WORKING DOCUMENT FOR COMMENT

Human Factors Guidelines for Unmanned Aircraft System Ground Control Stations.

A working document addressing the unique human factors considerations associated with beyond-line-of-sight operation of unmanned aircraft in the National Airspace System.

Preliminary Guidelines 1.0

Contractor Report prepared for NASA *UAS in the NAS* Project

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Alan Hobbs, Ph.D.
San Jose State University Research Foundation/NASA Ames Research Center
alan.hobbs@nasa.gov

Beth Lyall, Ph.D.
Research Integrations, Inc.
beth.lyall@researchintegrations.com

Authors' note

This working document has been prepared for NASA's *Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS) Project*. It contains a partial list of preliminary human factors guidelines for UAS Ground Control Stations (GCS) arranged within an organizing structure.

The UAS industry is expanding rapidly, and many US and international agencies (including RTCA, ICAO, JARUS, and the FAA) are working to develop operational concepts and standards. We aim to develop human factors guidelines that will be of value to the aforementioned organizations.

It is not our intention to list all human factors guidelines relevant to the GCS, as this would involve replicating a large number of existing guidelines for UAS, cockpit design, and other human system interfaces. Instead, the draft guidelines contained in this document are intended to supplement the existing human factors literature by focusing on the unique aspects of unmanned aviation and the capabilities and characteristics of the GCS to enable pilots to operate UAS in the NAS.

This early version of our working document is being made available for input and feedback. The document will be revised and updated periodically as information becomes available from research, reader comments, and operational experience. Placeholders, denoted by "TBA", indicate where future material will be added.

The reader should note that these guidelines address civil unmanned aircraft that are capable of operating beyond visual line-of-sight in all airspace classes of the NAS. We do not address unmanned aircraft that operate entirely at low level, or are controlled by visual reference of the pilot. Furthermore, although our focus is on UAS operations in the United States, we hope that our work will also be useful internationally.

Comments or questions can be sent to us via the email addresses on the title page of this document.

Alan Hobbs, Ph.D.
San Jose State University Research Foundation/NASA Ames Research Center

Beth Lyall, Ph.D.
Research Integrations, Inc.

Contents

Summary

This preliminary report presents a structure that may be used to organize human factors guidelines for the Ground Control Stations (GCSs) of unmanned aircraft that are capable of operating beyond line-of-sight in all airspace classes of the United States National Airspace System (NAS). The document contains a partial list of draft guidelines, as well as placeholders to indicate where future guidelines may be included.

Thousands of human factors guidelines and standards for technological systems have been published by standards organizations, regulatory authorities, the Department of Defense, and other agencies. In compiling this document, the intent was not to reproduce or re-state existing human factors material. Instead, this document focuses on the unique issues of civilian unmanned aviation, and contains guidelines specific to this sector. As a result, it should be seen as a supplement to, rather than a replacement for, existing aviation human factors standards and guidance material.

Two constraints have been used to focus the scope of this document. First, the assumptions contained in the FAA (2013a) UAS roadmap have been used to define the responsibilities that will be assigned to the pilot of a UAS operating in the NAS. This in turn, helps to define the tasks that the UAS pilot must perform via the GCS, and thereby the required features and characteristics of the GCS. Second, the points of difference between UAS and conventional aviation have been used to further focus the guidelines on the considerations that make piloting a UAS significantly different to piloting a conventional aircraft.

Five broad categories of guidelines are identified. These are (1) performance-based descriptions of pilot tasks that must be accomplished via the GCS, (2) information content of displays, (3) descriptions of control inputs, (4) properties of the interface, and (5) high-level design considerations. Some of the guidelines in this document have been adapted from existing UAS human factors material from several sources, including RTCA publications and Standardization Agreements (STANAGs) published by the North Atlantic Treaty Organization (NATO). The use of quotation marks indicates that the wording of the guideline remains in its original form. In

other cases, guidelines have been developed based on NASA research conducted under the *UAS in the NAS* project. In a few places, existing aviation standards or general human factors guidelines have been quoted when they have particular relevance to UAS.

Throughout this document, guidelines have been written with the words “should” or “will” except in cases where an existing guideline is quoted that contained a “shall” statement in its original form.

List of abbreviations

ADS-B	Automatic Dependent Surveillance – Broadcast
ANSI	American National Standards Institute
ASTM	ASTM International, *formerly American Society for Testing and Materials*
ATC	Air Traffic Control
C2	Control and Communications
CCTV	Closed Circuit Television
CFR	Code of Federal Regulations
COA	Certificate of Waiver or Authorization
COTS	Commercial Off-The-Shelf
CPDL	Controller-Pilot Data Link
CTAF	Common Traffic Advisory Frequency
DAA	Detect and Avoid
DTED	Digital Terrain Elevation Data
FAA	Federal Aviation Administration
GCS	Ground Control Station
HFES	Human Factors and Ergonomics Society
HMI	Human-Machine Interface
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
IMC	Instrument Meteorological Conditions
JARUS	Joint Authorities for Rulemaking of Unmanned Systems
MOPS	Minimum Operational Performance Standards
ms	Millisecond
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
PIC	Pilot in Command
RTCA	RTCA Inc. *formerly Radio Technical Commission for Aeronautics*
STANAG	NATO Standardization Agreement
TBA	To Be Added
TCAS	Traffic Alert and Collision Avoidance System
UA	Unmanned Aircraft
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle
VHF	Very High Frequency

Introduction

Unmanned Aircraft (UAs) have generally experienced a higher accident rate than conventionally piloted aircraft (Nullmeyer & Montijo, 2009). Many of these accidents appear to reflect the unique human challenges associated with piloting a UA, in combination with Ground Control Stations (GCS) that have been designed with insufficient regard for human factors principles (Williams, 2004).

