortium. This program will, if successful allow pilots to significantly reduce the amount of training required to become a pilot.

and scientific research) is influenced mostly by the availability of fiscal resources and political will. Commercial markets, on the other hand, are dependent on the business case, which is linked to consumer demand, regulatory approval, airspace/airport restrictions, and public acceptance.

2.5.1 Insurance Liability

Insurance liability for UAV systems has become a major concern among UAV manufactures and potential commercial operators. The insurance industry determines liability costs based on past safety performance and government certification criteria. For today's UAVs, the only historical safety record available is from military UAVs, which have a poor safety record, and certification criteria, which are non-existent. These conditions result in uncertainty, which in turn translates into high premiums or refusal to insure. In the few instances where liability amounts have been calculated, the costs far exceeded the rational cost basis for the business model. To lower costs, the industry will require better proof of system safety and reliability, and must work to gain certification standards acceptable to government regulators and the insurance industry.

The cost of liability insurance will have a direct influence on the size of the UAV market. Beyond the accident records and systems certification criteria, insurers will need to consider the intended mission, operational environments (i.e., flights in urban areas or dangerous environments), and the potential of the vehicle to cause damage or fatalities based on size and speed. In general, smaller vehicles operating in sparsely populated and low traffic areas would have less liability than a large and fast vehicle operating in or near a large airport or other high traffic areas. But this may not always be the case depending on the certainty of the systems used and on established safety records.

Accidents typically increase insurance premiums by lowering confidence in the reliability of the system or operation being insured. An additional cost of an accident, particularly for a commercial UAV operator, could be high litigation costs. Such litigation will raise questions about what the operator could have, or should have, known regarding unsettled issues surrounding the UAV system's reliability, general acceptance, or suitability for its intended use. This cost may increase further if the UAV were modified to suit a unique mission. Any modification, regardless of degree, raises the possibility of additional liability and added uncertainty.

Depending on the safety criteria applied to certification requirements, they may have a significant impact on lowering liability costs. The assurance of government oversight and enforcement of UAV manufacturing, operations and maintenance systems will lessen risks and uncertainty, and provide added public and commercial confidence in the safety of UAVs.

For UAV operators working directly for the government or those being contracted will, in most circumstances, be immune from liability. But this depends on several factors, not least of which is individual U.S. state and country statutes. In the U.S., the extent of liability could depend on the purpose of the flight, the public or private use of data collected, and the agency controlling or contracting control of the vehicle. Commercial UAV operations being conducted for the government may require cross-waivers, hold-harmless, and indemnity clauses as is currently being practiced with private space launch operations.[81]

Assessment

As more UAVs prove their capabilities and as certification standards come into existence, the cost of insurance will likely be lowered. Most UAV manufacturers today recognize the importance of improving reliability of their UAV systems as fundamental to lowering insurance costs and in bolstering market acceptance. The greatest liability costs will be borne by those first entering the UAV market (when the uncertainty is highest) or for those who choose to operate a new UAV system or conduct unique UAV mission from which the insurers have no precedent.

Safety Criticality	Technical Complexity	Legal Complexity	Socio-political Risk	Economic Cost
n/a	n/a	Low	Low	Moderate to High

2.5.2 Public Acceptance

For UAVs to be accepted, the media and public must be convinced that the perceived benefits (i.e., greater security, improved information, more services, lower costs) outweigh potential costs (i.e., increased noise, pollution, privacy concerns, safety risks, delays). The extent of media and public acceptance (or opposition) will likely affect political will, which, depending on the outcome, may either restrict or free up the market. Gaining public trust in UAVs will take time and require demonstrated safe, economical and socially responsible operations. But any trust gained through such efforts could be easily damaged or lost in a high exposure accident.

