Human Factor Challenges of Remotely Piloted Aircraft

Alan Hobbs[1] and R. Jay Shively[2]

[1]San Jose State University/NASA Ames Research Center, Moffett Field, USA

[2]NASA Ames Research Center, Moffett Field, USA

Abstract. The control stations of many unmanned systems have been characterized by less-than-adequate human-system interfaces. Some of the interface problems may have been prevented had an existing regulation or cockpit design principle been applied. In other cases, the design problems may indicate a lack of suitable guidance material.

The human factors of unmanned operations will be reviewed, and a NASA program to develop human-factor guidelines for control stations will be described. To be effective, guidelines must be relevant to a wide range of systems, must not be overly prescriptive, and must not impose premature standardization on evolving technologies. Several types of guidelines are described. These relate to required capabilities, information requirements, properties of the human machine interface, and general cognitive engineering principles.

Keywords: Unmanned, remotely piloted, human factor, guidelines.

Introduction

The civilian use of remotely piloted, or “unmanned” aircraft is likely to increase rapidly in the years ahead. Despite being referred to as “unmanned” some of the major challenges confronting this emerging sector relate to human factors. As unmanned aircraft systems (UAS) are introduced into civil airspace, a failure to adequately consider human factors could result in preventable accidents that may not only result in loss of life, but may also undermine public confidence in remotely piloted operations.

Many of the human factors principles for cockpit design, particularly in the first half of the 20th century, were identified through the investigation of accidents and incidents – an approach sometimes referred to as “tombstone safety”. Community expectations of safety and reliability have increased markedly since the early years of aviation, and it is no longer considered acceptable to field an immature system, and then rely on subsequent accidents and incidents to identify design deficiencies. For this reason, it is crucial that human factors design principles for UAS be identified as early as possible.

Ground control stations (GCS) of unmanned aircraft systems (UAS) range from commercial off-the-shelf laptops, to sophisticated purpose-built interfaces housed in shelter trailers or control facilities (see figure 1). Although some GCS possess aviation interfaces (such as sidestick controllers), most also include interfaces based on consumer electronic devices such as screen-based displays, pull-down menus, and “point-and-click” input devices (Scheff, 2012; Waraich, Mazzuchi, Sarkani & Rico, 2013). Widespread problems have been identified with control station interfaces, including error-provoking control placement, nonintuitive automation interfaces, an over-reliance on text displays, and complicated sequences of menu selection to perform minor or routine tasks (Cooke, Pringle, Pedersen & Connor, 2006). In some cases, the interface problem may have been prevented had an existing

Figure 1. Ground control station for the 7 kg MLB Bat (left), and the 14600 kg Global Hawk.

regulation or cockpit design principle been applied. In other cases, the design problems reflect emerging issues that are not covered by existing regulatory or advisory material.

As UAS are introduced to non-segregated airspace, a failure to adequately consider the human factors of unmanned aviation could result in easily preventable accidents that may undermine public confidence in this emerging sector. Critical human issues include the necessary crew qualifications to operate a UAS in non-segregated airspace, operational requirements, flight procedures, and safety management systems. This paper is focused on the design of the GCS. Some aspects of unmanned aviation with implications for its design include the following:

Reduced sensory cues – The rich sensory cues available to the pilot of a conventional aircraft include visual, auditory, proprioceptive and olfactory sensations. The absence of these cues in a UAS makes it more difficult for the pilot to maintain an awareness of the aircraft's state (Williams, 2008). Video imagery has been proposed as a partial solution, however video downlinks can impose significant bandwidth requirements (International Telecommunications Union, 2010) making them impractical in some situations.

Handovers between control stations – Control of an unmanned aircraft may be handed over in-flight between pilots at the same control station console, between consoles at the same control station, or between physically separated control stations (Williams, 2006). The control station and procedures must be designed to facilitate the required handovers. Where the unmanned aircraft is designed to remain aloft for an extended period, multiple crew handovers may occur during the course of a single flight (Tvaryanas, 2006).