Human factors and human factors engineering have been defined as follows: “Human Factors is a body of knowledge about human abilities, human limitations, and other human characteristics that are relevant to design. Human factors engineering is the application of human factors information to the design of tools, machines, systems, tasks, jobs, and environments for safe, comfortable, and effective human use” (Chapanis, 1991).

The 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. 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. Examples include error-provoking control placement, non-intuitive automation interfaces, a reliance on text displays, and complicated sequences of menu selection to perform minor or routine tasks (Cooke, Pringle, Pedersen & Connor, 2006). Some of these problems may have been prevented had an existing regulation or cockpit design principle been applied. In other cases, the design problem reflected an emerging UAS issue that was not covered by existing regulatory or advisory material.

The National Aeronautics and Space Administration (NASA) recognizes that human factors guidelines for the GCS will be a key requirement for safe and reliable operation of civilian UAS in the United States National Airspace System (NAS). As part of the NASA *UAS in the NAS* Project, the agency is working with key stakeholders to develop recommendations for GCS human factors guidelines with a focus on unmanned aircraft operating beyond visual line-of-sight.

This document contains preliminary human factors guidelines that have been developed on the basis of data from simulations, accident and incident analysis, and the literature on UAS human factors. The document also draws together existing UAS guidelines previously developed by NATO, RTCA, Access 5, and other organizations. Guidelines, by definition, are advisory in nature. Therefore we have used the terms “should” and “will”, except in cases where we have quoted an existing regulation or standard without modification.

Scope of the current activity

The compilation of human factors guidelines was based on the following intentions:

a) The guidelines will be developed for UAS capable of operating beyond line of sight within all classes of civilian airspace.

b) The focus will be the engineered system, comprising the GCS, and its immediate environment. Where appropriate, issues such as maintenance or ground support are also considered. Personnel training, crew qualifications, procedure design and physical security of the GCS are beyond the scope of this document.

c) The scope will not be limited to specific designs, or architectures, but covers as broad a range of UAS as practicable.

d) The control or management of payload will be out of scope, except where payload considerations may affect the safety of flight.

e) All stages of flight will be within scope, from flight planning to post-landing, including contingencies (non-normal situations) and in-flight handover, as shown in Figure 1.

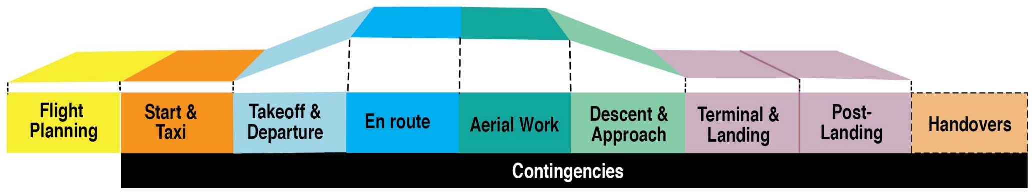

Figure 1. Stages-of-flight considered in the development of guidelines.

Focusing guidelines on the special challenges of UAS operations

A large number of human factors guidelines and standards for human-machine interfaces have been published by standards organizations, NASA, the FAA, military agencies, and others. A comprehensive set of guidelines for the GCS could conceivably include re-statements of all of this pre-existing material. Such a massive document would be of limited use. Not only would most of the material be available elsewhere, but original guidelines would be difficult to locate among all of the re-stated material.

In compiling guidelines for the GCS, we have specifically decided not to produce a comprehensive set of human factors guidelines, but instead to focus on the special challenges that will be relevant to the operation of UAS in the United States National Airspace System. Therefore, this set of guidelines is intended to supplement, rather than replace, existing material on cockpit design.

Most of the guidelines included in this document are UAS-specific and deal with issues that are not covered by guidelines typically used in the aviation industry. In a few parts of this document however, we have chosen to re-state general human factors principles that have particular applicability to UAS, particularly when we have found evidence that the principle has been overlooked by the designers of existing GCS.

The current effort has been guided by two complementary defining constraints. First, we have used a set of assumptions published by the FAA to define the types of operations that will be permitted by UAS in the NAS. These assumptions determine the capabilities that UAS must possess and the tasks that the pilot must be able to perform. Second, we have identified the special challenges presented by unmanned aviation, and focused on compiling guidelines relevant to these issues. These challenges are sometimes referred to as “deltas”, meaning the additional considerations that apply to UAS operations over and above those applying to manned aviation. A summary of the special challenges can be found in a following section.