A public opinion survey conducted in 2003 of the flying public found that “up to 68 percent of the population will support the FAA in cargo and commercial UAV applications, which is a sufficient percentage to allow immediate implementation of UAVs for cargo and commercial/civil use.” The same study went on to state the “the populace are not concerned with unmanned aircraft flying overhead,” and that several respondents to the survey cited job loss as their primary reason for not supporting UAV implementation, where others pointed to

81 Gabrynowicz, Joanne Irene, “Commercial High Altitude Unpiloted Aerial Remote Sensing: Some Legal Considerations,” http://space.edu/LibraryResearch/Remote_sensing_article.html, 1996.

uncertainty concerning the technology. Not surprising, only small percentage of survey respondents would support the use of UAVs to fly passengers.[82]

The importance of public perception in the success or failure of the UAV civil industry are obvious. But managing perceptions with a "new" technology (new at least to the public) is difficult. People's risk perceptions are based on a combination of subjective judgment and limited knowledge of the true risks imposed by a new technology. According to a recent study into UAV credibility with the public, there is a tendency by the public to over estimate small risks and to underestimate large risks, and that the public tends to focus on risk and how they can protect themselves from those risks. Conversely, experts tend to perceive risks within their competence area as much lower than the public. As a result, public trust seldom conforms to expert assessments of hazards associated with technologies, particularly when the technology is new to the public. The same study concludes that the industry needs to create credibility for the UAV industry and not merely sell UAVs.[83]

Environmental Concerns

The impact of UAVs on the environment can also influence public and market acceptance. Just as the Concord was limited to oceanic operations due to its sonic boom, UAVs may be limited by noise, emissions, or other environmental constraints. Many UAVs being considered for applications in urban areas today are indeed noisy and, if flown low and in great numbers, will become a nuisance. Also, merely adding to the aviation fleet will suggest further fuel consumption and more emissions. But whether an environmental backlash to UAVs occurs is doubtful. The trend is for UAVs to become more quiet (many being electrically powered) and fuel efficient, and their use may ultimately replace many of the larger and less efficient manned aircraft. New technologies being applied to UAVs, particularly with respect to the use of solar power, fuel cells, and other low emissions propulsion systems, could encourage their use among an environmentally conscience public. Further, many UAVs will be used to advance understanding and resolution of environmental issues (i.e., aerosol dispersion, wildlife tracking, atmospheric sampling, whaling violations).

Privacy Issues

With the growth in ever more intrusive technologies, privacy issues are likely to increase in their legal complexity and their importance to the public. While manned aircraft have long been used to collect sensor data for applications such as crop management, land use

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[82] MacSween-George, Sandra Lynn, "A Public Opinion Survey—Unmanned Aerial Vehicles for Cargo, Commercial, and Passenger Transport," The Boeing Company, paper presented to the 2nd AIAA "Unmanned Unlimited," Systems, Technologies, and Operations Conference, AIAA 2003-6519, 2003.

[83] Presentation to the 2004 UVS International Conference by Cecilia Lundin, Human Factors Specialist, SAAB Aerospace, Sweden.

mapping, and mineral exploration, they have largely been confined to high altitude operations. UAVs will be able to perform many of these same missions, but will also have the possibility of collecting information at a much lower altitudes (and lower cost) using some of the smaller, more quiet variants. This capability for collecting information, combined with the internet or other public media output could raise concerns when UAVs are used to collect data or imagery of persons, buildings, or private property that was largely free of public viewing.

Assessment

If the public perceives UAVs as being unsafe, an intrusion, or an annoyance, it could significantly limit the extent of operations, or even prohibit UAV access to civil airspace altogether. Currently, public trust and political acceptance of UAVs is being buoyed by recent military successes. However, this trust and acceptance could rapidly erode in the event of a fatal accident involving a UAV or if UAV sensors are used improperly to collect information on individual citizens. Even with such events, the relative newness of UAVs to the public alone makes them uniquely vulnerable to criticism, skepticism, and rejection.

To lessen the possibility of an adverse public reaction to UAVs, a strategy for communicating with the public is needed. A human factors specialist looking into public perception issues regarding UAVs recommends the following actions to mitigate negative perceptions on the part of the public:

- make people perceive UAV technology as a natural part of future society
- create positive interest in UAVs
- quickly and accurately report good and bad news concerning UAVs
- create a website where the public can get information and ask questions
- select a person or group to be responsible for industry's information flow
- deliver information to the public through presentations in the media
- select a group of public relations experts to be responsible for comments from industry
- create a strategy to be used in case a UAV accident occurs.[84]

In line with these recommendations, the benefits of UAVs must be better explained to the public. For example, the UAV community could stress the roles UAVs have in conducting humanitarian operations or in testing for airborne toxins, rather than focusing only on there

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[84] Lundin

military and security applications. Another message could emphasize the environmentally responsible technologies being researched and employed on UAVs (e.g., solar and fuel cell), or the many environmental research and humanitarian applications that UAVs will allow.

