

Remotely Piloted Aircraft Systems

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INTRODUCTION

Unmanned aviation may seem to be a recent development, but the history of unmanned aircraft goes back to the early years of powered flight. During World War I, autopilots and stability control enabled Sperry's unpowered aerial torpedo and the Kettering Bug to fly preset courses (Newcome, 2004) although in each case they were designed as flying bombs intended for one-way missions. In 1917, Archibald Low developed an aircraft that was piloted via radio signals (Bloom, 1958) and in subsequent years, radio-controlled aircraft were widely used as target drones. By the 1960s developments in sensors enabled reusable unmanned aircraft to perform military photo-reconnaissance and electronic warfare roles (Barry & Thomas, 2008). The technology of commercial model aircraft was also advancing, with the mass-production of inexpensive radio control units, servos and engines. In recent years, the capabilities of even the smallest unmanned aircraft have been expanded through advances in microprocessors, satellite navigation systems, miniaturized sensors, and batteries originally developed for cell phones and other consumer products.

The central message of this chapter is that the further development of unmanned aviation may be held back more by a lack of attention to human factors, than by technological hurdles. This chapter begins with a brief overview of remotely piloted aircraft, follows with a review of their accident record, and then focuses on human factors principles for Remote Pilot Stations (RPS).

FIGURE 1 ABOUT HERE

Remotely piloted aircraft range from quadcopter “drones” with endurance measured in minutes, to large, long endurance aircraft powered by jet turbine engines (see Figure 1). In the US, the Federal Aviation Administration permits drones weighing less than 25 kg to be operated at low-level, clear of controlled airspace, and within line-of-sight of the pilot (FAA Part 107). At the other extreme are High Altitude Long Endurance (HALE) aircraft, such as Global Hawk, with a

maximum takeoff weight of 14,600 kg. In between is a diverse range of fixed wing, rotary wing and lighter-than-air vehicles.

The range of uses for remotely piloted aircraft has rapidly extended beyond the “dull, dirty and dangerous” tasks that were once thought of as their niche. Remotely piloted aircraft are proving their value in areas as diverse as real estate photography, construction site surveys, mapping, firefighting, agriculture, and telecommunications relay. Rather than eliminating the human factor, the removal of the pilot from the aircraft has sometimes amplified the impact of human fallibility on system performance and given us a renewed appreciation of the contribution made by on-board pilots.

Despite their apparent differences, all unmanned aircraft are part of a wider system that includes a control interface, communication links, and support equipment. Throughout this chapter, the terms "Remotely Piloted Aircraft" (RPA) or "unmanned aircraft" will be used to refer to the airborne element of the system, and the terms Remote Pilot Station (RPS) or “pilot station” will refer to the facility from which the pilot controls the aircraft. The entire system, including the airborne and ground-based components will be referred to as a "Remotely Piloted Aircraft System" (RPAS).

This chapter is focused on remotely piloted aircraft that can operate beyond the line of sight of the pilot, in civil airspace in compliance with air traffic control. Fully autonomous aircraft and small drones operating at low altitude are outside the scope of this chapter. Rather than re-visiting topics that are covered elsewhere in this book, this chapter deals with the points of difference between RPAS and conventional aviation, as shown by the area on the right of Figure 2.

FIGURE 2 ABOUT HERE

THE ACCIDENT RECORD

Remotely piloted aircraft have experienced a significantly higher accident rate than conventionally piloted aircraft. The US Army has reported an accident rate of 24.9 per 100,000 flying hours for its unmanned aircraft, compared with 6.3 for its manned aircraft (US Army,

2017). Statistics for accidents in which the aircraft is destroyed enable the most reliable comparisons to be made between manned and unmanned aircraft as there is less potential for under-reporting or different definitions of an “accident.” In 2017, remotely piloted aircraft operated by the US Air Force (USAF) were destroyed at the rate of 1.9 per 100,000 hours flown, compared to the rate of 0.4 per 100,000 flying hours for the USAF’s manned aircraft (USAF, 2019). Accident rates for civilian RPAS operations are not available; however one manufacturer of small commercial unmanned aircraft has reported that it expects to lose one aircraft every 300 flight hours — approximately equivalent to a rate of 330 accidents per 100,000 hours.

The higher accident rate for RPAS may be attributed partly to technological factors such as the use of non-certificated components and a lack of system redundancy. However, inadequate consideration of human factors by system designers has undoubtedly contributed to the accident record (Tvaryanas, Thompson, & Constable, 2006; Williams, 2004).