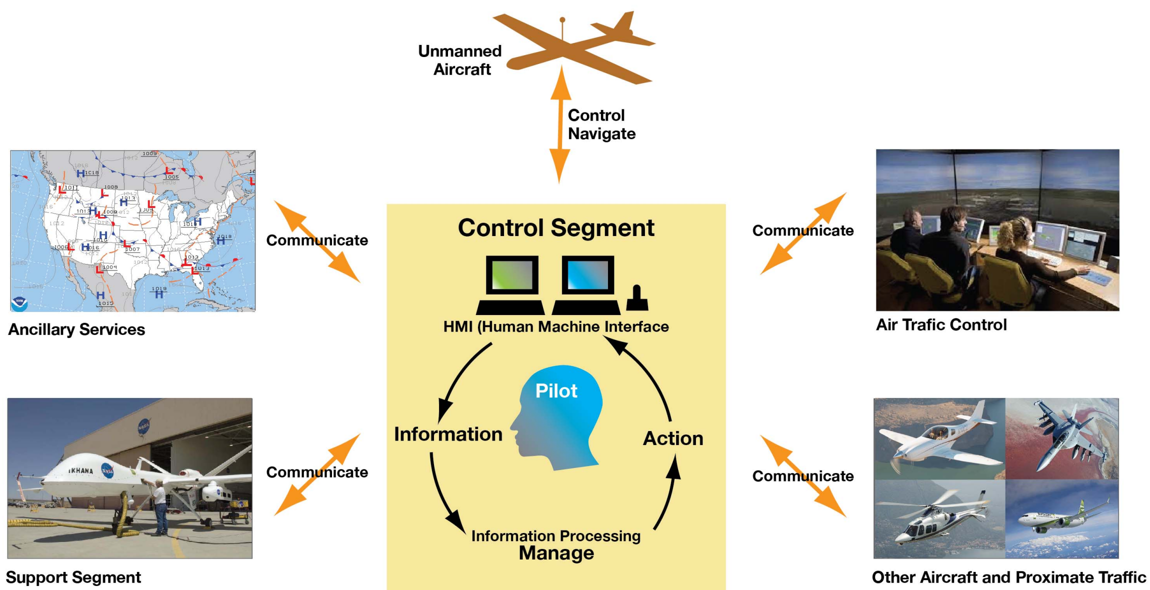

Figure 2. Control and communication responsibilities of a UAS pilot operating in the NAS.

FAA assumptions

The FAA (2013a) roadmap for integration of UAS into the National Airspace System includes a set of assumptions that will guide how civil UAS operating beyond line-of-sight of the flight crew will be integrated into the NAS. These assumptions are reproduced verbatim in Table 1 below. Several of the assumptions imply specific requirements that help to define the nature of

UAS operations and the role of the pilot. For example, from assumption three it follows that the pilot will comply with Instrument Flight Rules (IFR) procedures and will operate the aircraft on designated air routes. Assumption six makes it clear that there will be a role for a pilot in command, and that the control of multiple UAs by one pilot is not envisioned. Assumption seven requires that the pilot will have on-the-loop or in-the-loop control authority. This in turn, implies that the GCS must keep the pilot informed of the state of the aircraft and its systems. From assumption 13, it follows that the pilot will have the ability to communicate with Air Traffic Control (ATC), and will be capable of complying with ATC instructions as effectively as a pilot of a manned aircraft. Figure 2 (above) shows a simplified representation of the role of the pilot in a UAS operating as a full participant in the NAS.

Table 1. Assumptions from FAA UAS roadmap

1. UAS operators comply with existing, adapted, and/or new operating rules or procedures as a prerequisite for NAS integration.

2. Civil UAS operating in the NAS obtain an appropriate airworthiness certificate while public users retain their responsibility to determine airworthiness.

3. All UAS must file and fly an IFR flight plan.

4. All UAS are equipped with ADS-B (Out) and transponder with altitude-encoding capability. This requirement is independent of the FAA's rule-making for ADS-B (Out).

5. UAS meet performance and equipage requirements for the environment in which they are operating and adhere to the relevant procedures.

6. Each UAS has a flight crew appropriate to fulfill the operators' responsibilities, and includes a pilot-in-command (PIC). Each PIC controls only one UA.*

7. Autonomous operations are not permitted.** The PIC has full control, or override authority to assume control at all times during normal UAS operations.

8. Communications spectrum is available to support UAS operations.

9. No new classes or types of airspace are designated or created specifically for UAS operations.

10. FAA policy, guidelines, and automation support air traffic decision-makers on assigning priority for individual flights (or flight segments) and providing equitable access to airspace and air traffic services.

11. Air traffic separation minima in controlled airspace apply to UA.

12. ATC is responsible for separation services as required by airspace class and type of flight plan for both manned and unmanned aircraft.

13. The UAS PIC complies with all ATC instructions and uses standard phraseology per FAA Order (JO) 7110.65 and the Aeronautical Information Manual (AIM).

14. ATC has no direct link to the UA for flight control purposes.

* This restriction does not preclude the possibility of a formation of UA (with multiple pilots) or a "swarm" (one pilot controlling a group of UA) from transiting the NAS to/from restricted airspace, provided the formation or swarm is operating under a COA.