Safety Criticality	Technical Complexity	Legal Complexity	Socio-political Risk	Economic Cost
n/a	n/a	n/a	High	n/a

2.5.3 Government Investment

Unmanned operations will depend on the government providing the proper approvals as well as any needed changes to the air traffic system, regulations, data support, airspace, controller training, etc. The allocation of government funds to make the necessary changes will depend on economic justification determined by how UAV manufacturers and operators—as well as manned aircraft, the public, and the overall economy—will benefit. If costs are too high relative to the assessed benefit, the government may not be able to accommodate the changes desired by the UAV community or a specific commercial application.

The FAA, DoD, NASA, as well as foreign civil aviation authorities are working with various organizations to study the changes required in government regulations and infrastructure to accommodate UAVs (i.e., the JAA/Eurocontrol UAV Task Force). Determining the cost of the agreed upon changes is a consideration in the ongoing discussions and will be detailed when specific rulemaking or proposed in budget requests. At any rate, these decisions will largely determine whether UAV operations (some or all) can be supported from the government side, and will also set the pace of change.

Assessment

The current thinking in the UAV community and government organizations is to have UAVs conform to the existing construct of manned aviation. This means that infrastructure being supported by manned aircraft will, for the most part, be the same as those used by UAVs. However, there are likely to be exceptions. Depending on the latitude given to UAVs, there may be unique technologies or procedures requiring additional government investment. Conversely, UAVs may adopt technologies that are not currently being employed by manned aviation operations. But without the necessary investment to accommodate changes to the current system, the possibility of a substantial UAV market developing is small. What is needed is a better understanding of the type and amount of government investments that will be required to support UAV activities.

Safety Criticality	Technical Complexity	Legal Complexity	Socio-political Risk	Economic Cost
n/a	n/a	n/a	Low	Low to Moderate

2.5.4 Existing Market, Labor, and Users

As UAVs become more prevalent in the market, they will offer new opportunities, but will also threaten the existence of some jobs and perhaps even organizations. Those who can least adapt to the changing environment will most likely form the greatest resistance to their emergence. There is a latent concern as to the impact of UAVs operating in civil airspace. Today, however, overt resistance to the introduction of UAVs does not exist or is muted. This is probably due to the small size of the UAV industry relative to manned aircraft, as well as to a poor understanding of the nature of UAV operations and their potential effects on existing jobs and business models.

Pilots of manned aircraft are perhaps the most concerned about UAVs. Some see a safety threat. Others view their responsibilities as becoming marginalized to automation or see UAVs as eventually replacing their profession. Beyond these concerns, pilots may reject UAVs based simply on how it alters aviation's prestige and image to the public. This is termed the "silk scarf syndrome" by the Air Force. But whether UAVs will be actively opposed by pilots remains to be seen. The Aircraft Owners and Pilots Association and the Air Line Pilots Association have agreed to take an active role in the new RTCA special committee for UAVs and in the Access 5 initiative, respectively. Their objective is to stay apprised of UAV developments and to influence changes to the systems that may be perceived to adversely affect their constituents.

Assessment

As with all market transitions, those profiting from the existing market will oppose a new market unless they share in its benefits. Strong and established interest may seek to lobby against any changes, actively blocking initiatives or funding needed to allow UAV operations. On the other hand, individuals and organizations may seek to change and become a part of the new UAV market. For example, some pilots unable to fly due to medical conditions, or perhaps even a retired pilot, may find that flying UAVs offers a new opportunity. Additionally, pilot associations may find that they can expand their membership by including UAV pilots.

Safety Criticality	Technical Complexity	Legal Complexity	Socio-political Risk	Economic Cost
n/a	n/a	Moderate	High	Low to High

2.6 Issues Summary

A range of issues have been described which vary in complexity, criticality, and cost. Some issues are limited in scope, though most are multi-dimensional and mutually dependent on the successful resolution of other issues. Each issue will require considerable coordination and collaboration to overcome.