A Landmark RPAS Accident

A sentinel event for the RPAS industry was the April 2006 crash of a General Atomics MQ-9, operated by the U.S. Department of Homeland Security near the U.S. border with Mexico. When the facts of the accident began to emerge, media reports labeled it a case of “pilot error.” However, the National Transportation Safety Board (NTSB) investigation uncovered deeper systemic issues that are still relevant today.

The MQ-9 is a turboprop powered aircraft with a maximum takeoff weight of approximately 4700 kg. The aircraft is operated from a pilot station that has two side-by-side consoles. The aircraft controls on each console are almost identical, enabling control to be transferred between consoles if necessary. In normal operations, the pilot sits at the left console and a sensor operator seated at the right console controls a camera mounted on the aircraft. The condition lever, shown in Figure 3, operates in two modes. When the console is set to sensor mode, moving the condition lever forward opens the iris of the camera, moving it aft closes the iris, and placing it in the middle position locks the iris setting. However, when the console is set to pilot mode, the condition lever becomes a critical engine control. In the middle position the lever shuts off fuel to the engine, in the aft position it feathers the propeller.

The NTSB (2006) reported that several hours into the accident flight the pilot's console locked up, or "froze." The pilot decided to switch control to the right-hand console. The border patrol agent who had been seated at the right-hand console stood back to enable the pilot to transfer control. Although there was a checklist to guide the transfer between consoles, the pilot reported that, due to time pressure, he did not refer to it. He also did not notice that the condition lever on the right-hand console was in the middle (fuel shut-off) position when control was transferred. A warning tone sounded when the engine stopped, however the pilot station uses the same tone for all warnings. Personnel who heard the warning may have assumed that it indicated a noncritical situation, such as a temporary loss of satellite link.

FIGURE 3 ABOUT HERE

The pilot noticed that the aircraft was losing altitude. Unaware that the engine had stopped, he turned off the data uplink to activate the aircraft's lost link procedure. This would have directed the aircraft to climb to an altitude of 15,000 feet and fly a predetermined course until control could be reestablished, but the aircraft continued to descend until it was below line-of-sight communications.

The aircraft was equipped with an engine auto-ignition system that relied on a secondary, satellite-based, communication link. However, when the engine stopped, the aircraft automatically began shedding electrical load to conserve battery power. The satellite communication equipment was one of the systems that were shed. Consequently, the engine could not be restarted once the aircraft had descended below the coverage of the ground-based communication link. At around 3:50 A.M. the aircraft impacted the ground in a sparsely populated area near Nogales, Arizona.

The console lock-up was not the first to occur in the pilot station. There had been 16 of these in the preceding four months, including two that occurred during preparations for the accident flight. The maintenance response to these lock-ups had been to swap the main processor circuit

cards between the two consoles. It was not clear whether this was done to diagnose the problem or to clear the fault.

Some of the recommendations in the NTSB report were specific to the MQ-9, and dealt with console lock-ups, inadvertent engine shutdowns, and the need for an engine restart capability when a line-of-sight radio link is not available. More generally, the NTSB also recognized that the emerging RPAS industry lacks a safety reporting system. According to Williams (2006), two years prior to the Nogales accident, the crew of another MQ-9 had also inadvertently shut off the fuel when switching control between consoles, but had been able to re-start the engine. An incident reporting system may have brought attention to the problem before it led to an accident.

The Nogales accident involved a large and sophisticated aircraft. Yet many of the issues raised by the investigation are relevant to the design of Remote Pilot Stations (RPS), regardless of the size and complexity of the RPA.

DESIGN CONSIDERATIONS FOR THE REMOTE PILOT STATION

Remote Pilot Stations (RPS) range from sophisticated control rooms that bear little resemblance to traditional cockpits, to commercial off-the-shelf laptop computers (see Figure 4). In the 2000s, some military unmanned aircraft were rushed into service with problematic control interfaces. Problems included difficult-to-read color combinations, the placement of critical controls adjacent to non-critical controls, and a reliance on textual displays in place of analog flight instruments (Neville et al, 2012; Pedersen, Cooke, Pringle, & Connor, 2006). Textual displays can slow instrument scans by forcing the pilot to use the limited resource of foveal vision to obtain information that might otherwise be available via peripheral vision.