Air traffic management issues - NASA simulations are examining the interactions between UAS pilots and Air Traffic Control (ATC). This work has examined the ability of the UAS pilot to comply with ATC instructions in an efficient and timely manner (Fern, Shively & Johnson, 2012) and the impact of UAS non-normal situations on ATC operations (Fern, Rorie & Shively, 2012). Simulations are also examining display and information requirements to enable UAS pilots to detect and avoid other aircraft in the absence of an "out the window" view (Fern, 2012). The results of the NASA simulation studies will inform the development of GCS guidelines.

Latencies – Control links may introduce a delay between pilot input, response execution, and display of the response. These delays, ranging from hundreds of milliseconds to several seconds, will be most problematic when a system is under direct manual control, and less so when a system is under the control of automation (Mouloua, Gilson, Daskarolis-Kring, Kring & Hancock, 2001). Delays in voice communication may also occur in some circumstances. Latencies of around 750 milliseconds have been shown to disrupt ATC/pilot communications (Sollenberger, McAnulty & Kerns, 2003).

Flight termination considerations – In an emergency, the pilot of an unmanned aircraft may be required to destroy the aircraft by a controlled impact, ditching, or other flight termination method. Although no lives are at stake on board the aircraft, the pilot is still responsible for the protection of life and property on the ground. The information pilots will require to make this difficult decision and execute the action is yet to be determined. The risk of inadvertent activation of the flight termination system must also be considered (Hobbs, 2010).

Management of the data link and the potential for loss of link – The UAS communication and control link can be broken down into four basic elements. (1) The telecommand or uplink, (2) The telemetry or downlink, (3) Communication links, and (4) Payload links. Links may utilize terrestrial radio or satellite communications. As well as flying the aircraft, the pilot must also "fly the link". This requires the pilot to maintain an awareness of the strength of the control link, link latencies, factors that may eliminate or reduce the strength of the link, and manage situations in which the link is lost. No control link can be guaranteed to be 100% reliable, and systems must be designed to tolerate contingencies in which the pilot may be out of the control loop due to an abnormal or undesired event, such as a loss of control link.

Workload management – A challenge for the designer of the ground control station is to maintain pilot engagement during extended periods of low workload, particularly when the pilot's role is to perform supervisory control of automation (Cummings, Mastracchio, Thornburg, Mkrtchyan, 2013). In addition, the pilot must be prepared for the possibility that workload may increase rapidly.

Guidelines for the ground control station

The National Aeronautics and Space Administration (NASA) has recognised that human factors guidelines for the GCS will be a key requirement for safe and reliable operation of civilian UAS. The agency is working with key stakeholders to develop recommendations for GCS human factor guidelines with a focus on unmanned aircraft operating beyond visual line-of-sight. The focus will be the control station, and its immediate environment. Where appropriate, issues such as maintenance or ground support will also be considered. Personnel training, crew qualifications, procedure design and physical security of the GCS are critical issues deserving of specific attention, but are outside the scope of this work, except as they relate to the design of the human-machine interface (HMI) or the work environment.

In compiling guidelines for the GCS for UAS operating in civilian airspace, NASA is building upon the existing material on GCS human factors (Berson, Gershzohn, Wolf, Schultz, 2005, ICAO, 2011, Office of the Under Secretary of Defense, 2012; NATO, 2004, 2007, 2009) and human factors material with relevance to HMI design from FAA, EASA, and industry human factor standards.

In contrast to regulations, guidelines are not mandatory requirements, however, by encapsulating solutions to identified problems or areas of risk, guidelines can assist system developers, particularly those lacking extensive experience in aerospace. User communities benefit from greater standardization, improved reliability and safety due to a reduction in design-induced errors, and may use guidelines to evaluate systems prior to acquisition. Lastly, regulatory agencies may draw on guidelines when developing regulations or advisory material. Regardless of the area of technology in question or the form of the guideline, useful guidelines possess the following characteristics:

