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International Symposium on Aviation Psychology - 2009

International Symposium on Aviation Psychology

2009

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HUMAN FACTORS IN THE GROUND-SUPPORT OF SMALL UNMANNED AIRCRAFT SYSTEMS

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A growing body of research has been directed at the human factors of Unmanned Aircraft System (UAS) flight operations, yet up to now, virtually no attention has been given to the human factors of UAS maintenance. The aim of the current research program was to identify the challenges facing the maintainers of small unmanned aircraft systems. Unlike their counterparts in conventional aviation, UAS maintenance technicians are responsible for the functioning of an entire system, comprising airborne and ground-based components. Challenges include absent or poor maintenance documentation, the need to make frequent decisions about salvaging components, difficulties in troubleshooting software problems, the maintenance of radio control model aircraft components, and the potential unfamiliarity of UAS maintenance personnel with the culture and practices of the aviation industry. A "dirty dozen" list of UAS human factors is proposed.

Unmanned aircraft range from small inexpensive, hand-launched micro air vehicles such as micro-electric helicopters to large, high-altitude-long-endurance vehicles such as the Global Hawk. In between these extremes are a vast array of vehicles and systems. As well as military applications, unmanned aircraft systems (UAS) have many potential non-military uses, including law enforcement, firefighting, traffic monitoring, aerial photography, agriculture, search and rescue, border surveillance, wildlife monitoring, power-line inspection, minerals exploration and homeland security activities. At present, concerns about collision avoidance are holding back the operation of unmanned aircraft in civilian airspace (Flight Safety Foundation, 2005). Assuming that this issue can be resolved, small, inexpensive unmanned aircraft may become a common sight.

The most rapid growth in the emerging civil UAS sector may occur with small systems, defined here as those in which the aircraft weighs less than 100 lbs. Technological developments, such as miniaturization of sensor equipment and autopilot systems, and developments in battery technology, are allowing small unmanned aircraft to perform tasks that would have previously required large, expensive aircraft. Large unmanned systems are generally maintained by specialist maintenance technicians. However, small commercial UAS are frequently operated by generalist teams of multi-skilled individuals who perform all ground tasks including assembly, flight preparation, in-flight operation, and maintenance. Throughout this paper, the terms "maintenance personnel" or "maintainer" are used to refer to anyone who maintains a UAS, even though the individual also may perform other roles as a member of the UAS operating team.

The nascent UAS industry has an accident rate significantly greater than that of conventional aviation (Williams, 2004) and human factors are emerging as major challenges to be resolved (McCarley & Wickens, 2005; Cooke, Pringle, Pedersen & Connor, 2006). If unmanned aircraft are to be permitted to share civilian airspace with conventional aircraft, it will be necessary to understand the human factors associated with these vehicles. Rather than eliminating the potential for human error, the removal of the on-board pilot may transfer some of the risk of human error to personnel on the ground, including maintenance technicians. Furthermore, tele-operated transport systems such as unmanned aircraft may be especially vulnerable to maintenance error due to the absence of an on-site operator able to respond rapidly to an anomalous situation.

A large amount of information has been published on human factors of airline maintenance, much of it based on FAA-sponsored research (Johnson, 2006). Issues such as stress, distraction, and poor access for maintainability are now widely identified as hazards in conventional aircraft maintenance. While recognizing that these issues also apply to UAS maintenance, this research was focused on issues that uniquely affect UAS maintenance.

The research approach

The objective of the research program described in this paper was to identify the human challenges in maintaining small UAS. For the current purposes maintenance was defined as any activity performed on the ground before or after flight to ensure the successful and safe operation of the system. This definition covers a wide range of ground-support activities including assembly, fuelling, updates to software, and pre-flight testing. As this was an area that had not been examined previously, the research involved the gathering of qualitative information that would enable broad issues to be identified. Three approaches were used to gather data. First, a series of site visits were made to UAS maintenance or manufacturing facilities, and UAS flight operations were observed. Second, structured interviews were conducted with UAS maintenance personnel. These interviews focused on the qualifications and skills of maintenance personnel and the challenges they face in the course of their work. Details of this stage of data collection can be found at Hobbs and Herwitz (2006) and Herwitz and Hobbs (2006). In a second round of interviews, questions focused on the specific tasks performed on UAS components, including ground systems such as computers. A summary of the results can be found in Hobbs and Herwitz, (2009). The sections below outline some of the key differences between the job of UAS maintainer and that of a conventional aircraft mechanic.