** Autonomous operations refer to any system design that precludes any person from affecting the normal operations of the aircraft.

FAA (2013a). Integration of Civil Unmanned Aircraft Systems (UAS) in the National Airspace System (NAS) Roadmap (pp 33-334)

Special considerations of UAS

Unmanned aviation shares many of the same human factors considerations that apply in manned aviation; however the points of difference have implications for GCS design (Kaliardos & Lyall, 2014). These special considerations are listed in Table 2 below and are described in detail in the sections that follow. The guidelines in this document are intended to address human factors challenges that exist within the problem space defined by these eight broad considerations.

Table 2. Special considerations of UAS with implications for guidelines development

A. Loss of natural sensing

B. Control and communication via radio link

C. Physical characteristics of the control station

D. In-flight transfer of control

E. Unique flight characteristics of unmanned aircraft

F. Flight termination

G. Reliance on automation

H. Widespread use of interfaces based on consumer products

A. Loss of natural sensing

Potential for reduced awareness of aircraft state: The rich sensory cues available to the pilot of a conventional aircraft include visual, auditory, proprioceptive and olfactory sensations. The absence of these cues when operating a UAS can make it more difficult for the pilot to maintain an awareness of the aircraft's state.

Implications for error-self correction: Observations of airline pilots have indicated that "pilot error" is a relatively frequent event, yet most of these errors are rapidly identified and corrected by the crews themselves before any consequences occur (ICAO, 2002). The UAS pilot, no longer co-located with their aircraft, may have more difficulty identifying and self-correcting errors.

Collision avoidance and separation assurance: In the absence of an out-the-window view, the pilot must rely on alternative sources of information, and will be unable to comply with ATC visual clearances in the usual way. In the cruise flight phase, a UAS pilot lacking information from an out-the-window view may be in a comparable situation to the pilot of a conventional aircraft during flight in instrument meteorological conditions (IMC). However, the comparison between conventional instrument flying and UAS operations may not apply when the UA is on the ground or in terminal airspace. The situation awareness provided by an out-the-window view may be particularly critical during taxiing and takeoff, and during the approach and landing phases. In collaboration with RTCA Special Committee 228, NASA is conducting studies to define the requirements for UAS traffic displays to be used for self-separation and collision avoidance.

Foveal bottleneck: Some UAS designers have attempted to compensate for the lack of rich sensory cues with text-based displays in the GCS. However, this risks overloading the visual channel of the pilot by requiring the pilot to invest the limited resource of foveal vision to obtain information that would be available to a conventional pilot via other sensory channels, including peripheral vision.

Potential for perceptual illusions or distortions related to on-board cameras: If an on-board camera is used to assist with piloting tasks, there is the potential for perceptual illusions or distortions that do not occur in conventional aviation. Camera views can produce misleading depth cues, some of which may be related to the lack of binocular cues. Misleading cues may be particularly noticeable during takeoff or landing. If a moveable camera located on board a UA is not aligned as expected by the pilot, or moves unexpectedly, there may be an illusion of yaw, or other undesired aircraft state.

B. Control and communication via radio link

Control latencies: The transmission of radio signals, and the associated processing, may introduce operationally significant delays between pilot control input, aircraft response execution, and display of the response to the pilot. These latencies will be particularly noticeable when the link is via a geostationary satellite, however, terrestrial radio systems may also introduce significant latencies.

Voice latencies: In controlled airspace, most communication between pilots and ATC occur over VHF radio. All pilots on the same frequency are able to monitor transmissions due to the "party line" nature of the radio. This provides situation awareness, and also enables pilots to time their transmissions to minimize "step-ons", in which two people attempt to transmit simultaneously. In busy airspace, it can become challenging to identify the brief gaps in which transmissions can be made**.**

The near-term communication and control architecture being developed for UAS operations in the NAS will involve a digital relay of UAS pilot voice communications via L band or C band radios from the ground to the UA, from where the message will be converted to analogue form, and re-broadcast over VHF radio. The transmissions of other pilots and controllers will be relayed to the UAS pilot using the same system. The relay of UAS voice communications from the GCS via the UA will introduce a delay between the communications of the UAS pilot with reference to other pilots on frequency. Most of this latency will be due to processing before and after signal transmission. In order to seamlessly integrate UAS into the NAS, it will be important that the latency between UAS and non-UAS voice communications does not reach a level that disrupts communication.

Link management: In addition to flying the aircraft, the pilot must manage and monitor the Control and Communications (C2) link. This requires the pilot to be aware of the current status of the control link, anticipate potential changes in the quality of the link as the flight progresses, and diagnose and respond to any changes that occur. The pilot may be required to interact with security features designed to prevent unauthorized persons from taking control of the UA or interfering with the control link. In the event of a link interruption, the UA must be capable of continued flight in accordance with the expectations of the pilot and air traffic control.

C. Physical characteristics of the control station

The ground control station (GCS), located remote to the aircraft, is likely to increasingly resemble a control room rather than a cockpit. Guidelines may cover not only the human-machine interface (HMI), but also the physical environment of the GCS, including noise levels, access controls, temperature control, and lighting.