- Evidence-based. Guidelines should be linked to areas of need identified from operational experience, simulations or analysis.
- Organized. Guidelines should be organized hierarchically, with general statements preceding specific statements.
- Not overly prescriptive. Overly prescriptive statements should be avoided as they may constrain innovation. In the case of immature or evolving technologies, guidelines must be developed with the awareness that prematurely developed guidelines may not reflect the characteristics of the technology once it matures.
- Applicable to diverse systems. Guidelines must be compatible with a wide range of technological solutions and capabilities. Some guidelines will have general applicability across platforms and capabilities, while others will address issues unique to particular technologies.
- Consistent. As well as being internally consistent, guidelines should not conflict with regulations and other mandatory requirements.
- Achievable. Achieving the intent of the guideline should be within current technical capabilities.
- Assessable. It should be possible to evaluate whether the intent of a particular guideline has been met.

Several types of human factor guidelines can be identified. These include statements of capabilities, statements of information requirements, and properties of the human machine interface, broad cognitive engineering principles, and human factors engineering processes. These are described below.

<u>Statements of capabilities</u> - Certain guidelines take the form of statements of desired capabilities, such as descriptions of tasks that the pilot is expected to be able to perform via the interface. Examples include voice communication with ATC, and the ability to direct the aircraft on to a magnetic heading when instructed by ATC. In general, capability statements will not define how the task will be performed, although a desired level of accuracy or speed may be specified. Some functions that must be performed by a human will have universal relevance to all UAS operations in civil airspace, for example, voice communication with Air Traffic Control. In other cases, the need for a specific human task demand will depend on system design choices, and whether a function is assigned to a machine or to a human.

<u>Information statements</u> - These guidelines deal with the information that the interface is expected to provide to the pilot, or inputs that the human is expected to make to the system via controls. These guidelines will typically be expressed in general terms, leaving the HMI designer free to create an interface that meets the intent of the guideline. For example it may be stated that the pilot should receive an alert if communication with the air vehicle is lost, without defining the form that this alert should take.

Properties of the human-machine interface (HMI) - The properties of an interface can be specified at either a physical level (its physical form or appearance) or at a functional level (how it should work). Physical properties include layout, shape, visibility, color, hard vs soft controls or displays, and menu structure. Functional properties may include features to prevent, detect and recover from predictable pilot errors, prioritization and context sensitivity of information, minimization of clutter & nuisance alerts.

General cognitive engineering principles - At the broadest level are statements of design philosophy that are agnostic with respect to the form of the interface. Some broad principles relate to the overall functioning of the GCS, in particular properties or characteristics that emerge from the operation of all sub-systems together. Examples are the general design principles for human-system interfaces proposed by Norman (1988) and Shneiderman and Plaisant (2005). These deal with issues such as the internal consistency of the interface, the need for feedback on control inputs, and features to prevent, detect and recover from anticipated operator errors. Endsley and Jones (2012) propose a set of 50 design principles intended to maximize situational awareness. Draft NATO guidelines on UAS human machine interface refer to the need to consider cognitive engineering issues including feedback, mental workload, consistency, minimization of memory load, consistency, and accommodation of individual differences (NATO, 2007).

Recommended human factors engineering processes - In addition to design guidelines that relate to the characteristics of the HMI, it is also useful to specify guidelines that relate to the processes used to develop the HMI. Human factors engineering processes occur during the design and development phase of a technological system to ensure that it will operate safely and effectively, and will be consistent with the capabilities and limitations of the human operator (O'Hara, Higgins, Persensky, Lewis & Bongarra, 2004). Process-related guidelines are critical because even the most comprehensive design guidelines cannot capture every potential HMI issue. Process-related guidelines have the potential to uncover and address previously unrecognized issues during the development phase of the HMI. Human engineering processes include the use of mock-ups and simulations, task analysis, and human failure modes and effects analysis (HFMEA).

The guidelines development process

The development of human factors guidelines begins by defining the role of the human in the system. A description of the roles and responsibilities of the human can then enable areas where guidelines are needed to be identified. Existing guidelines or standards can then be identified and adapted, and new guidelines can be created where necessary.