Provided here is a table illustrating a high-level assessment of the safety criticality, technical complexity, legal complexity, socio-political risk, and potential economic cost associated with each issue. The economic cost occasionally reference a spread in measures (e.g., low to moderate), meaning that the final cost will depend on a number of factors such as the stringency of regulatory requirements or the technology chosen to resolve the issue.

Issue	Safety Criticality	Technical Complexity	Legal Complexity	Socio-political Risk	Economic Cost
2.1.1 Collision Avoidance	High	High	Low	Low	Low to High
2.1.2 System Reliability	High	Low	Low	Low	High
2.1.3 Human Factors	Moderate	Moderate	Low	Low	Low
2.1.4 Weather	Moderate	Moderate	Low	Low	Moderate
2.2.1 Ground infrastructure security	Low	Low	Low	Low	Moderate
2.2.2 Communications signal security	Low	Moderate	Moderate	Low	Moderate
2.2.3 Data security	Moderate	Moderate	Moderate	Low	Moderate
2.2.4 Technology and Operational Controls	Low	Low	Low	Low	Low
3.3.1 Air Traffic Management	Moderate	Moderate	Low	Moderate	Low
2.3.2 System Interoperability	Low	Moderate	Low	Low	Low to Moderate
2.3.3 Information Networks	Moderate	Moderate	Low	Low	Low
2.3.4 Communications	Moderate	High	Low	Low	Low to High
2.3.5 Navigation	Moderate	Low	Low	Low	Low
2.3.6 Equipage	Moderate	Moderate	Moderate	Moderate	Low to Moderate

Issue	Safety Criticality	Technical Complexity	Legal Complexity	Socio-political Risk	Economic Cost
2.3.7 Emergency flight recovery	Moderate	Low	Moderate	Low	Low
2.3.8 Airspace	Moderate	Moderate	Moderate	Low	Low
2.3.9 Surface operations	Low	Low	Low	Low	Low
2.4.1 Classification schemes	Moderate	Low	High	Low	n/a
2.4.2 Standards	High	Moderate	High	Low	Low to High
2.4.3 Regulation	High	Low	High	Low	Low to High
2.4.4 Airworthiness Certification	High	Moderate	High	Low	Low to High
2.4.5 Pilot Certification	High	Low	Low	Low	Low
2.5.1 Insurance Liability	n/a	n/a	Low	Low	Moderate to High
2.5.2 Public Acceptance	n/a	n/a	n/a	High	n/a
2.5.3 Government Investment	n/a	n/a	n/a	Low	Low to Moderate
2.5.4 Existing Market, Labor, and Users	n/a	n/a	Moderate	High	Low to High

Section 3

Recommended Actions

This section provides ten recommended actions needed to permit the routine and safe integration of UAVs into civil airspace. These recommendations are broad in nature and intended to stimulate consensus building and promote strategic planning among the many organizations having a stake in the emergence of UAVs.

In the past several years, various initiatives from around the world have been formed specifically to address issues pertaining to the integration of UAVs in civil airspace. These initiatives, including several roadmaps, have laid much of the groundwork for future progress. Yet while much has been accomplished, much work remains. Policies must be established, workable classifications created, regulations codified, frequencies allocated, technologies developed, systems tested and certified, and resource made available to effectively enact change. These actions fall collectively on the governments, manufactures, users, and associative interest of UAVs. No single entity can solve the problem. They must instead leverage their early work and come together with a common plan.

The overarching goal of the UAV community is clear: Achieve routine and safe integration of UAVs into civil airspace. Within this goal there are several high-level, mutually dependent objectives. Ten are listed here. These objectives are not the responsibility of any single organization, as each requires some degree of collaboration and consensus to be achieved. An estimated timeframe to achieve each objective is indicated in parenthesis at the end of each objective statement.

Objective 1: Agree upon a concept of operations for UAV flights in civil airspace. (2005)

> Manufacturers, operators, airspace users, and regulators need to come to a consensus on how UAVs will operate within a future airspace system, including specific terms and conditions related the different vehicle types. Several operational concepts already exist (e.g., Access 5, JAA/Eurocontrol, ASTM, AIAA, NATO FINAS, etc.) but these do not always share a common vision, nor are they coordinated. Most operational concepts seek to fit UAVs within the existing framework for manned flight operations, which is reasonable; however, this may not be practical for the small UAVs and those having unique capabilities and performance characteristics (e.g., stratospheric airships).