Potential to add displays: The relative spaciousness of the GCS compared to a traditional cockpit enables additional screens to be added easily and without the forethought that would be needed to add them to a cockpit. A proliferation of information displays can affect the pilot's performance and interaction with the GCS. Consideration will need to be given to determining whether the addition of a display to the GCS should be considered a significant or minor modification for GCS design and certification purposes.

Ability of maintenance personnel to access GCS during flight: Current UAS operations sometimes involve in-flight troubleshooting such as diagnosing and correcting console lock-ups, software problems, and problems with cable connections. In contrast to conventional aviation, UAS maintenance personnel have the opportunity to gain access to the pilot station during flight operations, and may have hands-on interactions with the GCS while a flight is underway. As a result, maintenance errors may have an immediate operational impact (Hobbs & Herwitz, 2008).

D. In-flight transfer of control

Control of a UA may be transferred during flight operations between pilots at the same control station console, between consoles at the same control station, or between physically separated control stations (Williams, 2006). These handovers can be a time of particular risk, associated with system mode errors and coordination breakdowns. For example, there have been cases of inadvertent transfer of control between GCS due to controls set in error. The control of a longendurance aircraft may be transferred multiple times during the course of a single flight (Tvaryanas, 2006), with each handover contributing to a cumulative level of risk.

E. Unique characteristics of UAS flight

Compared to manned aircraft, unmanned aircraft are more likely to have unconventional flight characteristics. They may fly at lower speeds, climb and descend more slowly, and be more likely to loiter over a location than fly point-to-point. UAS operations may also start and end with launch and recovery systems rather than conventional runways.

Extended periods of low workload: A challenge for the designer of the GCS 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 rapid increases in workload during emergencies or non-normal situations.

F. Flight termination

In an emergency, the pilot of a remotely piloted aircraft may be required to perform an off-airport landing, or otherwise terminate the flight by destroying the aircraft by a controlled impact, ditching, or other method. Although no lives are at stake on board the aircraft[1], the pilot is still responsible for the safety of other users of the NAS, and the protection of life and property on the ground. The GCS must provide the information needed for pilot decision-making and enable the pilot to issue the necessary commands to the UA. The risk of inadvertent activation of the flight termination system must also be considered (Hobbs, 2010).

[1] We assume that UAS will not carry passengers.

G. Reliance on automation

Many conventional transport aircraft designs incorporate sophisticated automated systems, however the pilot of a conventional civilian aircraft will generally have the ability to turn-off or minimize the use of the automated systems and exert human-in-the-loop manual control of the aircraft, even if this is via fly-by-wire systems. Most current designs of advanced UAs rely entirely on automated systems for basic flight control, and do not provide options for pilot manual control. Instead, the UAS pilot is responsible for the supervisory control of the automation. Therefore manual flight control becomes less of an issue for the UAS pilot, making automation management issues of critical importance.

H. Widespread use of interfaces based on consumer products

Ground control stations (GCS) increasingly resemble office workstations, with keyboard, mouse or trackball interface devices, and displays based on computer screens. In many cases, interfaces have not been designed in accord with aviation regulations or standards. In some cases, the interfaces operate on consumer computer software. Observed problems have included a heavy reliance on textual information, complicated sequences of menu selection required to perform time-critical or frequent tasks, and screen displays that can be obscured behind pop-up windows or dialog boxes. A GCS that contains controls and displays sourced from diverse commercial off-the-shelf (COTS) providers is likely to suffer from a lack of consistency and other integration issues. This may result in increased crew training requirements, reduced efficiency, and an increased potential for operator errors.

Overview of existing relevant guidelines

A range of existing sources provide guidance and requirements that may be relevant to the design of the GCS. As shown in Appendix 1, these include human factors material from the FAA, EASA, and Department of Defense, as well as general standards with relevance to HMI design. The current project is not the first to address human factors guidelines for GCS. In the early 2000s, the “Access 5” program made progress in developing human system integration guidance for GCS focusing on operations above Flight Level 430 (Berson, Gershzohn, Wolf & Schultz, 2005). The Office of the Under Secretary of Defense (2012) released a GCS human-machine interface development and standardization guide for military UAS. The most recent version of Military Standard 1472G (Human Engineering) includes a brief section on UAS interface design (Department of Defense, 2012). Material touching on the human factors of military GCS has also been produced by the North Atlantic Treaty Organization (NATO) in Standardization Agreements (2007, 2009). Organizations such as ASTM (2007, 2014), RTCA (2007, 2010, 2013) and the International Civil Aviation Organization (ICAO, 2011) are also addressing the issues of UAS integration.

Much of the preceding work dealt with military applications, or provided general comprehensive human factors guidelines for system designers. In contrast, the current project has a narrower focus, limited to the special requirements of civilian UAS operations.

Types of guidelines

Several areas where guidelines may be useful can be identified by asking the questions shown in Figure 3. The process leads to five broad types of guidelines, described in further detail in the following sections.