Emerging human factors in UAS maintenance

The task of maintaining an unmanned aircraft system. A significant difference between UAS maintenance and conventional aircraft maintenance is that the UAS maintainer is responsible for a complete system, comprising the aircraft, a diverse set of ground-based equipment, and the links between these elements, (see Figure 1). While the aircraft may be the most obvious element of the system, the ground based elements also require attention and maintenance.

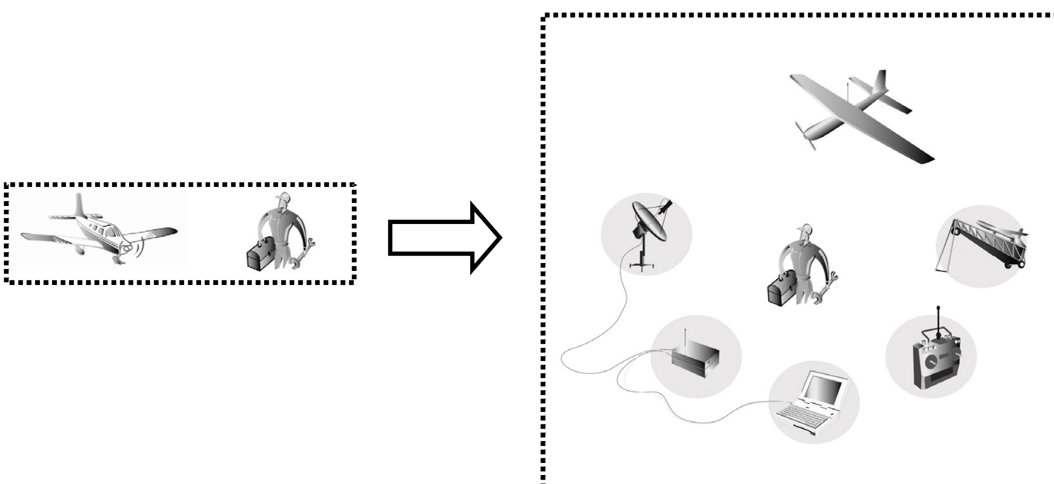

Figure 1. In conventional aviation, the aircraft maintenance technician is responsible for the airworthiness of an aircraft, whereas the UAS maintenance technician is responsible for a system comprised of diverse elements, including the aircraft, radio transmission equipment, modems, computers, and in some cases, handheld controllers and launch/recovery equipment.

Key differences between a UAS and a conventional aircraft are:

- Commercial "off the shelf" desktop or laptop computers are likely to be part of flight system.
- System elements frequently assembled and disassembled between flights.
- Modular construction facilitates repair by replacement and shipping of components to specialist repair facilities.
- Unmanned flight is not possible without functioning avionics and/or communication equipment.
- Some UAS components were originally intended for radio control model aircraft, and have limited reliability data.
- Payload is more likely to interfere with operation of aircraft, e.g., through electromagnetic interference.

Shift of risk. The introduction of unmanned aviation shifts the balance of risk in ways that must be understood by maintenance personnel. In conventional aviation, the safety risks associated with flight are in large part borne by the people who receive the benefit of flight, i.e., flight crew and passengers. Sometimes referred to as "shared fate," a threat to the safety of a conventional aircraft is also a threat to the occupants of the aircraft.

In unmanned aviation, the beneficiaries of the flight remain on the ground, and the safety risks are borne largely by non-involved individuals -- occupants of conventional aircraft, people under the flight path of the aircraft, and property owners. With no on-board lives at risk, the maintenance person is not necessarily conducting maintenance for the safety of specific identifiable individuals, but for the safety of the community as a whole. The public tends to demand especially high safety standards for technologies that are new, are not well understood, and where exposure to risk is involuntary (Slovic, 2000). For these reasons, there may be a low public tolerance of incidents involving unmanned aircraft, even when the consequences are limited to property damage.

