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HUMAN FACTORS GUIDELINES FOR UAS IN THE NATIONAL AIRSPACE SYSTEM

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The ground control stations (GCS) of some UAS have been characterized by less-than-adequate human-system interfaces. In some cases this may reflect a failure to apply an existing regulation or human factors standard. In other cases, the problem may indicate a lack of suitable guidance material. NASA is leading a community effort to develop recommendations for human factors guidelines for GCS to support routine beyond-line-of-sight UAS operations in the national airspace system (NAS). In contrast to regulations, guidelines are not mandatory requirements. However, by encapsulating solutions to identified problems or areas of risk, guidelines can provide assistance to system developers, users and regulatory agencies. 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. By assuming that a pilot will be responsible for each UAS operating in the NAS, and that the aircraft will be required to operate in a manner comparable to conventionally piloted aircraft, it is possible to identify a generic set of pilot tasks and the information, control and communication requirements needed to support those tasks. Areas where guidelines will be useful can then be identified, utilizing information from simulations, operational experience and the human factors literature. In developing guidelines, we recognize that existing regulatory and guidance material may already provide adequate coverage of certain issues. In other cases suitable guidelines may be found in existing military or industry human factors standards. In cases where appropriate existing standards cannot be identified, original guidelines will be proposed.

INTRODUCTION

The National Aeronautics and Space Administration (NASA) is conducting a multi-year project to address the barriers to routine access for unmanned aircraft systems (UAS) to the national airspace system (NAS). This project, referred to as “UAS in the NAS” addresses five broad areas; separation assurance and collision avoidance, command and control systems, airworthiness certification standards, human systems integration, and integrated testing and evaluation of emerging UAS technologies. This paper describes how the human system integration element of the UAS in the NAS project is working with community partners to develop a set of recommendations for human factor guidelines for the ground control station (GCS).

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Early in the development of manned aviation, it was recognized that many “pilot error” accidents reflected poorly-designed or non-standard cockpit interfaces[1]. Over time, human factors principles for cockpit displays and controls were incorporated into standards and regulations that ultimately led to safer and more reliable aviation. These principles are contained not only in the Code of Federal Regulations such as 14 CFR parts 23 and 25[2,3] but also in military standards[4] and industry publications such as those produced by the General Aviation Manufacturers Association[5]. As new waves of technology have appeared in the cockpits of manned aircraft, human factor standards have evolved to keep pace. 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 would no longer be considered acceptable to introduce an immature system to the NAS, and then rely on subsequent accidents and incidents to identify design deficiencies. For this reason, it is crucial that human factors design principles for GCS be identified as early as possible, using the available operational information, supplemented with research techniques such as human-in-the-loop simulation and prototyping.

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. A challenge for the designers of GCS is to enable the UAS pilot to maintain situational awareness in the absence of the rich perceptual cues available to the pilot of a conventional aircraft[6]. Many of the display requirements are similar to those in manned aircraft, such as airspeed, attitude and the performance of on-board systems. In other cases, the GCS may provide the UAS pilot with information that would not be required in the cockpit of a conventionally piloted aircraft. This may include the strength of the command link, information from on-board cameras, and status information on the GCS itself. An additional point of difference with manned aircraft is that UAS are increasingly controlled via computer interfaces, including “point and click” input devices and text-based menus. Other aspects of unmanned aviation with implications for the design of the GCS include in-flight transfer of control, the presence of sense and avoid systems, flight termination systems, time delays in control and communication, and the challenges of maintaining pilot engagement during extended periods of low workload[7,8].

Inadequate human-system interfaces have been noted across many unmanned systems. Problems have included error-provoking control placement, non-intuitive automation interfaces, an over-reliance on text displays, and complicated sequences of menu selection to perform minor or routine tasks[9]. In some cases, the interface problem may have been prevented had an existing 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.

The National Aeronautics and Space Administration has recognized that human factors guidelines for the GCS will be a key requirement for safe and reliable operation of civilian UAS in the NAS. The agency is working with key stakeholders to develop recommendations for GCS human factor guidelines with a focus on UAs larger than 55 pounds operating beyond visual line-of-sight.

DEFINING GUIDELINES

In contrast to regulations, guidelines are not mandatory, and do not generally contain the words “shall” or “must”. Guidelines can serve several purposes. 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.