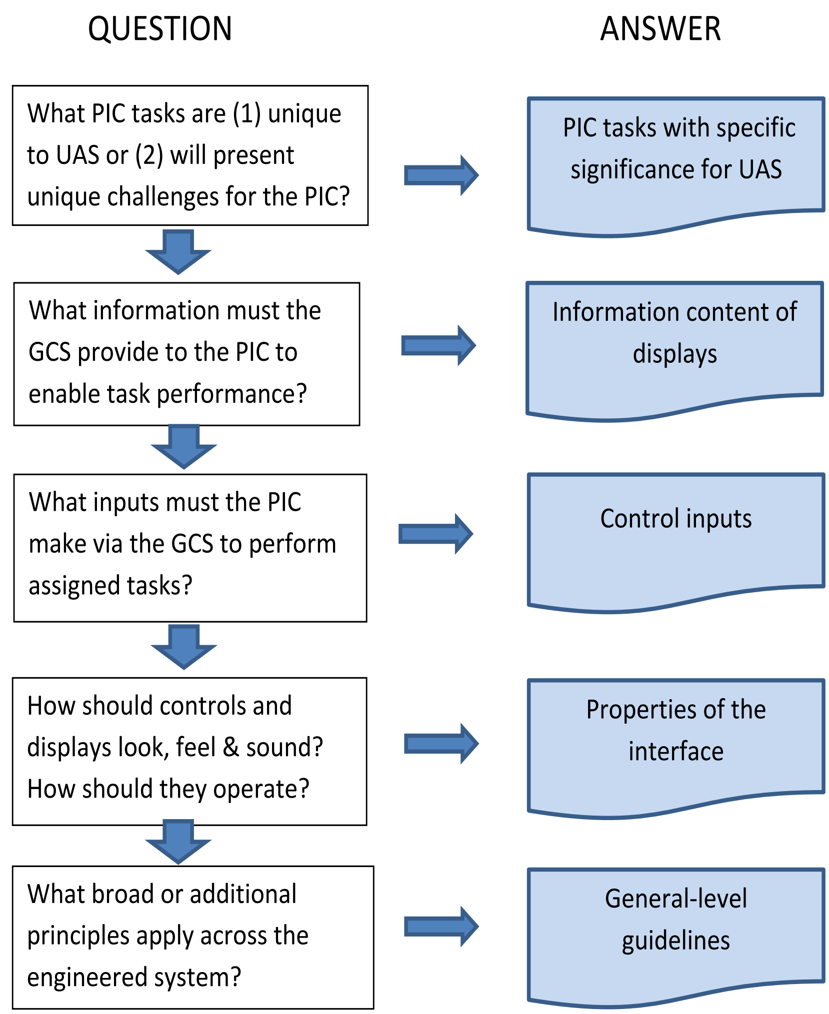

Figure 3. Questions about human-system interaction that lead to five types of guidelines.

Pilot tasks that must be performed via the interface

Certain guidelines provide descriptions of pilot tasks that the human operator should be able to perform via the interface. For example, as a participant in the NAS, the UAS pilot may be required by ATC to direct the aircraft on to a magnetic heading. Therefore the GCS must provide displays and controls to support this task. In general, a guideline that takes the form of a task statement is a form of performance-based standard that describes the outcome without defining *how* it will be achieved, although a desired level of accuracy or speed may be specified. An advantage of task statements is that they tend to be independent of specific technologies or design solutions, and are likely to remain relevant and "future-proof," even as technology evolves. In this document, we focus on pilot tasks that are unique to UAS operations, or tasks that present significant additional challenges for UAS pilot compared to the pilot of a conventional aircraft.

Information content of displays

These guidelines deal with the information that the interface is expected to provide to the pilot via displays. These guidelines do not specify the form that the information should take. For example, it may be stated that the pilot should receive an alert if the control link is lost, without specifying whether the alert should be communicated using auditory, visual, or haptic means, or some combination of these modes. 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.

Control inputs

These are inputs that the GCS must be capable of receiving from the pilot. The requirement may specify key attributes of the input, such as timing and precision, but will remain agnostic with respect to the device used to make the input.

Properties of the interface

The properties of the HMI include layout, shape, physical accessibility, visibility, the use of color and the structure of specific computer interfaces. Despite a widespread use of electronic displays, menu structures and *point and click* input devices, physical ergonomics are still relevant for the design of ground control stations, as several analyses of UAS interfaces have identified issues such as controls that are out of reach of the pilot, or critical controls in locations where they can be activated inadvertently.

General guidelines

General design guidelines are “overarching” principles that have general applicability to the GCS and relevance to multiple displays and controls. In most cases, these are agnostic with respect to the form of the interface. Examples are general design principles for human-machine interfaces dealing with issues such as the internal consistency of the interface, the need to manage data overload, and the avoidance of competing alarms (Endsley & Jones, 2012; Norman, 1988; Shneiderman & Plaisant, 2005). Some general guidelines relate to the overall functioning of the GCS, including characteristics that emerge from the operation of all sub-systems together. For example, visual clutter, display competition for attention and the prioritization of information.

UAS pilot responsibilities

Figure 4 presents a high-level model of the responsibilities of the UAS pilot, consistent with FAA assumptions, adapted from Mutuel, Wargo and DiFelici (2015). The model can act as a checklist to ensure that all areas of human-system interaction are considered when developing guidelines for the human-machine interface. In some cases, broad areas of responsibility are common to both conventional and unmanned aviation, yet may present special challenges for the UAS pilot. These include monitoring and controlling the status of radio links, control hand-offs, and flight termination.