The first step in the guidelines development process is the identification of key tasks and functions assigned to the pilot. The uncertainties of functional allocation between the human and the machine can present a potential problem at this stage, however this uncertainty is greatly reduced once some basic assumptions are made concerning the role of the human in the system. The FAA (2013) roadmap for the integration of UAS contains a set of 14 assumptions concerning the operation beyond visual line-of-sight of UAS. Despite the diversity of unmanned systems, varying levels of automation, and different operating environments, the FAA assumptions imply a minimum set of generic pilot tasks and functions that will be applicable regardless of the characteristics or capabilities of the specific UAS.
Among the fundamental assumptions are the following:

a) Each UAS will have a pilot in command,
b) Flight will be in compliance with existing rules and procedures,
c) Operations will not be autonomous under normal conditions,
d) The pilot will have the ability to assume control at all times during normal operations.

Working with members of the human factors team of RTCA SC-203 a generic list of UAS pilot tasks based on existing descriptions of tasks for UAS and manned aircraft was developed. The task list is being supplemented with information from NASA's UAS simulation work, a NASA-sponsored review of UAS pilot information requirements, UAS accident and incident reports, human factors literature, and input from UAS pilots.

A pilot-centred model of the UAS can be used to organize and present the set of pilot tasks. The model presented in Figure 2 shows the pilot as a central element of the UAS, interacting with other system elements via the GCS. The nature of the interactions will change according to several conditions, including the stage of flight, airspace involved, level of automation involved, and the presence of contingencies such as lost link. At a fundamental level, pilot interactions involve the receipt of information from displays, pilot information processing and control inputs made via the GCS. Additionally, the pilot communicates with air traffic control, other airspace users, the support segment, and ancillary services such as weather briefers.

