Unmanned Aerial Systems

Risks & Opportunities in the Workplace

By David Sullivan-Nightengale

Unmanned aerial systems (UAS) have been flying in the U.S. for almost 80 years. However, commercial use of UAS is relatively new to U.S. workplaces; often, this use violates federal aviation regulations [K. Morris (FAA), personal communication, June 24, 2014].

UAS may be one of the most technically challenging and disruptive systems for the Federal Aviation Administration (FAA) to integrate into the National Airspace System (NAS). The recent U.S. Department of Transportation Inspector General Report (Hampton, 2014) on these challenges is particularly noteworthy. Integrating UAS into the workplace is also going to be technically challenging for safety professionals. However, with sound risk management policies and effective system safety and security engineering, these devices can deliver safety advantages.

IN BRIEF
- **Unmanned aerial systems pose multiple challenges to safety professionals both in their design and operations.**
- **System design criteria must address design reliability, human factors and the operating limitations from a total system point of view to ensure airworthiness.**
- **Careful deployment of certified unmanned aerial systems can help safety professionals improve safety.**

Understanding the Risks

Government regulators face the pressing challenge of integrating UAS into the National Airspace System (NAS). Some UAS operators erroneously view the *Pirker v. Huerta* (2014) decision by an administrative law judge (later reversed by National Transportation Safety Board in November 2014) as blanket permission to fly uncertified aircraft in the NAS wherever they please. This has included flying around commercial aircraft, over major metropolitan areas, over crowds and even invading privacy.

Other safety-related concerns include airworthiness certification [airworthiness is the ability of an aircraft system/vehicle to safely attain, sustain and terminate flight in accordance with an approved usage and limitation (MIL-HDBK-516B)], pilot certification and operating rules that include privacy protections. This article provides a baseline for understanding these hazards, many of which have become evident from operational experience in defense and aerospace. These concerns can be broken into the system elements of the UAS: aircraft, control system, people and operational environment.

The Aircraft

The first military UAS in the U.S. were used as aerial targets in the 1930s. One of the U.S. Navy's first unmanned combat aerial vehicles, the TDN-1, was developed at the Philadelphia Naval Yard's Naval Air Experimental Station, also known as the Naval Aircraft Factory (Trimble, 1990).

The aircraft part of a UAS is sometimes referred to as a drone, an air vehicle or a remotely piloted vehicle. The aircraft can be optionally piloted; for example, a QF-16 can fly with or without the pilot on board or entirely unmanned. They range in size from as small as a hummingbird to wing spans larger than a Boeing 737. An analysis conducted by the Unmanned Systems Working Group of the Defense Safety Oversight Council indicated that UAS share much risk in common with manned systems (DOD, 2007). The areas in which they differ are primarily reliability, communications, and launch and recovery.

UAS components are considerably less reliable than those used in manned aircraft as one might expect (DOD, 2011). Styrofoam wings and duct tape repair kits are often the norm for small UAS. In general, the larger the UAS, the more reliable

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it must be to ensure safety. However, that is not always the case; in fact, some in the military consider UAS to be expendable resources much like fuel, food and ammunition. Furthermore, some UAS in the military, such as aerial target drones, are largely exempt from mishap reporting requirements (DOD, 2011).

Such thinking is not acceptable for commercial viability and safety in airspace integration or the workplace. Engine failures, alternator failures and communications system failures have been the leading causes of failure in the field for the military, and these mishaps can result in missing or lost aircraft. On the low end, a military UAS costs $10,000; for many businesses, recovering such costs would take significant time.

Engine and alternator failures have plagued many military UAS because small engines tend to be less reliable than large ones. For electric aircraft used by the military, the most common failure mode is a lost link. Most military UAS have not completed an airworthiness certification process similar to aircraft sold commercially in the U.S. Some were deployed overseas quickly with no safety analysis to rapidly boost capability. The result was the loss of hundreds of UAS.

In addition, UAS parts tend to be inexpensive and do not generally go through the rigorous configuration management practices used to manufacture manned aircraft. For manned aircraft, purchasing aerospace-grade parts is an expectation of regulatory agencies. These practices are uncommon for UAS manufacturers, whose objective has been to field UAS to the military quickly, often without the scrutiny given to manned military aircraft.

Although many military UAS have not undergone a system safety analysis in accordance with the military's Standard Practice for System Safety (MIL-STD-882), acceptance by the military is currently an FAA criteria for considering a UAS safe for operation under restricted operating rules. Specifically, the FAA (2012) policy on certifying restricted category aircraft, as written, will accept a small UAS without a pedigree if it was acceptable to the military. New rules that FAA published under Section 333 of the FAA Modernization and Reform Act of 2012 allow exemptions, but do not specify how a "level of safety" is to be measured.

> You are entitled to submit a petition for exemption if you believe following a rule will burden you, you can provide a level of safety at least equal to that provided by the rule from which you seek the exemption, and your request is in the public interest.

How an organization would demonstrate airworthiness using something other than proven, objective airworthiness processes in use remains suspect. Operational controls for safety have repeatedly proven inadequate when failures occur. Current aircraft systems must operate safely under single-point failures. Many UAS development organizations lack the reliability and system safety analysis capabilities needed to adequately demonstrate an equal level of safety under these normal failure conditions.