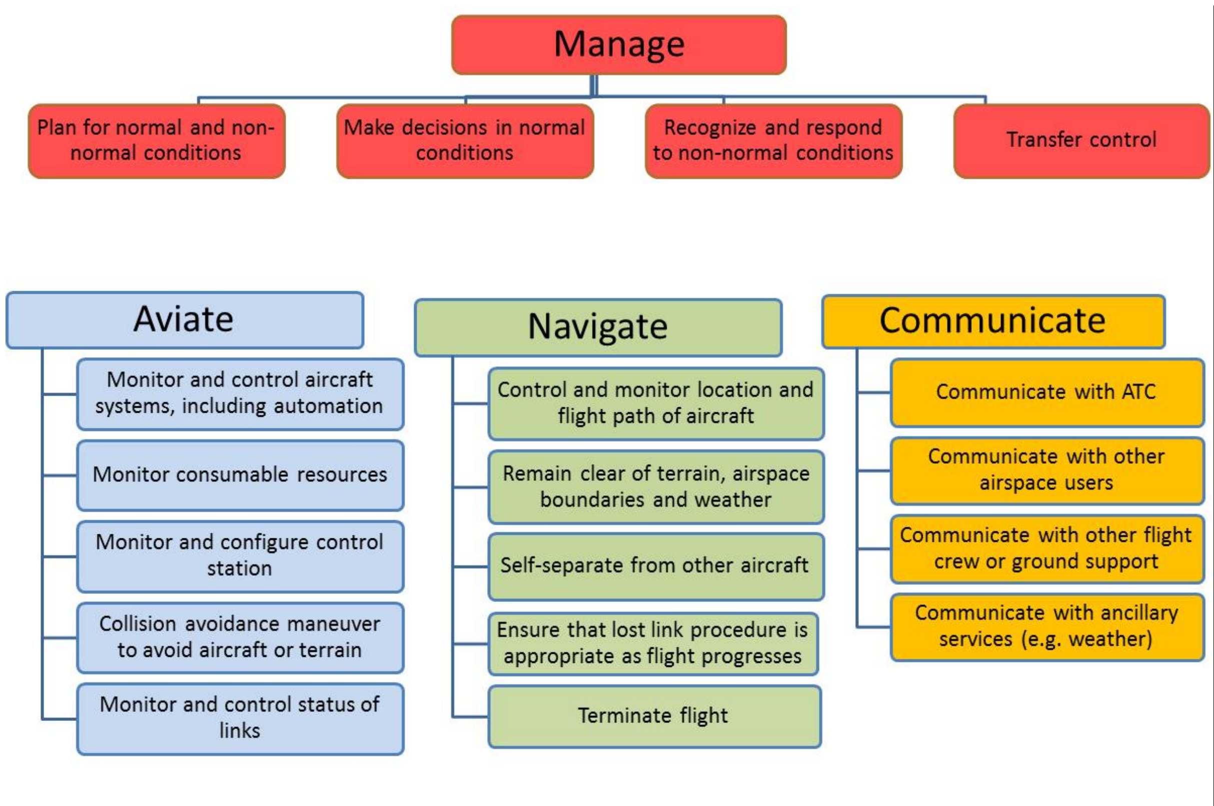

Figure 4. Responsibilities of the UAS pilot

Manage: The "Manage" category includes the overall planning, decision-making, and management responsibilities that must be accomplished by the pilot, supported by the human-machine interface. For ease of presentation, management responsibilities are shown separately in Figure 4, although they overlap and cut-across other responsibilities.

Aviate: These responsibilities include tactical, or short-term, control of the air vehicle and its ground-based equipment, and the control link. In most cases, the continuous control functions necessary for the maintenance of stable flight are allocated to on-board automation, however the pilot is still required to provide supervisory oversight and control the configuration of systems. Maneuvers to avoid collisions with other aircraft or objects are included in these responsibilities.

Navigate: The navigation responsibilities involve strategic, or longer-term, control of the air vehicle and its ground-based equipment. Controlling and monitoring the location and flight path of the aircraft includes ensuring that the aircraft navigates with respect to airspace boundaries, terrain and other considerations. The self-separation responsibility must be accomplished in the absence of an out-the-window view, necessitating reliance on a traffic situation display in the GCS. The two final responsibilities listed under “Navigate” are specific to unmanned aviation. The pilot must maintain an awareness of the aircraft’s pre-programmed lost link maneuver, and ensure that the maneuver is updated as necessary as the flight progresses. Finally, in the event of a serious in-flight anomaly, the pilot may be required to terminate the flight, possibly by directing the aircraft to a suitable location for a controlled impact or ditching, or by deploying a parachute system. In either case, the pilot must minimize risk to people and property.