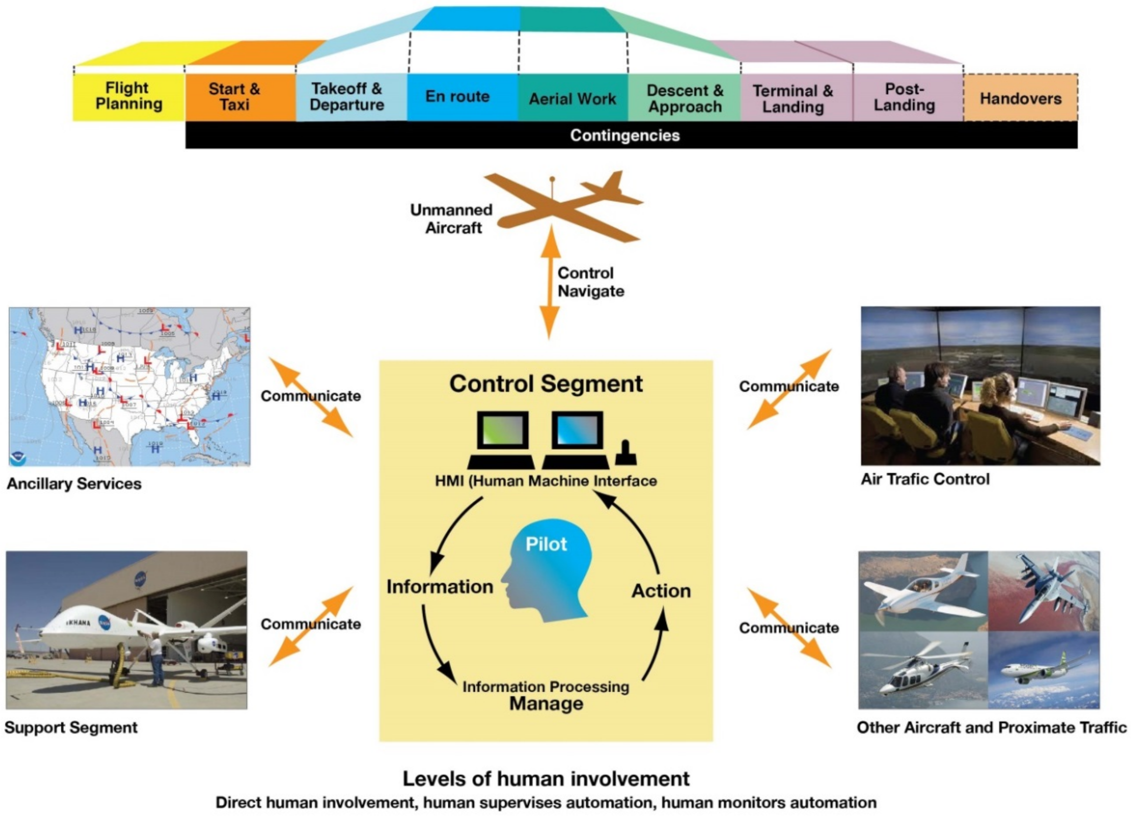

Figure 2. Proposed pilot-centred model of a UAS

Figure 3 presents a system-level breakdown of UAS pilot tasks. This model provides an overview of the role of the pilot and can act as a checklist to ensure that all areas of human-system interaction are considered when developing guidelines for the human interface. The "Manage" category includes the overall planning, decision-making, and management functions that must be accomplished by the pilot, supported by the human-machine interface. For ease of presentation, these tasks are shown as separate in figure 3, although they overlap and cut-across other tasks.