Objective 2: Develop a classification scheme and definitions for UAVs as they relate to operations in civil airspace. (2005)

> A common understanding of UAV classifications and definitions is a fundamental first step to the development of regulations, standards, and certification requirements.

These should be international in scope. Classifications should be based more on the airspace intended for use rather than on vehicle size, endurance levels, and mission types, as is currently practiced. Other factors should also be considered, such as communication capabilities and range, navigational accuracy, levels of autonomous control, kinetic energy values, and an ability to be "seen" by air traffic providers and manned aircraft.

Objective 3: Establish regulations for UAV system certification, flight operations, and ground controller qualifications. (2010)

There are no established civil regulations for certifying the operational safety of UAV systems. Ground control stations, communications links, flight control systems, and software all need to be considered in the certification process. While each component will be certified individually, a certification of the entire system (possibly to include integration with air traffic systems) will also likely be required. Additionally, ground control operators (pilots) and commercial UAV business operations will require specific regulations and certification requirements. These will be based primarily on existing certification requirements for pilots and commercial operators of manned aircraft, but will require modified or new requirements for unique aspects of UAV flights and operations. The existence of government/industry consensus standards and classification scheme for UAVs (as mentioned earlier) is a prerequisite to defining these requirements.

Objective 4: Develop effective technologies and procedures to prevent collisions of UAVs with other aircraft, the ground, or other obstacles. (2008)

Collision avoidance is the primary safety concern for UAVs. Standards and regulations should define clearly the *requirement* for a safe and effective collision avoidance system, but should not specify a given technology or procedure. This requirement should apply, at a minimum, an equivalency standard to manned see-and-avoid capabilities. Solutions must be mindful of the cost; effectiveness (under various conditions); reliability; interoperability with ground and airborne systems; and weight, size, and power requirements relative to the class of vehicle and the airspace to be used.

Objective 5: Institute security controls and approvals for UAV operations. (2008)

UAVs may present a unique security issue as they are controlled from the ground, making them potentially vulnerable to rogue transmissions, jamming, and the physical disruption of the ground control and datalink infrastructure. The security requirements of UAV communications system and the components that it links must be a fundamental consideration in system designs and operational policies and procedures. This may require new datalink encryption technologies for civil applications. Also, operational controls and monitoring of UAV movements will be required. The wide variation in take-off/launch capabilities, flight environments and missions make the secure control of UAV flights a unique challenge. This concern may be exacerbated by low-cost, highly capable, miniature autopilot and navigation systems that will make autonomous UAVs increasingly affordable to large segment of the population.

Objective 6: Develop and implement communications solutions for UAV systems. (2015)

Effective and assured data link communications are essential to UAV operations, yet in the civil environment there is not a reserved, government-protected frequency available for this purpose. It is possible that the FAA, as well as other CAAs, will not allow the allocation of a UAV frequency for control or emergency termination that lies outside of its protected bands. Therefore, a frequency (or set of frequencies) needs to be negotiated with the international community. This could take years. Also, the communications infrastructure needs to ensure that it can support the heavy data exchange rates, in an encrypted and secure format, at a sufficient integrity level. Further, new concepts that rely on ground-based links between ground control stations and air traffic control need to be explored as a means to reduce dependence on the frequency spectrum.

Objective 7: Develop an aeronautical data exchange, processing, and synchronization network that accounts for unique UAV requirements. (2020)

Most UAVs, especially those operating autonomously, are reliant on accurate and timely data for navigational guidance, vertical guidance, thrust control, and flight path optimization. In the future, data requirements for UAVs will need to align with the information being processed, distributed, and communicated by the air traffic system for both manned and unmanned flights. Incorporating unique data requirements of UAVs early in the development of data management systems, such as SWIM, will facilitate their integration and acceptance. Such data may include the geographic locations of emergency flight recovery and termination areas and dynamically changing airspace restrictions on UAV activities, if necessary. Standards concerning the security, availability, and integrity of the data also need to be assured.

Objective 8: Harmonize UAV regulations, certification standards, and operational procedures. (2008)

UAVs will operate in a global context. Without a common set of approaches to manufacture, operate, and maintain UAV systems, the market for UAVs will suffer and acquisition and operating costs will be unnecessarily inflated. Additionally, the safety of UAV systems could be compromised if multiple requirements are to be tracked and complied with. Further, civil aviation authorities will find the cost and complexity of achieving interoperable systems among ground and airborne elements to be difficult, and oversight and enforcement of UAV operations and systems more challenging. Harmonizing various national and international approaches is vital to the development of the UAV market and will help in controlling costs.