Tvaryanas and Thompson (2008) identified a range of design deficiencies with military RPS, including “non-intuitive automation, multifunctional controls and displays, hierarchical menu trees and non-integrated data that provide . . . inadequate feedback to crewmembers on system settings and states, overload crew members with raw data and require sustained attention and complex instrument scans” (p. 530).

FIGURE 4 ABOUT HERE

Remote Pilot Stations commonly include keyboards, mice, trackballs, menu structures, touch-screens and other input devices typical of consumer electronics and office workstations. The relative spaciousness of a control room enables additional screens to be added as the need arises, potentially creating a clutter of ad-hoc displays (Hobbs & Lyall, 2016a). Keyboard controls, in combination with a lack of sensory feedback, can result in otherwise trivial keypress errors going unnoticed (Hobbs, 2018). Displays are sometimes obscured behind pop-up dialog boxes, or removed from view as windows are closed, moved, or minimized. It may be necessary to click through menu options to view primary flight instruments such as altimeter and airspeed indicator. Even then, the information may be presented in non-standard units, such as airspeed in meters per second instead of knots.

Neville and Williams (2017) note that some of the interface problems reflect poor application of existing cockpit design standards (e.g., Yeh, Jo, Donovan & Gabree, 2013), whereas others reflect issues specific to RPAS that are not yet covered by civil design guidelines or standards. Several military agencies have released human factors guidance material or standards for the RPS, including the United States Under Secretary of Defense (2012), United States Department of Defense (2012), and North Atlantic Treaty Organization (2007, 2009). In the absence of civil design standards, some modern RPS have nevertheless benefited from improvements developed through operational experience (see Figure 5).

FIGURE 5 ABOUT HERE

The rest of this chapter addresses six areas of human factors where RPS differ from traditional cockpits. Each of these topics must be considered by designers and may need to be reflected in future regulations. These topics are (1) reduced sensory cues; (2) physical environment of the RPS; (3) control via radio link; (4) control transitions; (5) flight termination; and (6) control of multiple RPA. Where appropriate, examples from a set of RPS design guidelines prepared for

NASA (Hobbs & Lyall, 2016a, 2016b) will be presented to illustrate how each problem might be addressed; elsewhere, unanswered questions will be raised.

Reduced sensory cues

The pilot of an unmanned aircraft has no cockpit window through which to see the world, and lacks the auditory, tactile, and vestibular cues available to pilots of conventional aircraft. The perceptual gulf between pilot and aircraft is illustrated by reports from military RPAS pilots who were unaware their aircraft was being targeted by ground fire until they saw fuel splash on to the camera lens. In other cases, pilots have been slow to recognize that their engine had stopped, or that they were flying upside down (Whitlock, 2014).

There have been proposals to add synthetic cues such as sound or vibration to improve the pilot's awareness of aircraft state (Gawron, Gambold, Scheff & Shively, 2017; Ruff, Draper, Lu, Poole, & Repperger, 2000; Lam, Mulder, & van Passen, 2007). Research has yet to establish the dividing line between sensory cues that are worth replicating, and those that are not. For example, there have been suggestions that the Remote Pilot Station (RPS) should be housed in a full-motion simulator, but this may provide little benefit at great cost. Generations of pilots have been urged to disregard potentially misleading bodily sensations when flying on instruments, and we must ask why artificially re-introducing these sensations would be beneficial.

Imagery from an on-board camera could augment information from sensors, and assist the pilot with tasks such as in-flight troubleshooting, traffic separation, and weather-related decision-making. Imagery could also be critical during take-offs and landings. However, not all current RPA are equipped with cameras, and the available radio spectrum cannot provide sufficient bandwidth for the widespread use of video imagery (International Telecommunications Union, 2010). Future research could determine whether imagery with low bandwidth demands would still be useful to the pilot. Synthetic imagery, such as that shown in Figure 6, may also assist the pilot with situational awareness.

On-board cameras have the potential to create perceptual illusions or distortions that do not occur in conventional aviation. Misleading visual cues may be particularly noticeable during take-off

or landing. For example, unexpected camera movements can create an illusion of a change in aircraft attitude. These issues bring new relevance to old research on the role of binocular and peripheral depth cues in pilot performance (see Roscoe, 1948).

FIGURE 6 ABOUT HERE

Lack of “out the window” view and collision avoidance

The FAA requires pilots to keep a lookout for other aircraft and remain well clear whenever weather conditions permit, even when flying under instrument flight rules (14 CFR 91.113). Detect and Avoid (DAA) systems for RPAS have been a major focus of recent human factors research, including work by NASA to support the development of industry standards for DAA displays (Shively, 2017). Detecting and avoiding other aircraft is generally considered to involve two related concepts: (1) remaining well clear of traffic, and (2) avoiding collisions.