The lack of airworthiness certification and system safety assessments of military UAS has not gone unnoticed by NATO allies purchasing U.S.-manufactured UAS (DCDC, 2011). The U.K. Ministry of Defense (MOD) began to independently evaluate UAS coming from the U.S. in 2007 following hundreds of UAS mishap reports. MOD noted that these UAS lacked a safety analysis required by defense standards and voiced its criticism during a meeting of the Technical Cooperation Program. Considerable differences between safety programs can only be partially explained by the amount of money spent in each country. According to Steve Mattern of the International System Safety Society, MOD budgets a greater percentage of its acquisition funds toward system safety programs than does the DOD.

Understanding mishaps and the hazards leading to them gives UAS developers, maintainers and operators insights into how to safely integrate them into the workplace.

Differences in Airworthiness Criteria

Another concern is that even those UAS that have had a system safety analysis conducted in accordance with DOD acquisition regulations would not likely meet the more rigorous FAA requirements. DOD did not formally adopt functional hazard analysis techniques that are the norm for commercial aircraft programs following the Society of Automotive Engineer's Aerospace Recommended Practices into MIL-STD-882E until 2012. The military also has never fully adopted a software certification standard meeting the criteria of Radio Technical Commission for Aeronautics (RTCA) Document DO-178C.

DOD purchases aircraft that are commercial derivatives of civilian aircraft. For example, the KC-46 Pegasus air-to-air refueling aircraft and the P-8 maritime patrol aircraft are derivatives of the Boeing 767 and Boeing 737, respectively. These aircraft must meet RTCA DO-178 in their software development programs. Another exception has been the Joint Strike Fighter and Joint Tactical Radio System that adopted a combined framework under Lockheed Martin's Safety Evidence Assurance Levels (SEAL) development environment (Bridges, 2007). Since unmanned aerial systems have complex, safety-critical software both on the air vehicles and control stations, certification of the software and operating systems must be a priority for all categories of UAS to be reasonably safe in the NAS.

Power Systems

UAS power systems are often nonstandard. This means that instead of the 400 Hz three-phase power supply normal to manned commercial aircraft, the UAS can supply variable frequency power between 500 and 1200 Hz in up to six phases. So, instead of dwelling at 400 Hz during electromagnetic susceptibility testing, one must scan over a broader spectrum to test electromagnetic interference with avionics. Furthermore, small airframes mean less mass to attach ground planes, which creates the possibility of floating ground and losing signals across wiring. Care must be taken to use conductive paint and other techniques to increase the conductivity of carbon fiber small airframes and the like.

Communications

The UAS control station allows the pilot and other crew to interface with the air vehicle through radio communications. The communications system and control station can be as simple as a radio controller, smartphone or tablet, or as complex as a system of mobile control stations that are geographically separated and dynamically networked.

Communications systems engineering is an area of specialization within electrical engineering; it is central to connecting the human operator to the air vehicle. Understanding communications systems is critical to both UAS design and operation, and many software tools exist to help developers and operators maintain control and data links for the UAS. Doing so correctly often requires a significantly higher level of flight planning than that for manned aircraft pilots.

A leading cause of failure in small, battery-powered UAS is lost link (DOD) (called “link loss” by NATO and “flyaway” by Academy of Model Aeronautics) (Figure 1). It occurs when communications are lost between a control station and the unmanned aircraft. Sometimes, the signal is completely lost; other times, interference prevents usable data from getting to or from the control station or craft. In other cases, delays and distortions, such as control lag or video jitter, may adversely affect safe operations. A lost link can be a precursor to a midair collision and thus can have catastrophic consequences for commercial aircraft.

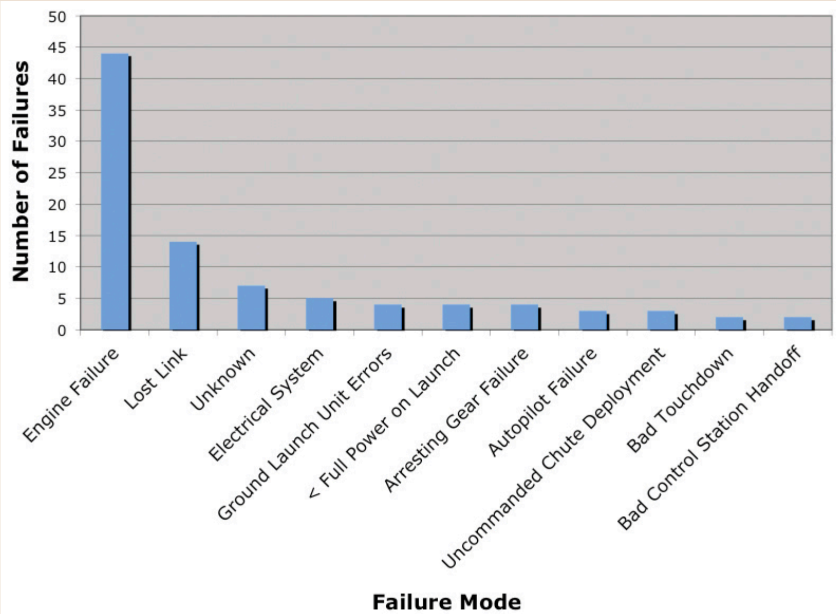
The simplest communications system has three components that can experience link loss: the two radios and the communications medium. Each radio can have a multitude of failures (too many to enumerate here) that could interrupt the link. The basic communications model (Figure 3) shows three causal factors of lost link. Extending the system’s range increases the single-point failures (Figure 4), while adding redundancy (Figure 5) improves reliability.