In collaboration with the human factors team of RTCA SC-203, we identified several categories of human factor guidelines[10]. These include broad cognitive engineering principles, statements of capabilities, definitions of information requirements, and physical ergonomic principles.

Cognitive engineering principles. At the broadest level are statements of design philosophy that are agnostic with respect to the form of the interface. Examples are the general design principles for human-system interfaces proposed by Don Norman[11] and Shneiderman and Plaisant[12]. 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.

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. For example, guidelines may address issues such as visual clutter, display competition for attention, and nuisance alerts.

Statements of capabilities. 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.

Information statements. These guidelines deal with the information that the interface is expected to provide to the pilot. Such guidelines can be expressed in a manner that does not specify how this exchange will occur. 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.

Physical properties of the human-machine interface. Some guidelines will deal with the physical ergonomics of the GCS. Relevant issues include reach, visibility, the size and color of fonts and the characteristics of input devices such as trackballs, touchscreens, or menu systems.

Regardless of the area of technology in question or the form of the guideline, useful guidelines possess the characteristics outlined in Table 1.

EXISTING WORK ON UAS HUMAN FACTOR GUIDELINES

The current project is not the first to address human factor guidelines for GCS. Ten years ago, the “Access 5” program made progress in developing human system integration guidance for the GCS[13]. In 2012 the Office of the Under Secretary of Defense released a GCS human-machine interface development and standardization guide[14]. The most recent version of Military Standard 1472G (Human Engineering) includes a section on UAS interface design[15]. Material touching on the human factors of the GCS has also been produced by the North Atlantic Treaty Organization (NATO) in Standardization Agreements[16,17]. Organizations such as ASTM, RTCA and the International Civil Aviation Organization (ICAO) are also addressing the issues of UAS integration[18].

In compiling guidelines for the GCS, NASA is building upon the existing material on GCS human factors, supplemented with research results from the NASA UAS in the NAS program. In contrast to some of the preceding work dealing with military applications, NASA is focusing on requirements for the operation of UAS in civilian airspace.

Table 1. Desired characteristics of guidelines

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.
Assessable	It should be possible to evaluate whether the intent of a particular guideline has been met.

DEVELOPING HUMAN FACTORS GUIDELINES

Identifying the role of the human in the system. The first step in the guidelines development process is the identification of key tasks and functions assigned to the pilot. The FAA Concept of Operations for the integration of UAS into the NAS[19] contains a set of 14 assumptions concerning the operation beyond visual line-of-sight of UAS larger than 55 pounds. Among the assumptions is that each UAS will have a pilot in command, flight will be in compliance with existing rules and procedures, operations will not be autonomous, and the pilot will have the authority to assume control at all times during normal operations. 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 that will be applicable regardless of the characteristics or capabilities of the specific UAS.

Working with members of the human factors team of RTCA SC-203 we have built a generic list of UAS pilot tasks based on existing descriptions of tasks for UAS and manned aircraft[13,20,21,22]. The task list is being supplemented with information from a NASA-sponsored review of UAS pilot information requirements, UAS accident and incident reports, human factors literature, and input from UAS pilots.

A pilot-centered model of the UAS can be used to organize and present the set of pilot tasks. The model presented in Figure 1 was developed by the human factors team of RTCA SC-203. The model 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 (including decisions necessary for flight management) 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.

Once a list of tasks is defined, each task can be analyzed according to the requirements necessary to perform it in terms of information, pilot information processing, and control inputs. These will vary according to the level of human involvement ranging from direct manual control through to the monitoring of automation. Tasks can also be organized according to a generic functional breakdown using the broad categories of "aviate", "navigate", "communicate" and "manage". An illustration of a possible functional breakdown of pilot tasks is shown in the appendix.