Objective 9: Ensure interoperability with the air traffic system and assess potential impacts on the air traffic system and its regulatory and operational environment. (2010)

New communication, navigation, and surveillance systems used to direct, track, and monitor UAVs will need to interoperate with air traffic systems. Interoperability assures connectedness, creates efficiencies, and typically lowers costs. Beyond the technical systems, air traffic regulations and operating procedures will also need to be structured in a way to safely accommodate the unique properties, equipage, environments, and trajectories flown by future UAV systems. Such regulations and procedures will need to address the human element as well as ground and airborne components of the air traffic system.

Objective 10: Gain public acceptance and actively communicate with all potentially affected parties. (Continuous)

Communicating UAV developments and intentions to all interested parties will be vital to acceptance in the aviation community and, more importantly, with the general public. Transparency in planning, research, and implementation activities will provide perspectives and inputs that may otherwise go unnoticed until it is too late. Awaiting public acceptance can lead to costly fixes or preclude an otherwise viable market from being realized. Another important component will be in educating the wider aviation community, media reporters, and the public as to the benefits UAVs will bring.

Section 4

Conclusion

History has shown that technology advances associated with military aircraft eventually makes their way into the civilian fold. The revolutionary concepts and cutting-edge technologies currently being researched and applied by the military to UAV systems will facilitate the development of a much broader civil government and commercial UAV market. Homeland security needs will further act as a catalyst in the emergence of this market. Additionally, expected changes in airspace system, particularly with respect to the development of an information management system and data exchange networks, will be key enablers to the development of the UAV market.

While the emergence of a civil UAV market seems apparent, it is unknown what form and size the market will take. Regardless, it is prudent to prepare for and support its growth. There is, of course, a cost to supporting UAV developments, but there is also a cost in underplaying or ignoring the emergence of this market. A potentially lucrative industry could be lost, technology advances curtailed, and operational standards and environments defined by others. The U.S. has the led in UAV technology and operational experience and should not let this slip due to inattentiveness or inaction. At the same time, the U.S. must work with international organizations to ensure the development of a harmonized, interoperable environment that supports trade and cross-border operations.

Accommodating the UAV market, while desirable in one respect, does have side effects. Market growth, combined with the unique flight characteristics and capabilities of UAVs, will place pressure on a mature air traffic system—a system designed around the needs of manned aircraft. A successful UAV market will, therefore, present a wildcard to the existing aviation market and the air traffic system, having the potential to change not only specific technologies and procedures, but to disrupt the entire aviation system. This may not be evident today as UAVs are few in number, frequently more costly, less reliable, and more restrictive to operate than manned aircraft. But it is often these qualities that describe the advent of a disruptive technology. Professor Clayton M. Christensen of the Harvard Business Schools notes in his book, *The Innovator's Dilemma*, that such technologies and innovations are rarely acknowledged by major markets because they frequently perform worse on criteria of interest to mainstream customers and therefore initially attract only marginal clients with unique needs. These innovative technologies are typically started by small companies or an off shoot of a larger firm. As a disruptive technology grows, it often radically changes the primary market.

Today the major aviation stakeholders—airlines, aircraft manufacturers, general aviation—are focused on their customer base: manned aircraft, as they should be. Mannedaircraft will not disappear with the growth of UAVs. However, these firms must acknowledge the changing environment and be adaptive to changes brought on by UAVs. Major aviation firms have the opportunity to take advantage of UAV-related technology advances, to ensure proper integration of these systems into the manned aviation environment, and perhaps even to enter the UAV market themselves. Managing change in the context of a newly emerging and potentially disruptive technology may challenge existing assumptions and business models. This is not to say the UAVs will replace manned operations (they won't), but that the entry of this technology may transform existing operational practices (e.g., manned aircraft being co-pilot by a ground-based operator) and technologies (e.g., intelligent reconfigurable control). These firms must learn to adapt or risk being marginalized or replaced.

