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COMMENTARY

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Unmanned aerial vehicles in construction and worker safety

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Applications of unmanned aerial vehicles (UAVs) for military, recreational, public, and commercial uses have expanded significantly in recent years. In the construction industry, UAVs are used primarily for monitoring of construction workflow and job site logistics, inspecting construction sites to assess structural integrity, and for maintenance assessments. As is the case with other emerging technologies, occupational safety assessments of UAVs lag behind technological advancements. UAVs may create new workplace hazards that need to be evaluated and managed to ensure their safe operation around human workers. At the same time, UAVs can perform dangerous tasks, thereby improving workplace safety. This paper describes the four major uses of UAVs, including their use in construction, the potential risks of their use to workers, approaches for risk mitigation, and the important role that safety and health professionals can play in ensuring safe approaches to the their use in the workplace.

KEYWORDS
construction, drone, FAA, part 107, worker safety

1 | INTRODUCTION

In the past few years, new technologies and methods have emerged in residential and commercial construction aimed at increasing efficiency and decreasing waste. Advances in 3D printing have spurred the development of additive building construction[1] which may help eliminate material waste, expand the scope of construction designs, and lead to the on-demand production of mass-customized structures.[2] The use of small unmanned aerial vehicles (UAVs) is another emerging technology that is being increasingly employed in construction.[3] Small UAVs have the potential to improve construction site logistics, accelerate project progress reports, and enhance construction site safety.[4,5]

UAVs can be categorized into four main types depending on their primary use: (1) military; (2) recreational; (3) public; and (4) commercial. Military uses of large UAVs have a long history as surveillance tools and as weapon systems.[6] Model aircraft, otherwise known as UAVs, also have a long history and are now used by an increasing number of hobbyists for recreational enjoyment.[7] Recently, public sector government agencies are finding multiple uses for small UAVs from border security to police surveillance.[8] The commercial use of small UAVs is being seen across several industrial sectors such as construction, agriculture, and mining.[9]

The economic market for military and civilian UAVs is predicted to grow quickly. The Federal Aviation Administration (FAA) Aerospace Forecast for fiscal years 2016 to 2036 predicts that the sales of small UAVs will increase from 2.5 to 7 million by 2020.[10] The Association for Unmanned Vehicle Systems International (AUVSI) expects 100 000 jobs to be created by 2025 from the expanding market for small UAVs.[11] Spending on all categories of UAVs is likely to total $100 billion by 2020.[12] While national defense uses will continue to represent the largest segment of the economic market for UAVs, the market for civilian uses continues to expand. Global market revenue for recreational and commercial use (including public use) is expected to increase 34 percent to reach more than $6 billion in 2017 and to grow to more than $11.2 billion by 2020.[13]

The same aeronautical dynamics apply to remotely piloted aerial vehicles as they do to manned aircraft. An unmanned aerial system

(UAS) is composed of the vehicle airframe and power supply, vehicle sensors, remote operator, an onboard computer, and vehicle actuators.[6] Sensors gather information about the vehicle's environment and actuators cause movement of the vehicle.[6] The operator can receive information by looking directly at the vehicle (flying by "line-of-sight") or by looking at a video transmitted from the vehicle (flying by "first-person view").[6] A computer can receive commands from the operator and communicates them to the actuators ("flying-by-wire").[6] Some experimental UAVs are said to be "autonomous" by "flying along a set path called 'waypoints' and returning back to the home location when the flight is complete."[14]

Unlike the industrial robots introduced in the 1970s in the automobile manufacturing industry which are fixed in place, newer types of "flying robots" like small UAVs are mobile above or within the workplace. Their mobility can present safety risks to their proximate human co-workers.[15] While their increasing use by industry has many business advantages, it is important to assess systematically the potential risks to worker safety and health associated with their use, and to disseminate widely best practices for managing any identified risks.

This article reviews the uses of military, recreational, public and commercial UAVs and the rules governing their use; uses of UAVs in construction and their potential hazards to workers; and emphasizes the important role that safety professionals can play in ensuring safe approaches to the use of small UAVs in the construction workplace.

