UNMANNED AIRCRAFT SYSTEMS FOR FIRE AND NATURAL RESOURCE MONITORING: TECHNOLOGY OVERVIEW AND FUTURE TRENDS

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ABSTRACT

Unmanned aircraft systems (UAS) have been developed alongside manned aircraft yet have seen widespread use only in the past decade. Their use for military applications has propelled advances in electronics and sensors to yield systems whose capabilities may be useful for many civilian applications. The needs of users in the fire science and wildfire surveillance community for high-resolution sensors and geospatially accurate data demand capabilities found in large, sophisticated platforms, but at sizes better suited for field deployment. An overview of the current UAS market reveals few options for combining sensor sophistication and small size. Furthermore, current regulations restrict UAS use for peacetime applications. Technological development and regulatory reforms are expected to allow civilian use of UAS in the coming years. Predictions for the future application of this technology for fire-related uses are provided, based on perceived technology needs of the field and capabilities of UAS currently under development. Suggestions are offered to potential users to evaluate UAS technology for their own applications as it becomes available.

Keywords: aerial survey, drone, FAA, fire monitoring, remote sensing, surveillance, technology, UAS, UAV, unmanned aircraft system.

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HISTORY OF UNMANNED AIRCRAFT

Although often considered to be novel technological achievements, unmanned aircraft have been developed throughout the history of aviation. Using a very loose definition, it may be argued that “unmanned aircraft” were used in warfare as early as the 1849 aerial bombardment of Venice using balloons (Anonymous 1849), and for a more peaceful mission in the biblical account of Noah’s use of a raven and a dove for reconnaissance (Genesis 8:6–12). Such early uses of flight not only predated manned flight, but also combined to inspire its pursuit. Much later, unmanned “aerial torpedoes” were developed during World War I, beginning a long and varied period of development for unmanned aircraft that paralleled that of human-piloted, “manned” aircraft (Newcome 2004). Throughout nearly their entire development, unmanned aircraft have been used as weapons of war, either as delivery platforms for munitions or as vehicles for battlefield reconnaissance. The National Aeronautics and Space Administration (NASA) attempted to develop unmanned aircraft for high-altitude atmospheric sampling during the 1970s and 1980s, but the “Mini-Sniffer” program was unsuccessful and represented the only major effort to use these vehicles for scientific research until NASA’s Environmental Research Aircraft and Sensor Technology (ERAST) programs in the 1990s. Unmanned aircraft were first used for detection or monitoring of wildland fires during a joint NASA and U.S. Forest Service technology demonstration in 2005; the following year, a large NASA unmanned aircraft was utilized in an experimental fire-monitoring operation, the Western States UAS Fire Mission (Ambrosia et al. 2006). The use only recently of unmanned aircraft for wildland fire missions is due to a number of factors related to the history, development, and regulation of this technology. Here, we briefly describe these factors and the continuing evolution of unmanned aircraft for peacetime uses, and offer some examples of possible roles for which they may be highly useful tools to the fire community in the future.

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During the 20th century, unmanned aircraft were known by a variety of names: robotic aircraft, drones, remotely operated vehicles (a term now often used for unmanned submarine vehicles), and remotely piloted vehicles. The latter term came into use during the Vietnam War era and was replaced by the term "unmanned aerial vehicle" (UAV), which became more appropriate as innovations such as computer autopilots became more widely used. During the late 1990s the term "unmanned aircraft system" (UAS) began to be used in Europe; despite reluctance of the American unmanned-systems industry to use a term explicitly acknowledging their products' status as aircraft, use of the new terminology is now nearly universal among industry and users.

Unmanned aircraft in their modern form (generally, a fixed- or rotary-wing aircraft with an internal guidance system) have been used by the military since World War I, in which they played a minor, largely experimental role as aerial targets for gunnery practice or bomb delivery platforms. Germany made great technological progress during World War II in guidance systems for unmanned aircraft, which it used in the V-1 and V-2 "flying bombs" with terrifying success. The Vietnam War saw the integration of new electronic payloads and imaging systems into unmanned aircraft, and UAS saw their roles expanded from munitions platforms and targets to signals intelligence and reconnaissance. The Hunter series of unmanned aircraft (General Atomics Aeronautical Systems, Inc., Poway, CA), deployed during the first Gulf War, were the first UAS to be used by the U.S. military for real-time imagery delivery during combat.