Networks that support UAS flight can be mobile. However, the longer the path, the less reliable it is. Out on edges of this reliability, a UAS can experience intermittent communications during which control is available for only a few seconds; this is not enough time to either control or command the aircraft to safely recover.

UAS communications are usually wireless, but some UAS, such as an unmanned tethered balloon or aerostat, are hard-wired. If electromagnetic interference and attenuating materials between the radios degrade the signal, the receiver cannot amplify the signal to distinguish it from background noise. The signal can also be delayed by distance and system throughput limitations, with some systems experiencing delays that can interfere with vehicle controllability in real

Figure 1

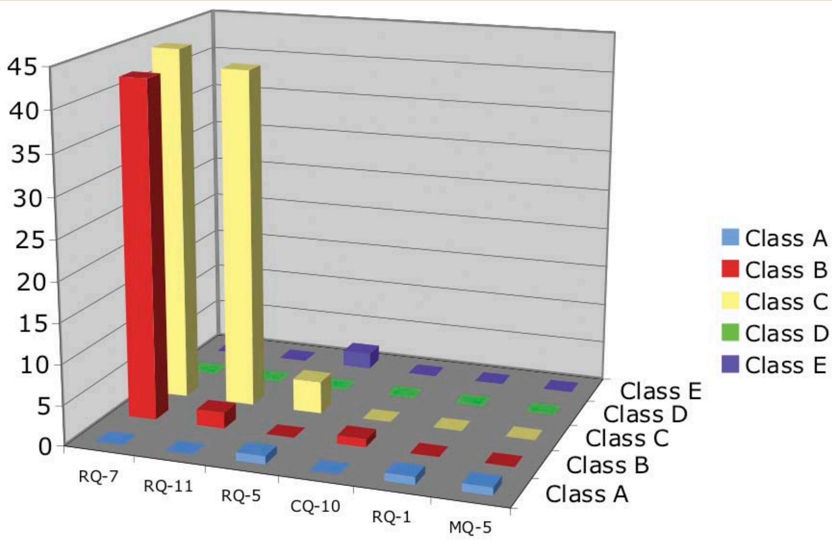
UAS Mishaps by Causal Factors



Note. *Failures by mode in reciprocating engine U.S. Army UAVs, January 2005 through October 2006.*

Figure 2

U.S. Army UAS Incident Data Derived From Army Flightfax Reports



Note. *U.S. Army UAS incidents by class, January 2005 through December 2006.*

time. Reliable radios, planning communications coverage for the flight route and alternate routes, and robust communications system design are essential for safe UAS flights.

Security is another important factor in preventing a lost link. Hijacking is a more sinister cause of communications systems failure. This can occur when a control link or a radio navigation system is compromised. While some reports described the purported hijacking of a Lockheed Martin RQ-170 by the Iranian military, such aircraft have navigation systems that are designed to detect spoofing of GPS by using inertial navigations systems referenced to distant stars to operate in environments that are considered GPS-denied. If someone jams or broadcasts misleading information (spoofing) to an aircraft, the onboard inertial navigation system will have a different position than the GPS and the system will default to the INS. Such a requirement is essential for the safety of manned aircraft operating in areas where GPS coverage is not perfect.

Malicious interference is another concern due to the ready availability of cell phone and GPS jammers. For example, GPS jammers were used to reset the GPS-guided precision landing system at Newark International Airport in 2010 (National PNT Advisory Board, 2010). While encryption can help prevent interference with digital radio information, it can also increase the failure rate. If encryption fails (like a neutron-induced single-event upset of encryption keys), then the link can be lost. The tradeoff often pays off, but there is a tradeoff nevertheless.

Pilot Certification

With more than 10,000 UAS operators and maintainers employed by militaries, the commercial environment will find a well-trained workforce with the discipline and skills necessary to help integrate UAS into the NAS. Schools such as University of North Dakota offer a professional UAS pilot training program, while other schools operate without third-party accreditation.

Leading defense contractors have developed best practices via trial and error. However, many original test pilots on small UAS have no prior flight experience in manned aircraft and no medical certificate from an aviation medical examiner. In such cases, experience working with Academy of Model Aeronautics clubs has been an essential part of training, along with completion of a private

Figure 3

Basic Communications Model

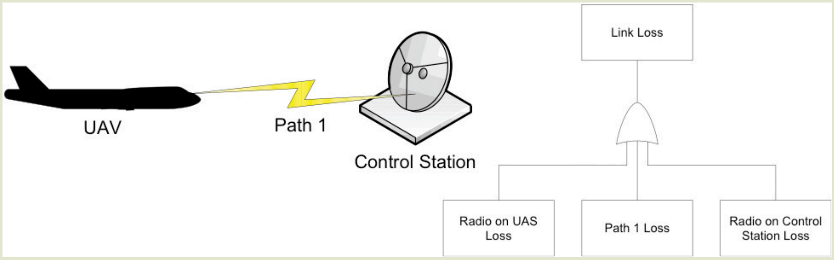
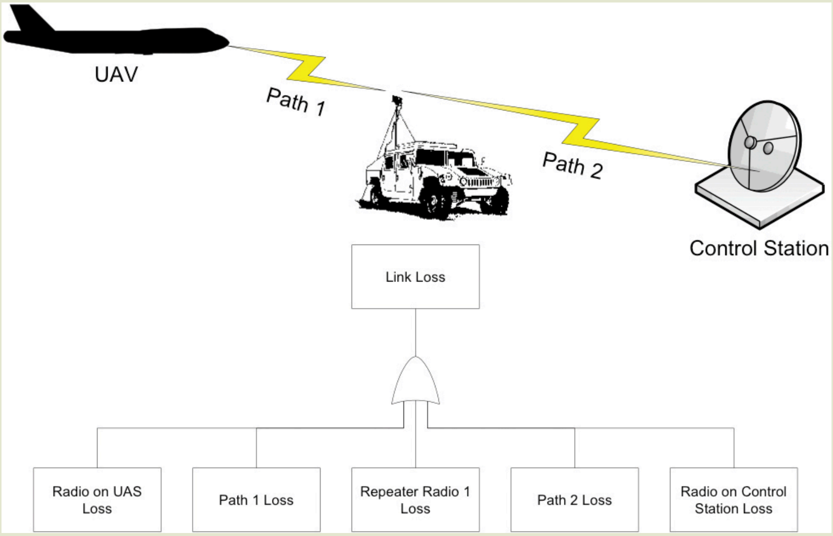