To remain well clear of other aircraft, the remote pilot must maintain an awareness of surrounding traffic and make any necessary separation maneuvers before the intruder aircraft poses an imminent threat. In controlled airspace, the pilot would be expected to coordinate with Air Traffic Control (ATC) before maneuvering. This may not be easy, because verbal communication between the RPAS pilot and ATC could be disrupted by time lags of several seconds when communication is via satellite (Drumm et al., 2004; McCarley & Wickens, 2005). The lack of an “out the window” view may be most problematic in the vicinity of airports, and during surface movements, where there is an expectation that the pilot can visually sight other aircraft.

Displays to assist the pilot to remain well clear can be informative, suggestive, or directive. An informative display provides traffic information but provides no further guidance on how to avoid the threat. A suggestive display provides the pilot with explicit guidance on which trajectories are predicted to lead to a loss of well clear and which are not, leaving the pilot free to formulate a course of action. Directive displays give the pilot a single recommended maneuver to remain well clear, and have been found to produce more rapid pilot response times than informative or suggestive displays. However the performance benefits of directive guidance may not be sufficient to justify the onerous certification process that would be required (Rorie, Fern,

& Shively, 2016). In simulation trials comparing informative and suggestive displays, Rorie et al. (2016) found that suggestive displays reduced the time it took the remote pilot to initiate a maneuver to remain well clear, reduced the size of the maneuver, and resulted in fewer and less severe losses of well clear (see Figure 7). The RTCA standard for Detect and Avoid systems (RTCA, 2017) contains human factors design standards for suggestive DAA displays.

If the RPA fails to remain well clear of traffic, it may be necessary to make a collision avoidance maneuver. The Airborne Collision Avoidance System currently under development for unmanned aircraft (ACAS Xu), will provide a collision avoidance system interoperable with the Traffic Alert and Collision Avoidance System (TCAS) of manned aircraft while also meeting DAA requirements. Given the possibility of link outages, and the need for a rapid pilot response, RPA equipped with airborne collision avoidance systems will probably need to be capable of an autonomous response to a resolution advisory.

FIGURE 7 ABOUT HERE

Threat and error management with reduced sensory cues

RPAS rely on automated systems to a greater extent than most conventional aircraft. In addition to managing the autopilot, the remote pilot may need to manage a range of automated systems performing takeoff, landings, collision avoidance, DAA and lost link maneuvers. Wiener (1988) noted that “... the introduction of automation tunes out small errors and creates the opportunities for large ones” (p. 453). Furthermore, as Endsley (1996) has warned, the operator of an automated system may adopt a more passive role, with a lower level of situational awareness than would be the case with direct manual control. Pilots of conventional aircraft routinely detect and recover from threats and errors that arise during the flight (Helmreich, 2000). High levels of automation combined with a lack of sensory cues can make it especially difficult for the remote pilot to perform threat and error management. This can include maintaining mode awareness, detecting data-entry errors, and responding to unexpected aircraft behavior. For example, a Global Hawk was severely damaged when, after landing, it taxied at high speed and ran off the paved surface. The investigation revealed that, six months before the flight, a data entry error had

resulted in a programmed taxi speed of 155 knots at that location, instead of the normal six knots (Department of Defense, 2000). The remote pilot, lacking the direct sensations of aircraft movement, did not detect the sudden acceleration in time to intervene. The accident report noted that a display that could have alerted the pilot to the incorrect speed setting was difficult to read due to its small font and low contrast gray-on-gray presentation. By isolating the remote pilot from natural sensory cues, we may have inadvertently revealed the extent to which pilots in conventional aircraft currently rely on these cues to detect threats and errors.

Physical environment of the remote pilot station

Remote pilot stations (RPS) increasingly resemble office cubicles or control rooms, overturning many of our assumptions about the cockpit environment. We need to consider not only the human-machine interface (HMI), but also the physical environment of the pilot's workplace, including noise levels, temperature control, lighting, and the implications for coordination of a workspace accessible to colleagues and managers.