Diverse skill and knowledge requirements. The UAS maintainer, whether a specialist or generalist, requires a skill set beyond the traditional skill and knowledge requirements of aviation airframe and powerplant mechanics. In addition to the maintenance of an engine and airframe, a UAS technician can be expected to interact with computer systems, micro autopilots, radio communication equipment, modems, and, in some cases, satellite phones. Ensuring the data link between the ground control station and the aircraft takes on a level of criticality not present in conventional aviation because the loss of communication is more likely to result in the loss of the aircraft.

Lack of direct feedback on aircraft performance. In conventional aviation, the on-board pilot has a direct experience of aircraft performance via the handling qualities of the aircraft, as well as sounds, vibrations, and even smells. With no on-board pilot, UAS maintenance personnel lack a key source of information about aircraft performance. To some extent, automated in-flight monitoring provides an alternative source of detailed information. However automated monitoring systems can at times provide an overwhelming volume of precise data with relatively little consolidated information.

Maintenance and fault diagnosis of IT systems. For most small UAS, the "cockpit on the ground" is a standard laptop or desktop computer exposed to the hazards of outdoor operations such as moisture, dust and temperature extremes. Computer system administration tasks now take on flight safety importance because system failures, such as screen lockups or software slowdowns that would be minor irritations in an office environment, can present significant hazards if they occur during a flight (Hobbs & Herwitz, 2008).

Fault diagnosis in software-based systems can be significantly more difficult than with electromechanical systems. Mysterious, ill-defined faults such as computer slowdowns, screen freezes, or radio frequency interference are sometimes resolved without the UAS technician understanding why the fault occurred, and whether their actions corrected the underlying problem or merely removed the symptoms. System re-boots are common responses to computer problems as illustrated in the following incident report (Hobbs & Herwitz, 2008).

> "The desktop computer, which was serving as the ground control system, locked up while the unmanned aircraft was in flight. The PC-based computer was housed in the ground control station trailer. The only alternative was to re-boot the computer, and this took about two to three minutes before command-and-control was reestablished. The unmanned aircraft's flight path, however, was already uploaded so there was no effect on the flight sequence."

Model aircraft culture. The personnel who maintain small UAS tend to have a background in radio-controlled model aircraft or engineering, and relatively few have experience in commercial aviation maintenance. These personnel may possess attitudes to risk that are significantly different to those held by qualified aircraft maintenance technicians. For example, they may be accustomed to operating without formal procedures or checklists, and may be unfamiliar with the ethics and standard practices of aircraft maintenance.

Task performance in the absence of documentation. Document design has been identified as a critical performance shaping factor in conventional aviation maintenance (Drury, Sarac, & Driscoll, 1997). Small UA generally have rudimentary flight manuals, however many are delivered without maintenance documentation. Users generally develop their own maintenance checklists and procedures to guide routine tasks such as system assembly, and scheduled pre-flight checks. However, for troubleshooting and corrective maintenance, maintainers may have no choice but to rely on "knowledge in the head" or "trial and error".

Salvage decisions. Compared to conventional aircraft, small unmanned aircraft are more likely to experience damage caused by events such as hard landings, contact with water, or landing in trees. Unmanned aircraft also tend to be less waterproof than conventional aircraft leading to a greater chance of water damage to internal components. To a greater extent than in conventional aviation, UAS maintenance personnel will be required to make judgments about the salvage, testing and re-use of components from damaged UA. In the case of modular aircraft designs, an apparently undamaged modular unit may have an unseen defect.

Repetitive assembly and handling. In contrast to conventional aircraft, most small unmanned systems are designed to be reassembled and disassembled before and after each flight, necessitating the frequent connection and disconnection of electrical, fuel and data systems. The probability of an error during a single connection task may be relatively low, in the order of 0.001 (Kirwan, 1994). However UAS maintenance personnel are exposed to this risk on a regular basis, and consequently the chance of an assembly error or maintenance-induced damage may become significant over the course of months or years. The following example illustrates an assembly error involving a small hand-launched unmanned aircraft:

> "After departure the unmanned aircraft performed unusually slow rates of turn to the right and tight turns to the left and struggled to track as designated by the operator. Approximately seven minutes into the flight, the outboard section of the right wing separated from the centre wing section. The aircraft immediately entered a rapid clockwise spiral before impacting the ground. The most likely explanation for the crash was that the outboard section of the right wing was incorrectly attached during pre-flight assembly and from launch it flew with difficulty until the wing section eventually separated." (Hobbs & Herwitz, 2008).