Figure 4

Communications Model With One Repeater



Note. *Communications model with one repeater and two more single point failures.*

Figure 5

Communications Model With Redundancy

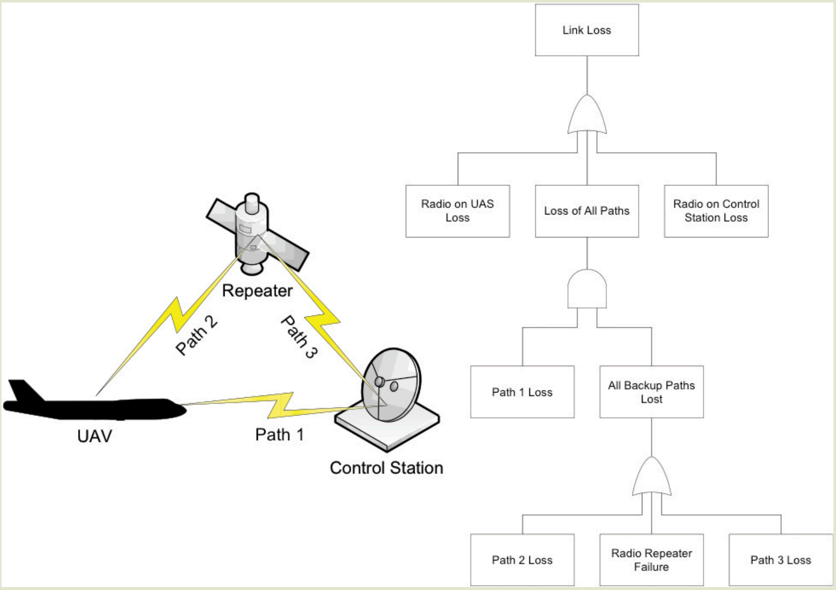


Table 1
Collision Probability Data

Year	Flight hours	Collisions	Collisions per flight hour
2001	24,866,254	3	1.21×10^{-7}
2002	20,468,069	8	3.91×10^{-7}
2003	20,758,052	8	3.85×10^{-7}
2004	21,931,950	10	4.56×10^{-7}
2005	20,994,832	8	3.81×10^{-7}
2006	21,692,506	6	1.84×10^{-7}
2007	19,151,755	3	4.18×10^{-7}
Total	**149,863,418**	**49**	$\mathbf{3.27 \times 10^{-7}}$

Note. *Collision probability data derived from NTSB reports and FAA statistics. From* Extension of Sensing Capabilities to Improve the Safety of Unmanned Aerial Systems, *by D. Sullivan-Nightengale, 2009, Daytona Beach, FL: Embry-Riddle Aeronautical University.*

pilot ground school to build basic aeronautical knowledge of weather and NAS flight operations. Some companies provide additional training in the use of advanced flight planning tools such as the Satellite Tool Kit to ensure adequate link coverage for all phases of flight.

FAA has proposed to require UAS pilots and observers to pass an online written exam to be qualified to pilot small UAS under limited flight rules. For larger aircraft and fewer flight restrictions, more privileges will likely mean more rigorous qualifications for pilots and other crewmembers, similar to those required of commercial pilots. This will likely include medical certificates similar to those currently required for manned aircraft. ASTM International is working on guidelines for training small UAS pilots, and RTCA is working on minimal operational performance standards for larger UAS.

Operations

Before examining each phase of flight operations, it is important to discuss a flight operations quality assurance (FOQA) program. No matter the size of the business, from as small as a professional photographer to a company delivering packages via UAS, an FOQA program is an effective way to reduce mishaps and it is a cornerstone of an effective aviation safety management system.

FOQA tracks flight metrics to identify ways to improve performance. To achieve this, a flight data recorder is used to track performance of both the air vehicle and the operator at the ground control station. Recorders can be as small as a memory card recording position and airspeed or as large as a crash-survivable version used on commercial aircraft, recording dozens of parameters. Some military UAS and general aviation pilots have used continuously transmitting systems such as the SPOT2 tracker to continuously transmit the position to a satellite. Some UAS are more capable than manned commercial and military aircraft in this regard.

Once data are downloaded, the pilot or company can review the data and decide what behaviors to change to become safer or more efficient at flying. While the DOD mandates military FOQA programs, FAA may encourage commercial operators of UAS to incorporate FOQA into their safety management systems as well.