Maintaining focus

The pilot stations for large RPA typically house not only pilots, but also technicians, sensor operators, and others. During critical in-flight events, additional personnel will sometimes enter the RPS to offer assistance (Hobbs, 2018). Visits from colleagues, opening and closing doors, telephone calls, and conversations can combine to create a distracting environment (Merlin, 2013). However, the RPS can be particularly un-stimulating during long-duration missions. RPAS operating crews have been found to experience greater levels of fatigue, burnout and boredom than aircrew in traditional cockpits (Cummings, Mastracchio, Thornburg, & Mkrtchyan, 2013; Tvaranas et al., 2006). Designers are faced with the double challenge of producing an RPS that minimizes pilot distraction, while simultaneously maintaining pilot engagement and enabling human interactions. The NASA guidelines contain the following recommendation: "The remote pilot station should provide a work environment that maintains pilot engagement and minimizes the negative impact of extended periods of low workload." (Hobbs & Lyall, 2016b, p. 76)

Maintenance while missions are underway

An irony of maintenance is that although it is essential for the continued reliability of technological systems, maintenance error is also a significant cause of system failure (Reason & Hobbs, 2003). In contrast to the cockpit of a conventional aircraft, the ground-based elements of a RPAS are always accessible to maintenance personnel. For example, an in-flight problem may require troubleshooting of ground equipment, or a restart of a computer in the RPS. A maintenance technician interacting with a “live” system requires a clear understanding of the operational implications of the planned intervention and must consider the potential effects of errors. For example, even a brief interruption to a computer's power supply can have an extended impact if it is followed by a slow reboot sequence.

Because maintenance introduces a risk of human error, the performance of non-urgent preventative maintenance in the RPS while an aircraft is in flight is rarely advisable. Nevertheless, if designers anticipate that some corrective maintenance may be necessary while the RPA is in flight, the RPS should be designed to enable personnel to perform these tasks in close coordination with flight crew. For more on the human factors of RPAS maintenance, see Hobbs & Herwitz, (2009).

Control via radio link

The pilot of a conventional aircraft cannot inadvertently disconnect the cockpit from the rest of their aircraft. The remote pilot, on the other hand, can break the connection between the control station and aircraft by flying outside the reach of the radio link, or by making any of a number of link management errors.

Management of control link

Management of the control link brings a new set of tasks that must be performed by the remote pilot. At present, the pilot, or another member of the crew, typically has an active role in managing the link; manually selecting frequencies, transmission power, and monitoring signal strength. Kaliardos and Lyall (2015) note that these tasks may impose an unacceptable workload on the pilot, and there may be a need for a specialist link manager in the RPS. Possibly the most fundamental display requirement for the crew is an alert that the link has been lost. The NASA

guidelines specify that this should take the form of unambiguous aural and visual signals, and that the aural warning should be a unique sound, not used to signify other conditions (Hobbs & Lyall, 2016b).

The remote flight crew not only needs to be aware of the current status and selected modes of the link but may also need predictive information on the quality of the link at various locations and altitudes. For example, predicted signal quality may be overlaid on a map display (see Figure 8) to produce what is sometimes referred to as a “bug splat” display. Research is needed to determine how best to provide the crew with a three-dimensional picture of link quality, reflecting changes in link performance at different locations and altitudes.

FIGURE 8 ABOUT HERE

Management of lost link procedure

No radio link can be guaranteed to be available 100% of the time. A pre-programmed lost link procedure enables the RPA to continue flight in a predictable manner during link interruptions. The procedure may involve either a simple maneuver such as climbing to re-gain a signal, or a more complex plan, such as flying to a pre-determined position. Rather than being considered an emergency, the activation of the lost link procedure may be seen as a response to a non-normal situation, analogous to a diversion or a go-around in a conventional aircraft.

A lost link event can consist of three stages, as shown in Figure 9. In Stage 1, the link has been interrupted, but the aircraft continues to fly in accordance with the last command received from the pilot. Some link outages last a few milliseconds, whereas others may extend for minutes or even hours. It would be disruptive if the RPA started to fly its lost link procedure each time a brief interruption occurred. Therefore, an on-board timer is needed to activate the lost link procedure after a pre-set interval has elapsed. In the terminal area, the lost link procedure may need to commence after an outage of a few seconds. Elsewhere, the RPA may be able to continue safely along its planned flightpath for an extended period.

FIGURE 9 ABOUT HERE

If the aircraft is programmed to remain in Stage 1 for a significant amount of time, the pilot must remain aware that a link interruption could result in the aircraft continuing to execute the last command it received. For example, a temporary turn towards rising terrain may become irreversible if the link is interrupted before a follow-up command can be sent to the aircraft.