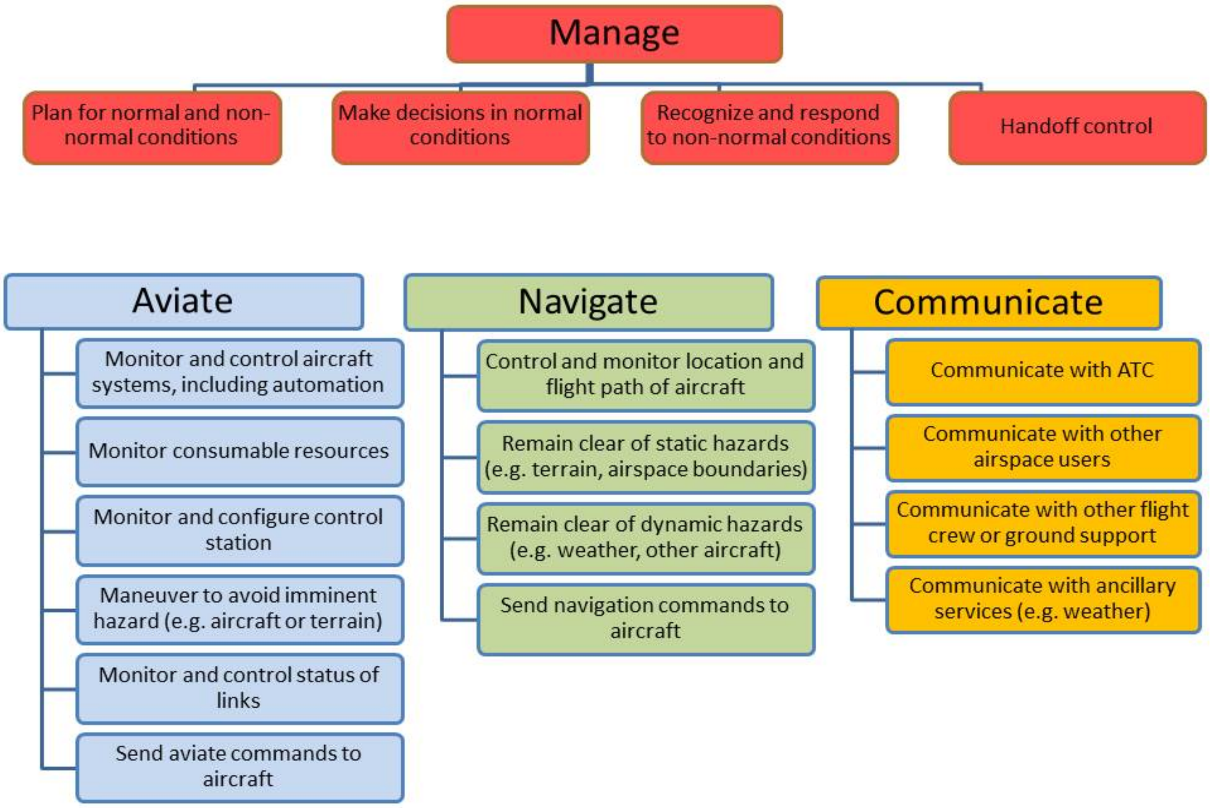

Figure 3. A model of UAS pilot tasks

Each pilot task can be analysed according to the information requirements necessary to perform it and the control inputs that the pilot will be required to make. Desired properties of the human machine interface can then be considered, along with general cognitive engineering principles. For example, the broad task "Monitor and control status of links" might be decomposed into subtasks including "Select communication mode", "Confirm that communication link is established with correct aircraft" and "Maintain awareness of link strength & quality". Each of these sub-tasks will in turn be associated with information and control requirements. For example, the pilot may require displays showing link strength, and the geographical limits of link coverage. The desired properties of these displays can then be considered. This could include whether link strength be communicated using textual, graphical or aural cues, and when the pilot should be warned of an impending loss of link.

It is not considered necessary to develop guidelines for every identified pilot task. Instead, areas where guidelines will be useful are being identified on the basis of criticality. These are areas where consequential errors could occur, or pilot functions that have been identified as worthy of attention based on simulations, operational experience, or the judgment of subject matter experts.

Each identified topic area will be reviewed against existing regulatory material and associated advisory material. If a regulation adequately deals with the topic, the material will be referenced and there will be no need to create new guidance. If regulatory material does not cover a particular topic, existing UAS standards will be reviewed to identify a guideline that covers the issue. If no suitable guideline is found, the next step will be to identify a general human factors standard that deals with the issue. Finally, original guidelines will be written.

Conclusions

A set of human factors guidelines for the GCS is needed to ensure that UAS can be operated safely and efficiently. Human factors guidelines for the cockpits of conventionally piloted aircraft were developed over many years, often in response to accidents and incidents. This method of development is no longer acceptable. Therefore it is important to identify the necessary principles as early as possible based on the results of simulations, early operational experience, and lessons learned from other application of teleoperation and related technologies.

Given that access to civilian airspace will require a human pilot to be responsible for each UAS, it is possible to broadly identify many of the tasks and functions that must be performed by the pilot. This in turn, enables the identification of areas where human factor guidelines may be of assistance. Guidelines, by their nature, are not regulations or mandatory statements, however we believe that they will be of value to all those involved in the integration of UAS.

Finally, it should be noted that guidelines must be updated as new information comes to light. While the development of control stations will be informed by guidelines, the guidelines will in turn be informed by the experience gained from UAS operations.

References

Berson, B., Gershzohn, G., Wolf, R., & Schultz, M. (2005*). Draft human systems integration requirements and functional decomposition*. Technical report DFRC-239; HSI007. Edwards, CA: NASA Dryden Flight Research Center. Retrieved from: http://ntrs.nasa.gov.

Cooke, N. J., Pringle, H. L., Pedersen, H. K., & Connor, O. (2006). (Eds*.), Human factors of remotely operated vehicles.* San Diego: Elsevier.

Cummings, M.L., Mastracchio, C., Thornburg, K.M., & Mkrtchyan, A. (2013). Boredom and distraction in multiple unmanned vehicle supervisory control. *Interacting with Computers, 25(1)*, 34-47.

Endsley, M. & Jones, D. (2012). *Designing for situation awareness*. Boca Raton, FL: Taylor and Francis.

Federal Aviation Administration. (2013). *Integration of Civil Unmanned Aircraft Systems (UAS) in the National Airspace System (NAS) Roadmap*. Washington, DC: Author.

Fern, L., Rorie, C. & Shively, R (2014, June). *UAS contingency management: The effect of different procedures on ATC performance in civil airspace operations*. Paper presented at AIAA Aviation Conference. Atlanta, GA.

Fern, L., Shively, R, & Johnson, W. (2012, October). *UAS Integration into the NAS: An Examination of Baseline Compliance in the Current Airspace System*. Paper presented at Human Factors and Ergonomics Society Meeting. Boston, MA.

Fern, L. (2012, October). *UAS Integration into the NAS: Unmanned Aircraft Systems (UAS) Delegation of Separation*. Paper presented at Human Factors and Ergonomics Society Meeting. Boston, MA.