Operational considerations depend largely on the involved risks to manned aircraft and the public. Examining how the military and aerospace contractors control these risk during each phase of flight from launch through recovery provides insight regarding how employers can control these risks. It is important to keep in mind that some risks of operating and developing UAS in the workplace will be outside the FAA's regulatory regime.

Sense & Avoid

The efficacy of the see-and-avoid principal has been debated for many years. Research has reported inadequacies of human vision in seeing aircraft on a collision course.

> Finally, the see-and-avoid concept misleads pilots and controllers by encouraging overconfidence in visual scanning while neglecting its physical and behavioral limitations and mitigation strategies. While visual scanning is necessary to prevent midair collisions, especially of aircraft flying slowly in close proximity and not yet on collision courses, it is not sufficient. (Morris, 2005)

FAA data indicate that it is difficult for general aviation pilots to see and avoid each other. By modeling and testing human vision over the years from fighter pilots to commercial pilots, it is known that the probability of detection with the human eye of a UAS on a collision course is almost impossible for all but the best-trained pilots in the world (Sullivan-Nightengale, 2009). Although fighter pilots consider themselves to be experts at spotting other aircraft, aerial target drones against which they regularly train must carry a tank of mineral oil that is injected into the engine exhaust to make the orange drone even more visible to the fighter pilot. The ramifications of this inherent difficulty to see and avoid will be a significant problem for civilian pilots as well. As Table 1 shows, the rate of midair collisions in general aviation continues to be unacceptable.

The Satellite Tool Kit is a popular tool for those designing unmanned systems. By modeling human vision, one can determine the amount of sky within a pilot's field of view that can be seen in a particular cockpit and compare with sensors such as radar, lidar and automated camera systems. Modeling and simulation of sensors to detect other aircraft and the integrity of communications links are all computed prior to flight to plan successful operations. Figure 6 shows a small example of this tool's capability to model human vision.

Launch

Manned aircraft traditionally take off and land. However, the general term used for UAS is *launch.*

A launch can be by various means, and, as with manned aircraft, it involves increased risks that must be managed. UAS can be launched by hand, rocket, slingshot, catapult or dropped from another aircraft, or it can take off like any manned aircraft. This flexibility offers the opportunity to launch from just about anywhere given enough space. Thus, launch area selection will be a key performance parameter for safe launch operations. To date, launch operations mishaps have damaged or destroyed UAS as well as their launchers. Personnel have been injured, and property has been damaged as a result of both engine failures on launch and human factors errors by ground crew personnel.

Such mishaps are avoidable. Determining vertical clearance over obstacles and safe zones in the event of an engine failure on launch will ensure safe operations for this critical phase of flight. A trained launch crew is essential to set up and arm any stored energy systems needed to launch an air vehicle safely. OSHA currently requires formal training to mitigate hazards during certain launch operations with higher risks, such as those with stored energy in compressed gas, rockets and ordnance. In addition, ASTM F2585-08 provides some basic guidance on launch systems using hydraulics and pneumatics systems.

Recovery

UAS can land just like manned aircraft. However, many can be recovered via parachute, caught with a net, make belly landings on land or water, or have wings that break apart to absorb landing. Location is the critical component of successful recovery. Designating a safe recovery area before launch reduces risk to people and private property and also reduces damage to the UAS. Many UAS can be programmed with one or several safe recovery areas in the event of a lost link or engine failure in flight.

The reliability of recovery systems has long been the focus of safety on DOD ranges. When DOD implemented parachute recovery for small UAS, it had a significant impact on the ability to recover aircraft after a link loss. By programming the flight control processors to recover the aircraft after a lost link, many UAS were saved.

To safely recover UAS via parachute:

1) The UAS must right itself to a straight and level flight to deploy the parachute successfully.

2) The UAS must be at an altitude and airspeed to allow for parachute opening; in cases when altitude is too low, the UAS must be able to climb safely to recover—too fast and the parachute can rip out of the fuselage, too slow and the parachute could entangle in structure.

3) The recovery area must be free of hazards.

4) The UAS must shut off the engine when the chute is deployed.

5) The parachute must deploy.

6) After landing, the parachute should be cut to prevent dragging (by wind) across the recovery area.

7) If landing on water, the UAS must be able to float.

8) Power systems must disarm any squibs or other ordnance used for recovery by removing power to them to keep recovery crews safe.

9) The UAS body must withstand impact without breaching a fuel tank and protect the batteries from damage.

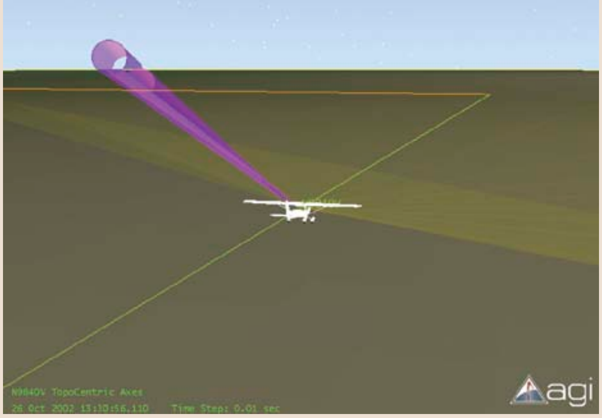
10) Personnel must have appropriate PPE to handle broken material (e.g., puncture-proof gloves for handling broken carbon fiber).

11) Personnel must be trained and have the correct equipment to handle unexploded ordnance if it is used for jettison equipment.