During the 1990s, the miniaturization of sophisticated surveillance payloads allowed a variety of size and capability classes to become well developed. Large UAS are aircraft comparable in size and weight to manned aircraft. These aircraft may carry weapons payloads or large reconnaissance payloads, and in some cases may be able to remain aloft for up to 36 hours. Medium-sized UAS include aircraft weighing at least 10 kg (25 lb); although an upper size limit is not well defined, these aircraft combine the long flight endurance and generous payload capabilities of larger platforms with the ability to be operated from short runways or from forward operating bases. Small UAS utilize aircraft under 10 kg (25 lb) in weight, and include some models that are hand-launched and operated by ground troops with limited pilot training. Micro air vehicles (MAVs), generally defined as unmanned aircraft with wingspans under 15 cm, are used for battlefield reconnaissance by combat troops. MAVs in use or under development can be transported in soldiers' backpacks, or even in cargo pockets. Military UAS have become well integrated in day-to-day operations and are particularly valuable for the so-called "dull, dirty, and dangerous" missions that put human pilots in harm's way. News stories regularly report the use of large UAS such as the Predator/Reaper or Global Hawk platforms (both General Atomics Aeronautical Systems, Inc., Poway, CA) to conduct strikes against ground targets using bombs or missiles. Ground troops also regularly use small UAS for situational awareness during combat, as well as data provided by larger UAS flying above combat zones. The ubiquity of UAS in military operations is illustrated by the often-quoted statistics that in 2008 unmanned aircraft flew more hours and more combat missions than manned combat aircraft.

CIVILIAN USES OF UAS

Because of their demonstrated capabilities for a variety of missions, UAS have tremendous potential for peacetime uses that involve reconnaissance, surveillance, or high-resolution surveys. Compared to satellites, UAS can only "see" a small portion of Earth and are suited for smaller scales of observation than orbiting platforms. Nevertheless, UAS can be brought over areas of interest on demand and are able to operate below cloud cover that might obscure objects of interest from their sensors. Also, the altitude at which UAS operate, combined with the sensor capabilities of some payloads, may allow for analysis at much finer spatial resolution than satellites permit. Human-piloted aircraft also have these capabilities but often are subject to delays due to local weather or other logistical problems. UAS offer the potential for rapid, on-demand, and local deployment. Computer autopilots found aboard modern UAS also have a far greater ability to precisely follow preprogrammed fight paths than do human pilots, making it possible for UAS to perform repeatable transect surveys from the air. Manned-aircraft surveys for wildlife are typically conducted at low altitudes and airspeeds, making them inherently dangerous; ever-increasing deaths from crashes during these surveys attest to the hazards of such missions.

For these uses, unmanned aircraft offer a reduction of risk just as they have for military operations; for operations in the vicinity of wildfires, the advantages of removing the human pilot from a dangerous flight environment is equally great. Given the potential that UAS offer to natural resource users, it may be surprising to some that their use has not become similarly widespread; indeed, predictions were made a decade ago that UAS would soon become used for a wide variety of law enforcement, communications, agricultural, and scientific pursuits (Reinhardt et al. 1999). The needs of aviation users in the fire-suppression and fire science community to reduce the safety risks of operating in crowded airspace, low visibility, and low altitudes and speeds are particularly great. Also, many mission profiles currently flown by human-piloted aircraft to observe fire behavior and the deployment of assets on the ground are similar in nature to military missions that are currently flown by unmanned reconnaissance aircraft. A large UAS at high altitudes could provide imagery of a large fire complex across a wide spectral range. The same aircraft could be outfitted with communications equipment and thus serve as a communications relay while reducing blackouts due to rugged terrain; the long flight durations and low operating costs of many UAS would enable such an airborne communications node to be maintained for extended periods. Smaller UAS could be stored in and deployed from engines, providing local situational awareness for any number of fire crews equipped with handheld receivers while also transmitting imagery to incident command posts where the same information would be available to planners. Given these needs and the demonstrated ability of UAS to address them on the battlefield, it may seem surprising that unmanned aircraft are not available for use in wildland fire scenarios, or to other civilian or scientific users. The slow rate at which UAS have been adopted for peacetime uses in the United States is due primarily to a trio of barriers: cost, appropriate technology, and regulation.