Risk associated with maintenance or disturbance of ground equipment while missions are underway. The cockpit of a conventional aircraft is beyond the reach of maintenance personnel once the aircraft is in flight. In contrast, the ground station of a UAS is always accessible to maintenance personnel on the ground. They may be required to perform corrective maintenance while a flight is underway, or may carry out other actions that could potentially impact system performance. For example, an in-flight problem may require troubleshooting of ground equipment, the checking of cables, or a re-start of the ground control computer. A maintenance technician interacting with a live system requires a clear understanding of the operational implications of the planned intervention. The technician must also consider the potential effects of errors, whether mistakes such as misdiagnosing a fault, or simple slips such as tripping over a cable. Even a brief interruption to a computer's power supply can have an extended impact if it leads to a slow re-boot sequence.

Conclusion

Technological developments have increased the capabilities of unmanned aircraft systems to the point where they can now potentially serve a large range of non-military purposes. Despite the absence of an on-board pilot, human factors are emerging as key issues in this sector. As automation decreases the role of humans as direct physical controllers of unmanned aircraft, it is possible that maintenance and other ground-support activities will become increasingly important.

The maintenance of unmanned aircraft systems introduces a new set of human factors in addition to those that apply in conventional aviation maintenance. The “Dirty Dozen” list has been widely used to educate airline maintenance technicians about human factors (Dupont, 1997). Table 1 contains a proposed “UAS Dirty Dozen” intended to raise awareness of the emerging maintenance human factors in small UAS operations. Each of the 12 issues is illustrated with an example of a dangerous attitude or situation. This list will be updated as more is learned about this topic.

Table 1: ***A “Dirty Dozen” for small UAS maintenance.***

Issue	*Example*
1. Mysterious software faults	*I don’t know why the software did that. I’ll just re-boot it. I’ll just swap the card.*
2. Lack of checklists for routine tasks	*I don’t need a checklist, I do this procedure all the time.*
3. Assembly and handling	*I’ve assembled this system hundreds of times.*
4. Laptop maintenance	*Need to check your email? Use the ground control laptop.*
5. Awareness of risk to public	*No-one’s life is at stake here.*
6. Salvage decisions	*We can re-use that component, it doesn’t look damaged.*
7. Payload interference with aircraft	*This is just a small change to the payload*
8. End-to-end connectivity	*All the individual components are working, I guess it will work when we connect it all up.*
9. Disclosure and sharing of information	*I don’t want my competitors to know about this problem. I don’t want the FAA to find out.*
10. Trial and error repair and troubleshooting	*Not sure how this goes back, but that looks right.*
11. Frequency management	*No one else seems to be using this frequency.*
12. Disturbance of ground equipment during flight	*Let’s move the ground control computer into the shade.*

Confidential reporting systems such as NASA’s Aviation Safety Reporting System (ASRS) have been valuable sources of human factors information in conventional aviation. The emerging UAS industry, where safety issues are least understood, lacks a confidential incident reporting system. Any future UAS reporting system must include maintenance personnel. In the course of discussions with UAS operators, it became apparent that concerns about commercial confidentiality and FAA enforcement action are currently suppressing the open disclosure of incidents, which in turn may make it difficult for the UAS industry to learn from experience.

Acknowledgements

This research was funded by the FAA under inter-agency agreement DTFA01-01-X-02045 between the Federal Aviation Administration (FAA) Human Factors Research and Engineering Division and the National Aeronautics and Space Administration (NASA) Aeronautical Safety and Human Factors. We would like to thank the many UAS operators and maintainers who agreed to be interviewed. We also acknowledge the assistance provided by Maj. Keirin Joyce of the Australian Defence Force.

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