In Stage 2 of a lost link event, the RPA's pre-programmed lost link procedure is activated. Different lost link procedures will be appropriate depending on the location of the aircraft and the stage of flight. The pilot must therefore remain aware of the current lost link procedure, updating it as frequently as every 10 minutes to ensure that it has not become stale, or would not create a hazardous situation if activated (Neville, Blickensderfer, Archer, Kaste, & Luxion, 2012).

In Stage 3 of the lost link sequence, the link is re-established and the aircraft transitions back to pilot control. The pilot must ensure that any control inputs made during the link interruption do not result in sudden changes in aircraft state when the link is re-established. Depending upon the length of the outage, the pilot may need to evaluate whether the original flight plan can be resumed.

Management of the lost link procedure introduces a set of pilot responsibilities that must be supported by new controls and displays. Among the NASA guidelines are provisions to ensure that the pilot can visualize the aircraft's future flight path should a lost link occur, can update the lost link procedure as conditions change, and can (if necessary) pre-select the length of interruption that will trigger the procedure (Hobbs & Lyall, 2016b).

Flight termination

In an emergency, the pilot of a disabled RPA may need to activate a flight termination system such as an engine kill switch or a parachute, or direct the aircraft towards a controlled impact or ditching site, while ensuring the safety of people and property on the ground. The information required by the pilot to make this decision must be readily available when needed. This may include real-time information to confirm that the site is safe for ditching, forced landing, or flight

termination. The events described below occurred south west of San Diego in 2014 and illustrate a case in which the pilot decided to destroy the aircraft to minimize the risk to the public.

The MQ-9 aircraft was en route to the assigned operational area at FL280. An audible alarm sounded followed by indications of a generator failure. The pilot attempted multiple unsuccessful generator resets. The crew analyzed the power supply options and determined that the aircraft lacked sufficient backup battery power to sustain flight for the time required to return to base, which would require a transit across populated areas. The crew proceeded to the Flight Termination Point (FTP) to complete an intentional ditching of the aircraft. While en route to the FTP, the pilot descended the aircraft to get below a marine overcast layer that was at approximately 2,000 feet to ensure the intended FTP was clear. Once it was determined that the ditch area was clear of maritime traffic, the pilot initiated a descent. At approximately 600 feet MSL, the crew lost link with the aircraft. After approximately two minutes, the crew was able to re-establish return link and found that the aircraft was climbing through 2,000 feet MSL on its lost link profile. The crew re-established the command link and positive control. The pilot maneuvered the aircraft back towards the FTP, actuated the condition lever to stop the engine and completed the ditching. The aircraft impacted the water and was destroyed. (NTSB, 2017)

Flight termination systems must have appropriate arming steps and precautions to minimize the risk of inadvertent activation. At least one accident involving the inadvertent activation of a flight termination system has been recorded (United States Department of Defense, 2003). The NASA RPAS guidelines include the provision that “two distinct and dissimilar actions of the RPAS crew should be required to initiate the flight termination command” (Hobbs & Lyall, 2016b, p.42).

FIGURE 10 ABOUT HERE

There appear to have been no studies of pilot decision-making in flight termination scenarios. Research could help to clarify when risk considerations call for the aircraft to be destroyed and the information needed to ensure that a controlled impact or ditching can be accomplished safely.

Transitions: handovers, pilot control transfers, and link switches

Crew changes and shift handovers are a significant area of risk in many industrial, medical and transport settings (Parke & Kanki, 2008). Although the in-flight transfer of control between pilots is an everyday aspect of conventional aviation, RPAS present unique challenges. The International Civil Aviation Organization (ICAO) distinguishes between three types of RPAS

transitions: (1) handovers between pilot stations, (2) transfers of control between pilots, and (3) link switches, in which the control link transitions from one radio system or frequency to another (ICAO, 2018). In some cases, a transition will involve all three types, for example when control of the aircraft is transitioned from a RPS linked to the aircraft via a ground-based antenna, to crew in a distant RPS operating via satellite.

As the endurance of unmanned aircraft increases from hours to months, control transitions will become increasingly critical (Tvaryanas, 2006). Aircraft operating as high altitude platforms (HAPs) may remain aloft for months at a time, requiring numerous crew transfers per flight. Although long-duration missions do not necessarily increase the probability of error associated with each transition, they increase the number of potential transitions per flight, and therefore the exposure to risk.