2 | UAV USES AND RULES

2.1 | Military uses

Although the use of recreational, public, and commercial small UAVs has occurred relatively recently, the military use of unmanned aerial objects to support warfare has a long history. In 1849, pilotless balloons armed with bombs were used to quell civil unrest in Venice.[16] During the American Civil War, reconnaissance balloons were used by both the Union and the Confederacy to determine enemy positions and to direct artillery fire during battle.[17] In the 1930s, the British Royal Navy developed the Queen Bee, an unmanned aircraft vehicle that was designed for use in anti-aircraft gunnery practice.[19] When the U.S. Navy developed a similar system, the name "drone" (after stingless male bees) was used to describe the U.S. version of the UAV in deference to Britain's Queen Bee.[18]

Any type of unmanned aircraft, ranging from the size of a small, radio-controlled "toy" model aircraft to the largest remotely controlled, weaponized military aircraft is commonly referred to as a "drone." However, the military describes drones more commonly as UAVs, Remotely Piloted Vehicles (RPVs), Unmanned Aerial Systems (UASs), or Remotely Piloted Systems (RPSs). UAVs and RPVs refer to the vehicle itself, and UASs and RPSs refer to vehicle and supporting equipment, including the on-the-ground operator.[19] In this article, the term "UAV" is synonymous with the term "drone."

For military operations, UAVs/RPVs can provide a 24-hour "eye in the sky," and/or can be equipped with weaponry to provide offensive capability for missions that are too dangerous for a human-piloted aircraft to undertake. UAVs can be controlled remotely by operators stationed anywhere in the world, and can remain aloft for much longer than can a human pilot.[19] Unlike other weaponry such as missiles, military UAVs are intended to land, or be recovered, after their mission is completed.

Operation of military UAVs is governed generally by the U.S. Department of Defense.[20] However, the military follows the regulations of the FAA when flying in the National Airspace System (NAS). The NAS is "the common network of U.S. airspace; air navigation facilities, equipment and services; airports or landing areas; aeronautical charts, information and services; rules, regulations and procedures; technical information; and manpower and material. Included are system components shared jointly with the military."[21]

2.2 | Recreational uses

The hobby of flying model airplanes also has a long history. Hobbyists began flying unmanned models even before manned aviation became the commercial industry that it is today. Safety was an early concern of hobbyists. In 1936, community-based safety and flight-training programs were developed by the Academy of Model Aeronautics (AMA) (http://www.modelaircraft.org/), 22 years before the FAA was created by the Federal Aviation Act of 1958.[22] In 2014, the AMA, the AUVSI (http://www.auvsi.org/home), and the Small UAV coalition (http://www.smalluavcoalition.org/), joined the FAA in launching the Know Before You Fly campaign (http://knowbeforeyoufly.org/) aimed at educating recreational users about basic safety rules when operating a small UAV for enjoyment.[23]

Safe use is important since hobbyists' model aircraft have come a long way from the "wood and glue" models of many years ago. Recent advances in consumer electronics, mobile technology, and battery power have led to the widespread use of small, self-powered, aerial devices chiefly for aerial photography.[24] Recreational UAVs have become increasingly popular because they can be outfitted with cameras, are capable of directional control by an on-the-ground operator, and do not require sophisticated training to operate.[25]

The increased recreational use of small UAVs has led to hobbyists facing new state laws and local ordinances. These new laws and ordinances impose civil and criminal penalties for various infractions such as invasion of privacy by flying over another person or property, crashes resulting in injuries to bystanders, and use in restricted areas, including national parks, prisons, and dense urban areas.[26,27] Use of UAVs near airports have led to near-miss incidents when aerial devices fly in close proximity to commercial airliners.[28] Recently, a UAV prompted closure of a runway at Gatwick airport near London.[29]

The FAA is aware of the expanding number of state laws and local ordinances governing UAV operations. In December 2015, it issued a fact sheet recognizing the current "patchwork quilt" of differing state and local rules, and asserting the FAA's exclusive authority "to regulate the areas of airspace use, management and efficiency, air traffic control, safety, navigational facilities, and aircraft noise at its source."[30]

Historically, the FAA has taken a voluntary approach to the use of model aircraft in the NAS. In 1981, the FAA advised persons interested in flying model aircraft for recreational use to adhere to a voluntary set of safety standards.[31] In 2007, the FAA restated its voluntary approach to the safe operation of model aircraft in the NAS.[32] In 2012, Congress enacted the FAA Modernization and Reform Act and recognized the safety efforts of the recreational UAV community by expressly prohibiting in Section 336(a) the FAA from promulgating "any rule or regulation regarding a model aircraft…"[33] In Section 336(c), Congress defined 'model aircraft' as an "unmanned aircraft that is capable of sustained flight in the atmosphere, flown within visual line of sight of the person operating the aircraft and flown for hobby or recreational purposes."[33]