12) If recovered, crews must understand how to safely lift the UAS. Lifting equipment must be certified or rated for worst-case recovery weight. Center of gravity should be marked on the UAS for full and empty tanks.

Figure 6

Pilot Visibility Study



Note. *Pilot visibility study modeling human visual sensation and perception.*

New Workplace Hazards

Currently, FAA has declined to regulate indoor flight of unmanned aircraft. This means that UAS could be operated indoors without the same level of safety as required by airworthy aircraft and certified pilots. For example, the Minnesota Sports Facilities Authority previously allowed UAS operations inside the Hubert H. Humphrey Metrodome and is considering doing the same at the Minnesota Vikings Stadium (T. Orth, personal communication, June 4, 2014).

Without federal regulations, this would leave local governments responsible for flight safety although they have received no guidance from OSHA on this issue. The OSH Act usually does not cover professional sports players and certainly not fans at events where UAS are deployed. Workers at risk of injury by UAS might be protected under OSHA provisions, but to date, Minnesota OSHA has received no guidance from federal OSHA on this issue leaving a gap in enforcement guidance (J. Isakson, personal communication, Feb. 6, 2014). OSHA (1993) fined a UAS developer several years ago when a worker lost a fingertip in a propeller strike. So, there is precedent for regulating operations under 29 CFR 1910.212 (General Requirements for all Machines) not regulated by 14 CFR.

The potential ease of inspection via UAS could encourage more frequent inspections of safety-critical systems, delivering additional safety benefits.

Indoor operations can be problematic because radio signals are attenuated by walls and interfered with by other communications devices and electronics. As noted, UAS do not currently meet the same criteria for safety as commercial aircraft and are usually made from less reliable and less robust components than manned aircraft. Communications system reliability is likely to be a leading cause of mishaps in commercial UAS as it is with military UAS. The communications environment in developed countries is significantly different from that in third-world areas where most military UAS have been operating, and where electromagnetic interference sources will be more problematic.

Converting military UAS to commercial use poses many challenges. No product safety mark covers UAS, and current airworthiness certification criteria address manned aircraft. The military did not intend many of these systems to be operated by civilians subject to 29 CFR, and aerospace companies familiar with military standards for system safety may not be familiar with their commercial equivalent for product safety. Furthermore, while MIL-STD-882E contains many of the MIL-STD-882C analyses, it is not equivalent to commercial aircraft functional safety standards.

Conversely, the military has previously accepted ground control stations with certification marks from nationally recognized test labs under MIL-HDBK-454B Guideline 1. Some military control stations have used gaming controllers hooked to laptop computers with the CE mark. However, no failure modes and effects analyses were used to evaluate many ground control stations for safety-critical operations such as UAS operations. As such, many of the commercially sold UAS contain single-point failure mechanisms that could result in loss of control of a craft. This would endanger workers and the public.

Lithium Batteries

Lithium batteries have been associated with fires in commercial aircraft, submarines and automobiles. Many small UAS (weighing less than 55 lb) use lithium batteries because of the high energy-density-to-weight ratio, similar to reasons for using lithium batteries in smartphones and other portable electronic devices. Lithium battery technology has become more reliable and robust over the past decade. Test regimes for UAS were primarily limited to UN testing initially. MIL-STD-810 and RTCA DO-160 have long been a staple of UAS testing, but no specific test was designated for lithium batteries. Among the military services, the Navy's Lithium Battery Control program stands out as a model. The U.S. Navy treats lithium batteries like explosives. RTCA Special Committee 225 developed DO-311 primarily for permanent installations on commercial aircraft, but its applicability to UAS is questionable since UAS batteries are often removable.

Lithium batteries used to power UAS have violently vented in the field due to imbalanced charging, reverse polarity charging, charging in high temperature conditions, using a Ni-Cad charge setting on a lithium battery and being dropped. Best practices for lithium battery charging outdoors come from the military and include digging a small ditch to contain mishap venting, keeping batteries out of the sun and limiting the number of batteries being charged at one time.

Extinguishing a lithium battery fire is not as important as preventing a burning cell from spreading to adjacent cells. Although it may seem counterintuitive to extinguish a burning metal fire with water, FAA experiments have determined that it is the best method to suppress a lithium battery fire until the burning cells deplete their fuel source. In essence, FAA discovered that pouring water on lithium battery fires prevents adjacent cells from catching fire by keeping them cool and isolating the fire. Class D fire extinguishers were determined to be ineffective because the batteries are embedded inside casing and the extinguishing material simply could not reach the fire to cool the cells adjacent to the burning cells. Some companies have modeled their lithium battery control programs after FAA guidelines. More recently, RTCA formed a committee to address problems with lithium batteries such as incidents on commercial aircraft like the Boeing 787.

Battery safety often is not addressed in undergraduate coursework in electrical engineering. Therefore, experience and on-the-job training will be needed to successfully develop UAS for the workplace. Consider this example: At a meeting of quad copter hobbyists in the Twin Cities, many did not understand basic electrical circuit design when they were assembling their UAS and complained of mismatching batteries to their aircraft power needs. As one lab manager stated, "We have to get the UAS engineers out of the hobby shop mentality."