BARRIERS TO CIVILIAN USE

Their military pedigree has resulted in the evolution of UAS to be robust, reliable, and sophisticated. These characteristics, rarely found together in new technology, have been pursued with relatively little regard for economy, due to the huge safety advantage that UAS offer the military to human pilots as well as ground forces. As a result, UAS tend to be unaffordable for most potential users. The largest UAS in the U.S. military's inventory, the Global Hawk, has system acquisition costs of approximately $60–70 million, and a per-aircraft cost of $20–30 million, while the well-known Predator/Reaper UAS has acquisition and aircraft costs of $30–50 million and $5–6 million, respectively. Even the medium-sized UAS, such as the Shadow (AAI Corporation, Hunt Valley, MD), have acquisition costs that may be above $500,000. Few civilian agencies can muster the resources to operate military-pedigree UAS by themselves, as evidenced by the partnership among NASA, the National Oceanic and Atmospheric Administration, and the Forest Service required for the modified Predator B UAS used in the Western States Fire Mission. (The U.S. Department of Homeland Security is one of the few with operational UAS, but it devoted between $20 million and $50 million per year to UAS operations in fiscal years 2005–2007.)

Despite their great cost, large military UAS are sought after by civilian agencies because of their impressive sensor capabilities. Although military payload capabilities are classified, the joint Western States Fire Mission delivered georeferenced, multispectral imagery to multiple users, integrated into interactive GIS and virtual terrain environments, in real time. Small UAS, whose costs and logistics requirements are arguably better suited to applications such as natural resource surveys and fire monitoring, do not have the sensor capabilities needed to provide meaningful data in most cases. This lack of small-UAS sensor capability reflects a dichotomous evolution of military UAS into essentially two combinations of size and capability: large UAS with long ranges and very sophisticated sensors, and small UAS that are portable and deployable by soldiers in the field but whose performance and sensor capabilities are limited. Many civilian users find neither of these solutions appropriate to their needs, and require a small, affordable UAS whose sensors are optimized for accurate, high-resolution surveys, not merely situational awareness or surveillance uses to which the sensors of most small UAS sensors limit them.

Ideal characteristics for a small UAS for field operations by civilian users include the capability to launch and recover the aircraft without a runway; to operate the UAS with one or two users who are not primarily pilots; and, importantly, the ability for imagery collected by the payload to be georeferenced (Watts et al. 2008). The lack of availability of this latter capability has led some organizations to develop their own UAS. University of Florida developed an electric-powered, amphibious UAS meeting these criteria (Watts et al. 2008). The Tadpole-Polaris UAS (Department of Defense designation Nova) has been used in surveys of bison (*Bison bison*) (Wilkinson 2007), shorebirds (Brush and Watts 2008), and for mapping shorebird habitat (Oberneufmann 2007). Improvements to sensor payloads are expected to confer direct image georeferencing capabilities for use in invasive-species monitoring by the U.S. Army Corps of Engineers. Other organizations have successfully operated purpose-built UAS to investigate their potential for aerial photographic surveys (Hardin and Jackson 2005) or crop monitoring (Lelong et al. 2008), further illustrating the demand for affordable UAS for civilian users.

This rapid expansion of experimentation in UAS technology by the public and private sectors stopped abruptly when, in 2006, the Federal Aviation Administration (FAA) clarified the legal status of UAS (FAA 2007). Prior to the FAA clarification, many UAS users had operated under the assumption that their small UAS either were legally classified as radio-controlled model aircraft or were not regulated. The 2007 clarification referred to existing statutes that classify unmanned aerial vehicles as aircraft, regardless of their size; it reminded or notified many operators that their UAS flights were illegal. The FAA's UAS Program Office did establish avenues by which users may legally operate UAS by obtaining either a Certificate of Airworthiness (CoA; for public, government users) or a Special Airworthiness Certificate (SAC; for private entities). The length of time required to process a CoA application—typically, applications must be submitted >60 days prior to an intended operation—severely limits the potential range of applications for which UAS can be used, while no SAC applications submitted to date have been approved. While these policies and processes arguably increase the safety of the National Airspace System by reducing the number of unmanned aircraft, an unintended consequence has been to prevent the development of commercial UAS operations in the United States.