In 2015, the FAA expressed concern that as more small UAVs entered the NAS, the risk of accidents would increase. The FAA thought that registration would help identify the UAV owner in the event of an accident. The FAA then promulgated a rule requiring owners of small UAVs weighing less than 55 pounds, "used exclusively as model aircraft" or "used as other than model aircraft," to register with the FAA.[34] Model aircraft operators objected to registration and sued the FAA.[35] In May 2017, the FAA's registration rule as it applied to model aircraft owners was vacated by the U.S. Court of Appeals for the District of Columbia Circuit.[36] The court said that the FAA Modernization and Reform Act explicitly prohibited the FAA from promulgating any rule regarding "model aircraft."[37] The court's ruling applies only to UAVs flown strictly for hobby or recreational use, and does not apply the UAV use for a public or commercial purpose.[38]

2.3 | Public sector uses

UAVs are being put to new uses by government agencies. A recent report indicates that 347 state and local police, sheriff, fire and emergency units in the U.S. have acquired UAVs.[39] UAVs are being used for various purposes including traffic management, search and rescue operations, tracking fire personnel in dangerous settings, aerial viewing of crowds for riot control, crime-scene photography, and mapping hazardous material spills.[40] Use of UAVs by police departments have resulted in some states requiring that police obtain a warrant before using a UAV for commencing a search or surveillance operation.[26] The International Association of Chiefs of Police,[41] the Police Foundation,[42] and the International Fire Chiefs Association,[43] have published guidelines for the public sector use of UAVs by municipal police and fire department.

2.4 | Commercial uses

Another emerging use of UAVs is as an enabling technology across many U.S. industry sectors, led by general aerial photography uses.[44] Commercial use of UAVs is still a small market compared to military and recreational uses, but rapid advances in drone technology and more permissive FAA rules for non-hobby and non-recreational purposes has led to a rise in commercial UAV use.[45]

In the 2012 FAA Modernization and Reform Act, Congress directed the FAA to "determine if certain unmanned aircraft systems may operate safely in the national airspace system."[46] While the FAA developed regulations governing the uses of commercial UAVs in the NAS, businesses wishing to fly a UAV for commercial purposes were required to obtain the same airworthiness certificate as any other type of aircraft. The only other alternative was for the commercial operator to apply for a "Section 333 exemption," which was reviewed and granted by the FAA on a case-by-case basis.[47] As a result, little commercial UAV use occurred.[48] In August 2016, the FAA finalized new operating and certification requirements (known as "Part 107") to allow UAVs to operate for "non-hobby and non-recreational purposes" in the NAS.[49]

The new FAA rules for commercial UAVs are extensive. General requirements include reporting to the FAA within ten calendar days any serious injury or loss of consciousness to any person and any property damage, other than to the UAV itself, above $500.00. Part 107 operating rules are extensive. The UAV must weigh less than 55 pounds, remain in visual line-of-sight of the remote pilot, operate in daylight only, stay away from bystanders, not operate over a human being unless the person is directly participating in the UAV operation, and fly at a maximum groundspeed of 100 miles per hour and at a maximum altitude of 400 feet above ground level, or if higher than 400 feet, remain within 400 feet radius of a structure. Part 107 remote pilot-in-command responsibilities include that the operator must hold a remote pilot airman certificate with a small UAV rating or be under the direct supervision of a person who holds such a certificate. Part 107 aircraft requirements state that an airworthiness certification is not required, but pre-flight checks for safe operation are required. Pilot requirements state that the operator must be 16 years old, pass an aeronautical knowledge test, and be vetted by the Transportation Security Administration (TSA).[50]

The commercial segment of the $100 billion UAV market is predicted to be the fastest growing between 2016 and 2020, with the construction industry accounting for the largest share of the growth.[12] By 2025, the U.S. commercial UAV sector is forecast to surpass five billion dollars in investments.[51] The markets for personal and commercial UAVs may be merging as many UAVs manufactured for recreational use can be adapted for commercial use in surveillance, 3D mapping and modeling.[13] Despite the technical merging of recreational and commercial UAV designs, the distinction between recreational and commercial uses is not straightforward.[52]