Normal & Alternative Fuels

Fuels present another potential safety concern. Hobbyists have long used a mitromethane-methanol blend in radio-controlled aircraft. Methanol is a powerful central nervous system depressant (Medina, 2014) and it is still used as rocket fuel. Nitromethane can burn without the presence of oxygen. Liquefied petroleum gas (a mixture of propane and butane) was recently used in a high-altitude UAS. Outfitting airports with additional sensors to detect a wider variety of flammable gasses should be considered before UAS operations begin, and airport certification criteria and plans will need to be revised for UAS operations with alternative fuels. JP-4, JP-8 and Jet A continue to be used in larger UAS engines just as they are in manned aircraft. Military UAS with reciprocating engines mostly use gasoline, but heavier fuels like diesel and Jet A are being used as well. Regardless of fuel type, a comprehensive fuel handling program and additional training will be required of airport operators to safely handle a wider variety of fuels than today.

Opportunities

Safety professionals often hear the phrase, "complacency kills." Many semiautonomous operations are best done by safety-instrumented systems that are unmanned. For example, UAS can cover large areas with remote sensing equipment to detect fires, track wildlife and animals, or monitor crops. Law enforcement and private security use manned aircraft to take video surveillance of metropolitan areas; it is only a matter of time before this becomes an unmanned operation.

Aiding Inspections & Firefighting Capabilities

Outside the U.S., UAS are being used to inspect flare stacks (gas flares) at refineries and offshore oil platforms. Some companies claim that UAS can also inspect for gas leaks. However, current technologies in the U.S. checking for gas leaks are usually part of a safety integrated system and must be intrinsically safe. As currently designed, UAS are neither intrinsically safe nor reliable enough to be considered part of a safety integrated system. On the other hand, inspecting pipeline operations via UAS holds promise.

Both NTSB and Transportation Safety Board of Canada have recorded fatalities resulting from manned flights conducted to inspect pipelines. Since 2000, there have been 30 aircraft incidents during pipeline survey flights and 20 fatalities (Figure 7). Use of unmanned aircraft would effectively eliminate these fatalities.

Low altitude operations such as crop dusting, insect control and firefighting carry inherent risks involving collisions with trees, power lines, bird strikes, buildings other aircraft and exposure to chemicals. Known formally as aerial application, this profession is acutely aware of risks inherent to its work. National Agricultural Aviation Association (2014) reports:

> In the last 10 years, 7.2% of aerial application fatalities were the result of collisions with towers, while collisions with power lines account for an additional 12.3% of the accidents and 13% of the reported fatalities in the industry. NAAA is urging the FAA to provide improved guidance on marking obstacles, including expanding tower marking guidance to include all guy wire and free-standing towers more than 50 ft in height.

UAS operations could reduce some of these risks, but could also pose new risks to manned application aircraft if sense-and-avoid systems fail.

The potential ease of inspection via UAS could encourage more frequent inspections of safety-critical systems, delivering additional safety benefits. Flare stack inspections, which are currently conducted in the U.K., are a good example of the type of inspections suited for UAS.

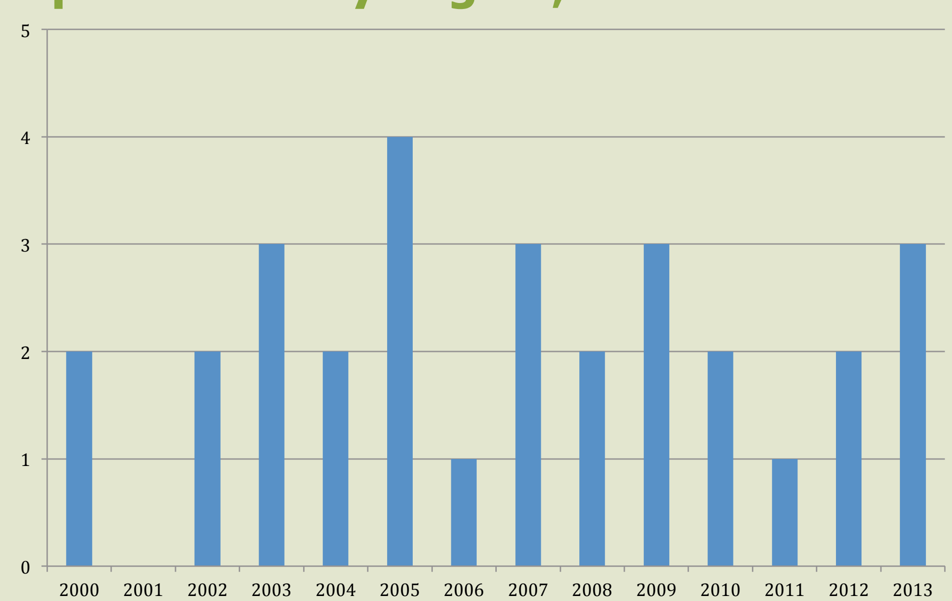
Aerial radiological monitoring has been demonstrated by an RQ-4 Global Hawk. Rather than expose Air Force personnel to radioactive material, radiation-hardened UAS can operate safely from a distance. Such units must be designed to be easily decontaminated in order to be reused and to prevent injury or illness due to radioactive, chemical or biological contaminants.

Firefighting operations face hazards such as carrying unstable loads of water, collisions with other aircraft, and exposure to smoke and fire. Swarms of unmanned aircraft could land on water, load up and drop water closer to the fire than what is currently allowed with manned aircraft. Unmanned aircraft have already been used to spot fires. However, this could result in manned and unmanned aircraft sharing similar airspace, which is difficult to coordinate. Reports suggest that amateur UAS operators have interfered with forest fire response. Thus, UAS operations surrounding fire areas must coordinate with the incident command.