Hobbs, A. (2010). Unmanned aircraft systems. In E. Salas & D. Maurino (Eds.). *Human factors in aviation, 2nd edition* (pp. 505-531). San Diego: Elsevier.

International Civil Aviation Organization. (2011). *Unmanned aircraft systems*. Circular 328. Montreal: Author.

International Telecommunications Union (2010*). Characteristics of unmanned aircraft systems and spectrum requirements to support their safe operation in non segregated airspace*. Report ITU-R M.2171. Geneva: Author. Retrieved from: http://www.itu.int

Mouloua, M., Gilson, R., Daskarolis-Kring, E., Kring, J., & Hancock, P. (2001). Ergonomics of UAV/UCAV mission success: Considerations for data link, control, and display issues. *Proceedings of the Human Factors and Ergonomics Society 45th Annual Meeting* (pp 144 – 148). Santa Monica, CA: Human Factors and Ergonomics Society.

Norman, D. A. (1988). *The psychology of everyday things*. New York: Basic Books.

North Atlantic Treaty Organization. (2004). *Standard Interfaces of UAV Control System for NATO UAV Interoperability*. (NATO Standardization Agreement 4568 (sic)). Brussels, BE: Author.

North Atlantic Treaty Organization. (2007). *Standard interfaces of UAV control systems (UCS) for NATO UAV Interoperability*. (NATO Standardization Agreement 4586, Edition 2). Brussels, BE: Author.

North Atlantic Treaty Organization. (2009). *Unmanned aerial vehicle systems airworthiness requirements*. (NATO Standardization Agreement 4671). Brussels, BE: Author.

Office of the Under Secretary of Defense. (2012). *Unmanned aircraft systems ground control station human-machine interface. Development and Standardization Guide*. Washington, DC: Author.

O'Hara, J., Higgins, J., Persensky, J., Lewis, P., & Bongarra, J. (2004). *Human factors engineering program review model* (NUREG-0711, Rev. 2). Washington, DC: U.S. Nuclear Regulatory Commission.

RTCA. (2007). *Guidance Material and Considerations for UAS*. (Report No. DO-304). Washington, DC: Author.

RTCA. (2010). *Operational Services and Environmental Definition for UAS*. (Report No. DO-320). Washington, DC: Author.

Scheff, S. (2012). *UAS Operation in the NAS GCS Catalog and Phase of Flight Requirements*. HF Designworks (2012).

Shneiderman, B. & Plaisant, C. (2005). *Designing the user interface: Strategies for effective human-computer interaction*. Boston: Pearson.

Sollenberger, R.L., McAnulty, D. M, & Kerns, K. (2003). *The effect of voice communications latency in high density, communications-intensive airspace.* (Report No. DOT/FAA/CT-TN03/04). Washington DC: Federal Aviation Authority.

Tvaryanas, A. P. (2006). *Human factors considerations in migration of unmanned aircraft system (UAS) operator control.* (USAF Performance Enhancement Research Division Report No. HSW-PE-BR-TE-2006 – 0002). Brooks City, TX: United States Air Force.

Waraich,Q. Mazzuchi, T. Sarkani, S. & Rico, D. (2013). Minimizing Human Factors Mishaps in Unmanned Aircraft Systems. *Ergonomics in Design, 21 (1),* 25-32.

Williams, K. W. (2006). Human factors implications of unmanned aircraft accidents: Flight control problems. In N. J Cooke, H. L. Pringle, H. K. Pedersen, & O. Connor (Eds.), *Human Factors of Remotely Operated Vehicles* (pp. 105 – 116). San Diego: Elsevier.

Williams, K.W. (2008). *Documentation of sensory information in the operation of unmanned aircraft systems*. (Report No. DOT/FAA/AM-08/23). Washington, DC: Federal Aviation Administration.

Contact Information

Alan Hobbs Ph.D. alan.hobbs@nasa.gov
San Jose State University Foundation
Human Systems Integration Division
NASA Ames Research Center
Moffett Field
California, 94035-1000