Commercial UAVs are now being used in construction[4,53]; agriculture and forestry[54]; mining[55–57]; warehousing[58]; motion picture production[59]; and transportation.[11] Robotic UAV applications are expanding capabilities for medical supply delivery[60]; search and rescue in disaster management[61]; remote pipeline inspection[62]; and cargo shipping and consumer delivery.[63–65] UAVs are even being studied as robotic "insect" pollinators to relieve the arduous, and costly, task of hand pollination.[66] As a business tool, the applications of commercial UAVs are growing rapidly in the construction sector promising benefits for construction management.[67]

3 | UAV USE IN CONSTRUCTION

The emerging uses of UAVs in the construction industry range from aiding with construction project planning by aerial mapping of the construction site[11] to extending to the actual building of structures.[2,68] More commonly, UAVs are being used today primarily for monitoring of construction work flow and job site logistics[53,69–70]; inspecting construction sites to assess structural integrity[71]; damage[72]; and for maintenance assessments.[4]

3.1 | Monitoring

Monitoring a large construction site is a challenge for construction management. A UAV can be deployed to send video footage of site conditions to construction management faster and more efficiently than can on-the-ground personnel. Video can be converted into a three-dimensional picture of the site and then compared to computerized architectural plans to show how accurately the project is progressing.[53] Monitoring information obtained by a UAV also serves as a useful input in the preparation of periodic construction progress reports. UAVs can be equipped with far and near infrared cameras, radar or laser-based range finders which can greatly enhance their surveillance and monitoring capabilities at a construction site.[70] In addition, tracking moving objects on construction sites such as people, equipment, and material are being developed,[73] as well as equipping UAVs with the capability of mapping indoor construction environments.[74] These applications are being implemented voluntarily and generally by large construction contractors which comprise less than ten percent of the industry. Their efforts could serve as an important source of data about the safety of UAVs to workers at construction sites.

3.2 | Inspection

UAVs can inspect a large worksite more efficiently through aerial photography than on-the-ground personnel can. UAV detection of hazardous conditions, materials and dangerous structures can aid in construction site hazard identification without placing a worker at risk.[75–76] Real-time UAV systems performing remote site inspections and violation detection at construction sites may be more efficient, safer and less costly than present construction site inspection methods.[70,77] UAV inspection of awkward locations on and under bridges and along highway can not only reduce the cost of personnel inspecting the entire expanse of a highway road or structure, but also reduce the risk of working along a busy highway or erecting equipment close to the flow of traffic.

Government inspections of construction sites could also be performed by a UAV. Because inspection of the site would be quicker than an individual government inspector walking an extensive construction site, UAVs could increase the scope and frequency of inspections of construction projects by federal, state and local government agencies.[78] Once potential violations were identified by aerial imaging, then inspectors could focus their investigation on sites where the potential violations were imaged.

3.3 | Maintenance

Using UAVs in carrying out planned or reactive maintenance inspections of tall structures, such as skyscrapers, bridges, and towers where access can be costly and pose a risk to workers of falling from a great height, appears to be a clear benefit for construction managers and workers.[4] New FAA rules permitting the commercial use of UAVs has prompted new guidelines for operating UAVs around vertical communications infrastructure.[79]

3.4 | Other uses

UAVs have been proposed as material handling vehicles, transporting tools, equipment and materials at construction sites[80] or used to spray-paint or waterproof a structural component.[81] UAVs can also be used to capture unique views of a structure for promotional photographic purposes.[4]

4 | UAVs AND CONSTRUCTION WORKER SAFETY

The presence of a UAV flying in close proximity to a human worker can create new hazards at a construction site, although data supporting the hazard potential of UAVs for workers arescarce. Safety professionals need to be aware of these new hazards, assess the risks arising from them, and apply controls to reduce the risks. There has been little published about the safety and health risks associated with the public or commercial use of UAVs, but the military has begun to assess the adverse health effects among remote pilots operating UAVs over conflict areas from a combination of long shifts of monotonous monitoring of a visual display screen, interrupted by activation of the UAVs weaponry with possible loss of human life.[82] Stress reactions have been seen in military personnel arising from their work as UAV operators.[83]