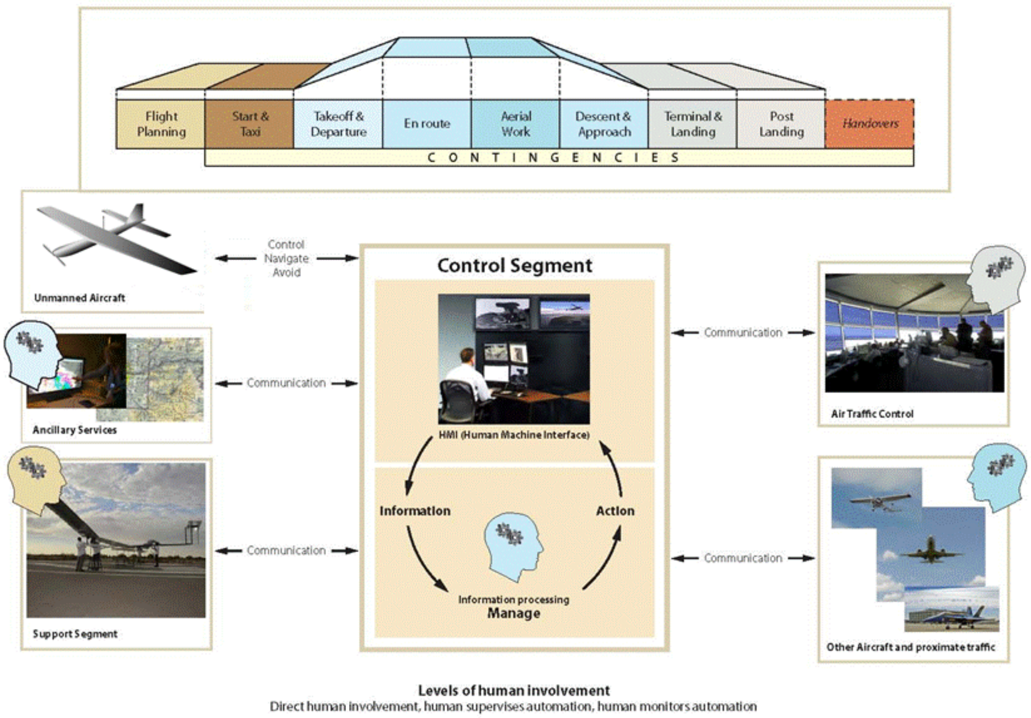

Figure 1. Proposed pilot-centered model of a UAS

Identification of potential topic areas for guidelines. It is not considered necessary to develop guidelines mirroring every identified pilot task or the requirements associated with each task. Instead, areas where guidelines will be useful are identified on the basis of criticality. These could be 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. Topics are expressed as statements of problems or risk that must be managed. Ultimately, guidelines are responses to these topics, and may relate to specific tasks, or the overall properties or operation of the system as a whole.

To illustrate, task-specific topics that may justify guidelines could include issues such as: the need for pilot awareness when the aircraft is approaching the limit of the control link; the need to reduce the risk of inadvertent activation of unguarded critical controls; and the need to ensure that flight termination messages (if relevant) are received by the intended asset. Examples of topics relevant to the overall properties or operation of the system include: the need to manage display clutter; the maintenance of pilot engagement during extended periods of low workload; and the need to ensure that time-critical tasks do not require time consuming interactions with computer interfaces.

Guidelines development. Each identified topic area will be reviewed against the Code of Federal Regulations (CFRs) and associated FAA advisory material. If a regulation, or other FAA material, adequately deals with the topic, the material will be referenced and there will be no need to create new guidance. If the CFRs do not cover a particular topic, existing UAS guidelines (such as NATO STANAGs) 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. This sequence is illustrated in Figure 2.

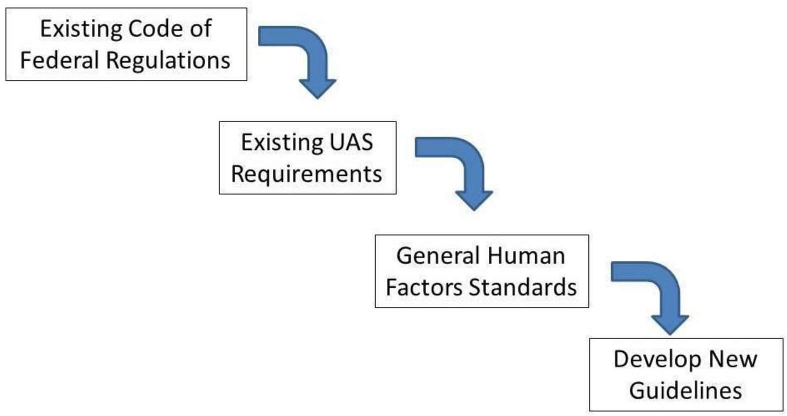

Figure 2. The waterfall approach to guidelines development.

CONCLUSION

A set of human factors guidelines for the GCS is needed to ensure that UAS can be operated in the NAS 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 the NAS 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 into the NAS.

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APPENDIX. An illustrative functional description of the task of a UAS pilot.