The limited perceptual cues available to RPAS pilots mean that the communication of situational information during control transitions is critical. The NASA guidelines give particular attention to how RPS can be designed to facilitate coordination during handovers. For example, the RPS must enable the pilots to confirm that flight-critical settings in the receiving RPS are consistent with settings in the giving RPS (Hobbs & Lyall, 2016b). As the handover progresses, the receiving RPS must clearly and unambiguously inform the pilot when an active command link has been established with the RPA.

Control of multiple RPA

An irony of “unmanned” aviation is that even small RPA typically require a team of pilots, sensor operators, and support personnel. Many RPAS users, particularly in the military, envision a future in which a single pilot will be able to supervise multiple vehicles. Yet before this can occur, the pilot-to-vehicle ratio must be brought down to 1:1. Icon-based display concepts, such as that developed by Friedrich (2018), could enable a pilot to rapidly recognize non-normal conditions in a group of homogenous aircraft (see Figure 11). However, simulation studies suggest that controlling two aircraft is significantly more challenging than controlling just one (Dixon, Wickens, & Chang, 2005; Ruff, Narayanan, & Draper, 2002).

Even if automation relieves the pilot of some control tasks, the communication demands of dealing with ATC, sensor operators and other personnel may emerge as the limiting factor (Gawron, Gambold & Shively, 2017). Ultimately, the feasibility of a single pilot controlling multiple aircraft may depend on the workload and the cost of failure. If the loss of the vehicle is deemed unacceptable, or if an accident could result in loss of life or property on the ground, the control of multiple aircraft may be difficult to justify.

FIGURE 11 ABOUT HERE

CONCLUSION

After 100 years of gradual development, unmanned aviation is entering a period of rapid expansion. The current unmanned aircraft sector can be compared with the automobile industry of 100 years ago, characterized by a large range of manufacturers, a lack of design standards and supporting regulations, and a high accident rate. Despite being referred to as “unmanned,” some of the major challenges confronting RPAS relate to human factors. Ironically, the removal of the human pilot from the aircraft may simultaneously increase the probability of accidents, while reducing their consequences.

Some of the challenges of RPAS operations (such as reduced perceptual cues, and link management) also apply to other teleoperated systems, including unmanned ground vehicles, remotely operated mining equipment, and undersea exploration vehicles. However, unlike remotely operated equipment on the land or under the sea, when teleoperated systems take to the air, their mishaps have greater potential to affect community safety, and will inevitably attract greater public scrutiny. With the pilot safely out of harm's way, the risks associated with unmanned aviation are borne largely by non-involved individuals: occupants of conventional aircraft, people under the flight path of the aircraft, and owners of property that might be damaged in the event of an accident. The public tends to have a lower acceptance of risk when technologies are new, are not well understood, and where the targets of a hazard have little control over their level of exposure (Slovic, 2000). For these reasons, there may be less community tolerance of mishaps involving unmanned aircraft than there would be for similar events involving aircraft with on-board pilots.

For many years, the human factors community focused on human error and the negative impact of human performance limitations. There is now a growing realization that human capabilities make a unique and positive contribution to system safety. Operational experience is suggesting that teleoperation can interfere with the ability of the remote pilot to remain aware of the state of the aircraft and its environment. The designers of RPS must not only avoid error-provoking interfaces, but must also strive to produce interfaces that take advantage of the positive human contribution by enabling the pilot to manage threats and errors as they arise.

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Figure 1. The diversity of unmanned aircraft. From left to right: The 14,600kg Global Hawk (Image courtesy Northrop Grumman); the 20 kg RnR APV3 (NASA image); and the 9.5 kg DJI Matrice M600 hexacopter (Image courtesy Werner von Stein, SF Droneschool).

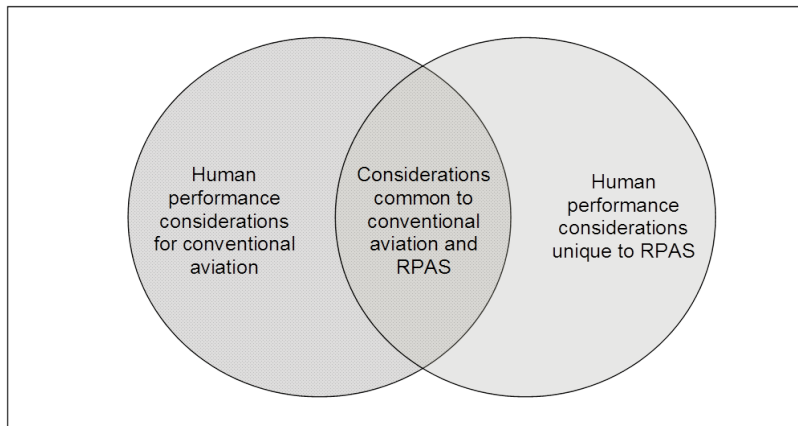


Figure 2. This chapter focuses on human performance considerations unique to RPAS.