FUTURE UAS EMPLOYMENT

Nearly every manufacturer of UAS has developed civilian-operations business models and are awaiting regulatory change to implement them. A few manufacturers, such as AAI (Hunt Valley, MD) and Advanced Ceramics (Tucson, AZ), have successfully marketed their UAS for scientific missions in areas beyond U.S. borders (e.g., Ramana et al. 2007). These shelved plans anticipate the vast growth in the civilian UAS market in the coming decade. One market study predicts that the worldwide UAS market will become over $55 billion by 2018 (Teal Group Incorporated 2008) with a nearly $3 billion contribution by the U.S. civilian market alone (Moire Incorporated 2007). The rapid growth forecast for the UAS market is expected to occur after the development of "see-and-avoid" technologies that allow manned and unmanned aircraft to locate and avoid one another.

Perhaps the first area in which UAS will see widespread civilian use following these technological and regulatory changes will be for wildland fire monitoring. MAV systems that store in and deploy from backpack-sized containers may be utilized by individual crews to observe the behavior or locations of approaching fires or to assist lookouts in watching for spotovers across firelines. Small or micro-sized aircraft equipped with temperature sensor payloads could be sent through smoke columns at varying altitudes to provide spatially explicit atmospheric data for fire modeling and attack planning. On larger incidents, medium-sized UAS operated from local runways may loiter above the orbit altitude of tanker aircraft, providing a persistent capability to monitor fire location and behavior as well as the position and effectiveness of ground assets. In each scenario, the data collected from the aircraft can be made available to every level simultaneously. This broadcast of data to multiple assets would improve the ability of ground assets to understand assigned tasks or to communicate local conditions to commanders. Command-level benefits to this approach may be reduced time spent communicating orders to individual assets and an ability to more quickly and efficiently allocate those assets to address changing fire conditions.

Based on current military applications of UAS and trends in the development of their technology, a few predictions can be made concerning initial employment of UAS for wildland fire monitoring and prediction efforts. First, even the smallest, most affordable UAS will deliver aerial imagery to multiple recipients (e.g., incident commanders as well as engine bosses, whose trucks may be the deployment site for UAS). This imagery will be delivered in formats readable by traditional GIS software as well as user-friendly software environments such as Google Earth (Google, Inc., Mountain View, CA); it will enable viewers to observe ground assets, firelines, and other features in real time. Conducting orientations for planning and crew or engine bosses to encourage their familiarity with these software programs will improve their ability to adapt to the technology and to use it with greater effectiveness once UAS arrive in their inventory. Personnel who model fire behavior for scientific research or for fireline predictions should prepare for the integration of detailed imagery (both visible-spectrum and infrared) into GIS environments. These data will enable great improvements to physics-based fire behavior models but may seem overwhelming in volume; training in remote sensing analysis will help these users to identify the capabilities UAS offer that will most benefit them. Second, UAS are likely to be deployed either by dedicated aircrews operating from remote airports (for large UAS) or in the fire theater by cross-trained personnel (for small UAS). In the latter scenario, the availability of a new stream of airborne information may come at the cost of space and seats in an engine, and additional considerations for the control of air traffic. From an operations standpoint, organizations should begin exploring the potential impact on logistics and operations associated with adding UAS to their inventory. Finally, despite the demonstrable safety advantages they will offer to the fire community, UAS will represent a considerable financial and time investment for most organizations. These costs will create a temptation to avoid employing UAS in the risky missions for which they were designed, particularly for early adopters of the technology. Ironically, considering small unmanned aircraft to be semi-expendable will improve the ability to justify their cost to the public as effective safety equipment.

The rapid and impressive technological advancements that have hallmarked UAS have primarily benefited military users to date, but similarly great advancements to science and natural resource applications are approaching. Users can count on manufacturers to respond rapidly to their needs, both because of the adaptive nature of the industry and the potential profits to be made by accommodating nonmilitary customers in the future. In addition to becoming aware of available and emerging UAS products and services, users should gain familiarity with current regulations and the CoA process, as well as anticipated regulatory changes. Knowledge of the technology and its intended applications, as well as regulatory limits, will enable quick adoption and early success with this revolutionary technology.

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