About 30 incidents of near-misses or crashes leading to human injury have been reported associated with the use of recreational UAVs.[27] Unstable flying conditions, operator errors, and faulty equipment may represent potential hazards to nearby workers from the commercial use of UAVs. Adding to the uncertainty about the hazards to workers from the emerging use of UAVs in construction and other industries, the arrival of autonomous or semi-autonomous UAVs may introduce new hazards arising from the absence of human control. New software algorithms for designing autonomous and semi-autonomous UAVs are in development and UAVs with new autonomous capabilities may be in use soon.[84]

It is important to develop hazard identification, risk characterization and mitigation approaches to ensure the safe operation of commercial UAVs as the use of UAVs promise significant benefits for industry. These approaches might incorporate prevention-through-design concepts such as lightweight manipulators, passive compliant systems, safe actuators, and passive robotic systems. Navigation and collision avoidance systems can be included in the design of commercial UAVs as a proactive safety measure. Collision avoidance in the three-dimensional environment is a main area of UAV design research.[85] Structural designs should consider stiffness and pliability factors that can reduce the impact force during collisions. Tools for the evaluation of UAV safety during the design[86] and certification stages[87] are being developed. As UAVs have limitations on the minimum size, weight, and structural design due to their airworthiness requirements,[88] prevention-through-design-based safety approaches have to be applied in collaboration with design engineers.

Adequate training of operators is essential to ensure the safe operation of the UAV. Operation of a UAV at a construction site should be done by a competent person similar to competent person requirement that is already a component of the Occupational Safety and Health Administration's (OSHA) general safety and health provisions at construction sites.[89] Similarly, a competent UAV operator is a person capable of identifying any potential hazard of operating a UAV in the particular construction site surroundings, especially any UAV operating condition that poses a hazard to workers on the ground. The competent UAV operator should be authorized by the construction manager to take prompt corrective measures to eliminate any hazard associated with operation of the UAV.

As the use of public and commercial UAVs gain in popularity, it will be important to review their uses to ensure that hazards and risks to workers are identified and mitigated. The emerging commercial use of UAVs in the construction industry presents a unique opportunity to develop safe approaches for the use of small, unmanned aerial vehicles. The development of approaches to the safe operation of small unmanned aerial systems, remotely piloted by worker/operators and flying in close proximity to other workers, can ensure that the management benefits of this promising new technology is shared between workers and management.

5 | FUTURE

Construction involves hazardous work. In 2015, 937 fatal work injuries occurred in the private construction industry. The Bureau of Labor Statistics (BLS) reported that in 2015 one in five worker deaths in the U.S. in 2015 due to construction hazards.[90] Any technology—including the emerging commercial use of UAVs that has the potential to reduce deaths and injuries from construction falls, toxic chemical exposures, electrical hazards, or traumatic injury from vehicle and equipment collisions during construction are welcome, but should be carefully studied. It may be too early to be certain about the safety benefits to workers of the emerging use of UAVs in construction, or in any other industry, but it is not too early to identify hazards associated with their use. As is the case with collaborative robots, “flying robots” or UAVs, proximate to human workers, may pose a potential hazard.

It will be important to collect and analyze objective data about negative safety outcomes in the future. There are several potential sources of information about injuries to workers from UAVs that may be useful. An FAA database of injuries caused by commercial UAVs, collected under Part 107 requirements, could serve as a source of information about worker injuries. Modifications to the BLS Survey of Occupational Injuries and Illnesses (SOII) and the Census of Fatal Occupational Injuries (CFOI) could facilitate identification of UAV-related incidents affecting workers. Accident investigations by OSHA and Fatality Assessment and Control Evaluation Program (FACE) investigations by the National Institute for Occupational Safety and Health could also serve as important sources of objective data about UAV risks to workers.

It is hoped that this commentary will increase awareness about the expanding use of UAVs in public and private sector workplaces and prompt safety professionals who are involved in their early use to share their experience. Occupational safety and health professional organizations should invite speakers to further increase awareness among their members. Safety professionals, organizations and government should adopt a proactive approach to the integration of UAV technology and work collaboratively to develop best safety practices that can promote the beneficial use of this promising new technology in construction and other industries while at the same time ensuring the safety and health of workers working with, nearby, and “below” these new workplace tools.

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