Not only do UAVs present a disruptive influence to the market, they also offer a test bed for experimenting with novel technologies and operational concepts. Being freed of many of the constraints associated with manned aircraft, many developers of UAVs are at liberty to apply new ideas and experiment with unusual, often cutting edge technologies. For aerospace engineers, taking the man out of the aircraft gives trade space for additional capabilities (i.e., endurance). Advances brought on by UAVs will spawn and facilitate the advent of novel communication architectures, collision avoidance systems, information sharing networks, alternative fuels, and autonomous controls. Many of these advances will likely have an impact on manned aircraft, such as improving cockpit and air traffic automation and by creating an environment conducive to automated traffic separation. These changes, if adequately encouraged and managed, will help in dealing with the mounting complexity of air traffic system.

Glossary

AC	Advisory Circular
ACAS	Automated Collision Avoidance System
ADS-B	Automated Dependent Surveillance-Broadcast
AFRL	Air Force Research Lab
AIAA	American Institute of Aeronautics and Astronautics
ASAS	Airborne Separation Assurance System
ASTM	American Society for Testing and Materials
ATC	Air Traffic Control
ATM	Air Traffic Management
AUVSI	Association for Unmanned Vehicle Systems International
CAA	Civil Aviation Authority
CAPECON	Civil UAV Applications & Economic effectiveness of potential CONfiguration solutions
CASR	Civil Aviation Safety Regulation
CFR	Code of Federal Regulations
COA	Certificate of Operations
DARPA	Defense Advance Research Project Agency
DGPS	Differential GPS
DHS	Department of Homeland Security
DOD	Department of Defense
EASA	European Aviation Safety Agency
ECAP	European Capabilities Action Plan
ERAM	En Route Automation Modernization
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FCL	Flight Crew Licensing

FINAS	Flight in Non-Segregated Airspace
GASR	Group of Airport Safety Regulators
GPS	Global Positioning System
HALE	High Altitude Long Endurance
ICAO	International Civil Aviation Organization
ICAT	International Center for Air Transport
ICB	Industry Consultative Body
IFR	Instrument Flight Rules
JAA	Joint Aviation Authority
JARs	Joint Aviation Requirements
JPDO	Joint Planning and Development Office
LEO	Low Earth Orbiting
MALE	Medium Altitude Long Endurance
MIT	Massachusetts Institute of Technology
MPS	Minimum Performance Standard
NAS	National Airspace System
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NBC	Nuclear, Biological, Chemical
OSD	Office of the Secretary of Defense
OSTP	Office of Science and Technology Policy
PSL	Physical Science Lab (part of New Mexico State University)
RC	Remote Control
RCP	Required Communications Performance
R&D	Research and Development
RNAV	Area Navigation
RNP	Required Navigational Performance
ROA	Remotely Operated Aircraft

RTCA	RTCA, Inc. (formerly Requirements and Technical Concepts for Aviation; and formerly Radio Technical Commission for Aeronautics)
RVSM	Reduced Vertical Separation Minima
SADL	Situational Awareness Data Link
SARPs	Standards and Recommended Practices
SATCOM	Satellite Communications
SATS	Small Aircraft Transport System
SID	Standard Instrument Departure
STANAG	Standard Agreement
STAR	Standard Terminal Arrival
SUA	Special Use Airspace
SWIM	System Wide Information Management
TAAC	Technical Analysis and Applications Center
TCAS	Traffic Collision Avoidance System
TIS-B	Traffic Information System-Broadcast
TIS-C	Traffic Information System in Contract mode
TSA	Transportation Security Agency
TUAV	Tactical Unmanned Aerial Vehicle
UAV	Unmanned Aerial Vehicle
UAVNET	UAV Thematic Network
UAVS	Unmanned Aerial Vehicle Systems
UCARE	UAV's Concerted Actions for Regulations
UCAV	Unmanned Combat Aerial Vehicle
UNITE	UAV National Industry Team
UNTF	UAV National Task Force
USICO	UAV Safety Issues for Civil Operations
USPC	Unmanned Systems program Committee

UVS	Unmanned Vehicle Systems
VDL	VHF Digital Link
VHF	Very High Frequency
VOR	Very High Frequency (VHF) Omnidirectional Range
VTOL	Vertical Take-Off and Landing
VUAV	Vertical Unmanned Aerial Vehicle