Figure 3. A general view of the MQ-9 pilot station, and a close view of the throttle controls. The dual-mode condition lever is second from the left (NTSB images).



Figure 4. Remote Pilot Stations (RPS) range from commercial off-the-shelf laptops, to purpose-built facilities. Shown here is the RPS for the 7 kg MLB Bat, with car-top launcher visible in background (NASA image); and the control room for NASA's Global Hawk Unmanned Aircraft at NASA Armstrong Flight Research Center. (NASA photo: Tony Landis.)



Figure 5. The Piccolo Remote Pilot Station for civilian RPAS. (Image courtesy of Collins Aerospace)



Figure 6. Concept demonstration of a synthetic display to assist the pilot with situational awareness. (Image courtesy of Mosaic ATM).



Figure 7. Air Force Research Laboratory's Vigilant Spirit Pilot Station, integrated with Detect and Avoid (DAA) alerting and suggestive guidance. (NASA Ames).

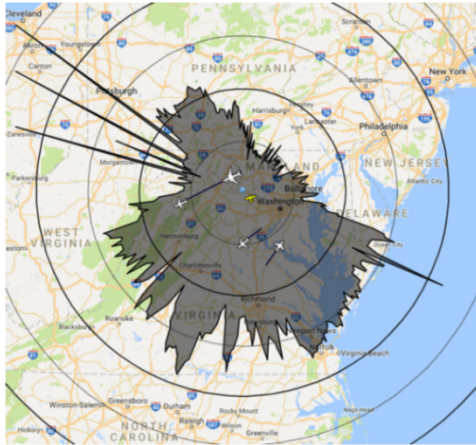


Figure 8. A plot showing the predicted strength of a control signal at various distances and directions from a ground transmitter (Image courtesy of uAvionix Corporation).

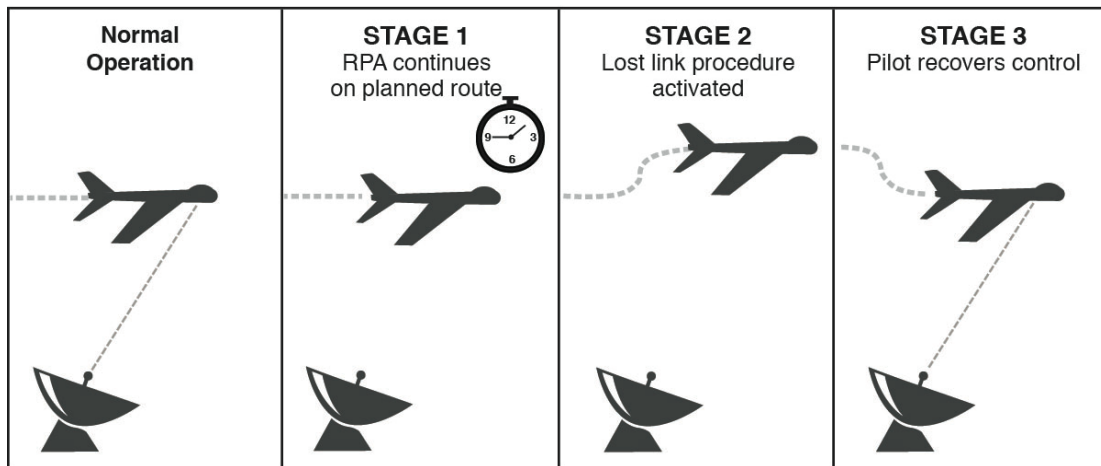


Figure 9. Stages of a lost link event.



Figure 10. Flight termination controls for a remotely piloted aircraft.

U-Fly DLR	UAS-1	UAS-2	UAS-3	UAS-4
Control				
				
				
				
				
				
Systems				
				
				
				
				
				
				
				
Protection				
				
				
				

Figure 11. A display concept for the control of multiple unmanned aircraft. (Image credit: Friedrich, 2018)