In other applications, helicopters have been used to locate tough-to-see structural fires. In urban areas where houses are tightly packed, the ability

Figure 7

U.S. Aircraft Incidents During Pipeline Survey Flights, 2000-13



to find fires coming out of the tops of buildings is difficult even with a ladder truck. Most communities cannot afford their own manned helicopter so must rely on those operated by a county or mutual aid organization. This often means additional travel time to the fire site, which can mean the difference between life and death. Firefighters using infrared remote sensing UAS at the local level could reduce the response time for both suppression and search-and-rescue operations.

Reducing Fall Hazards

Falls to a lower level are a persistent occupational hazard. It is difficult to determine, quantitatively, the role that UAS could play in reducing fall injuries. While potential UAS applications in this area require additional study, consider for example the possibility of using a UAS camera to perform inspections historically performed only visually due to inherent risks. Of course, human senses often detect things that a UAS may miss, such as the smell of outgassing from internal overheating of electrical components or sounds not detectable by microphone.

Security/Privacy

Safety managers often are responsible for facility security. UAS in the hands of criminals can pose significant challenges in the workplace. For example, Senator Dianne Feinstein (2014) reported having a micro UAS in front of her home window. At a meeting of quad copter enthusiasts, a professional photographer displayed up-close images of the tops of skyscrapers in Minneapolis, MN. In Denver, CO, a UAS peering into a skyscraper crashed into the building, landing on the street in front of pedestrians. Those who use wireless devices in public locations may find their information has been intercepted by a UAS spoofing a wireless network. System security contingencies must consider defenses against the use of unmanned systems.

For those who use UAS responsibly in the workplace, solutions exist to protect the privacy of information collected by video. One promising solution is similar to what Google does with images it collects from people driving around city streets. Personally identifiable information can be removed before transmission or storage. Absent regulations, companies developing and operating the UAS will need to determine workable privacy policies.

Conclusion

The examination of mishaps and the hazards leading to them gives UAS developers, maintainers and operators insights into how to safely integrate them into not only the NAS but also the workplace. Formal airworthiness certification, crew certification and operational regulations are critical to realizing the potential of UAS to reduce workplace risks without increasing risks manned flight, personnel and the public. OSH professionals can advocate for comprehensive programs that address acquiring and deploying UAS safely. **PS**

References

Bridges, M. (2007). JSF software safety process: Providing development assurance. *Proceedings of the 26th Annual IEEE Software Technology Conference.* Long Beach, CA: Institute for Electrical and Electronic Engineers.

The Development, Concepts and Doctrine Centre (DCDC). (2011). Joint doctrine note 2/11: The U.K. approach to unmanned aircraft systems. Wiltshire, U.K.: Ministry of Defense.

Federal Aviation Administration (FAA). (2012). Expanding use of small unmanned aircraft systems in the Arctic Implementation Plan (FAA Modernization and Reform Act of 2012). Washington, DC: Author.

Feinstein, D. (2014, Jan. 15). Testimony before the Senate Commerce Committee on the future of unmanned aviation in the U.S. economy: Safety and privacy considerations. Retrieved from www.commerce.senate.gov

Hampton, M. (2014). FAA faces significant barriers to safely integrate unmanned aircraft systems into the National Airspace System (FAA Report No. AV-2014-061). Washington, DC: U.S. DOT, FAA.

Medina, E. (2014, June). Methanol hazards and safeguards: Lessons learned from the global supply chain. *Professional Safety, 59*(6), 67-74.

Morris, C. (2005). Midair collisions: Limitations on the see-and-avoid concept in civil aviation. *Aviation, Space and Environmental Medicine, 76*(4), 357-365.

National PNT Advisory Board. (2010, Nov. 4). Comments on jamming the global positioning system: A national security threat—recent events and potential cures. Retrieved from www.gps.gov/governance/advisory/recommendations/2010-11-jammingwhitepaper.pdf

OSHA. (1993). Accident: 170068274; Report ID: 0352410; Event Date: 12/28/1993. Washington, DC: Author.

Ryan, J. (Ed.). (2006, Nov. 9). Desert Hawk: Video footage from "Slow Pigeon" [UAV video footage]. Wiltshire, U.K.: U.K. Ministry of Defense.

Sullivan-Nightengale, D. (2006). Modeling and simulation of general aviation midair collisions using commercially available tools. *Proceedings of the 24th International System Safety Conference.*

Sullivan-Nightengale, D. (2009). *Extension of sensing capabilities to improve the safety of unmanned aerial systems.* Daytona Beach, FL: Embry-Riddle Aeronautical University.

Trimble, W. (1990). *Wings for the Navy: A history of the Naval Aircraft Factory, 1917-1956.* Annapolis, MD: Naval Institute Press.

U.S. Department of Defense (DOD). (2003). Unmanned aerial vehicle reliability study. Washington, DC: Author.

U.S. DOD. (2007). Unmanned systems safety guide for DOD acquisition. Washington, DC: Author, Office of the Undersecretary of Defense, Acquisition, Technology and Logistics.

U.S. DOD. (2011). Mishap notification, investigation, reporting and recordkeeping (Department of Defense Instruction 6055.07). Washington, DC: Author, Office of the Undersecretary of Defense, Acquisition, Technology and Logistics.

Whitlock, C. (2014, June 20). When drones fall from the sky. *The Washington Post.* Retrieved from www.washingtonpost.com/sf/investigative/2014/06/20/when-drones-fall-from-the-sky