Communicate: The pilot in command must communicate with ATC, other airspace users, other members of the flight crew or support team, and ancillary services such as weather briefers. Communication and coordination within the UAS operating team is critical and the UAS human-system interface must be designed to enable team situation awareness to be achieved. If the UA is operating far from the GCS, pilot-ATC communications may be relayed using ground infrastructure, satellite, or air-to-air relays. Relays have the potential to introduce time delays, with disruptive implications for verbal communication.

Guidelines

This section contains two broad sets of preliminary human factors guidelines. Guidelines contained in the first set refer to specific characteristics or capabilities of the interface, and are organized using the model of pilot responsibilities shown in Figure 4. The letter at the beginning of each guideline code indicates the type of guideline. Guidelines with codes beginning with "T_" specify pilot tasks that must be facilitated by the GCS. Guidelines specifying the information content of displays have codes beginning with "I_". Control input guidelines have codes beginning with "C_", and guidelines specifying properties of displays and controls have "P_" codes. The second set of guidelines comprises considerations that have general applicability to the GCS, possibly across multiple pilot responsibilities. These guidelines are indicated by a "G_" code. This set of guidelines includes human engineering activities that the GCS developer is expected to accomplish in order to produce a GCS that can be operated safely and reliably, considering human capabilities and limitations. Placeholders, denoted by "TBA" indicate where future material is to be added.

Characteristics and capabilities of the interface

Aviate

The goal of "Aviate" activities is to ensure that the basic functions of the aircraft operate effectively. These responsibilities include tactical, or short-term, control of the air vehicle, the control link, and the control station.

Responsibility 1.1: Monitor and control aircraft systems, including automation
In most cases, the continuous control functions necessary for the maintenance of stable flight are allocated to on-board automation, however the pilot is still required to provide supervisory oversight and control the configuration of systems. This may include mode selections for automated systems. The information necessary to perform these functions will be provided by the telemetry (or downlink) element of the control link

Pilot tasks that must be performed using the interface
T_1.1.1 The GCS should enable the pilot to monitor which entity has control of the aircraft and to what extent the entity has control. (Access 5 (2006) T_1.1.2 If an on-board camera is used for flight control tasks, the GCS should enable the pilot to center the field of view of the camera.
Information content of displays
TBA.
Control inputs
TBA.
Properties of displays and controls
P_1.1.1 The GCS should not enable the pilot to disengage automation in flight if the aircraft will depart from controlled flight as a result. P_1.1.2 The GCS should prevent multiple operators from operating the same application/procedures at any one time. (NATO, 2004) P_1.1.3 The GCS should provide the ability to allow other operators to view the status of aircraft systems. (NATO, 2004)
Related special considerations
A. Loss of natural sensing; B. Control and communication via radio link

Responsibility 1.2: Monitor consumable resources
Consumable resources on the UA can be expected to reduce in quantity over the course of a flight. Depending upon the design of the aircraft, these resources may include fuel, oil, and battery power. The GCS must enable the pilot to monitor the status of these resources. Many aspects of this responsibility will be the same for unmanned and manned aircraft. The task of monitoring consumable resources may involve aspects unique to UAS, including

unconventional propulsion systems and long duration flights. Additionally, the pilot must be prepared for the possibility that a lost link procedure may place additional demands on consumable resources, and the pilot may be unable to intervene while the aircraft is performing the lost link procedure.
Pilot tasks that must be performed using the interface
T_1.2.1 The GCS should enable the pilot to monitor the status of consumable resources.
Information content of displays
I_1.2.1 The GCS should provide the pilot with information on the status of consumable resources.
Control inputs
TBA.
Properties of displays and controls
Related special considerations
E. Unique flight characteristics of unmanned aircraft

Responsibility 1.3: Monitor and configure control station
Management of the GCS will require the pilot or other crewmembers to monitor and configure the status of the GCS, and identify and respond to abnormal conditions. This may include managing the performance of computer systems and power supplies. Unique considerations could include the need to manage uninterruptable power supplies and air conditioning required for computer systems. If a second GCS is planned to be used during the flight, or is available on standby, the pilot may also need to maintain an awareness of the state of readiness of this GCS.
Pilot tasks that must be performed using the interface

T_1.3.1 The GCS should enable the pilot to perform ground station performance checks. T_1.3.2 The GCS should enable the pilot to perform a pre-flight check on an alternate control station, or confirm that this check has been performed. (RTCA, 2007) T_1.3.3 The GCS should enable the pilot to check the control station for damage and function. T_1.3.4 The GCS should enable the pilot to monitor the performance of GCS support services, e.g. air conditioning and electrical power.
Information content of displays
I_1.3.1 The GCS should provide the pilot with health and status information on the GCS.
Control inputs
TBA.
Properties of displays and controls
TBA.
Related special considerations
C. Physical characteristics of the GCS

Responsibility 1.4: Maneuver to avoid imminent hazard – Collision Avoidance
This responsibility refers to tactical maneuvers to avoid collisions with proximate aircraft or objects. It includes the time-critical Collision Avoidance element of Detect and Avoid (DAA)*. In the case of collision avoidance with other aircraft, the human/machine system must detect the presence of proximate traffic, identify traffic that poses a collision threat, determine and carry out an appropriate response, as well as communicating with ATC. Given the speed with which a collision avoidance maneuver must be made, it is likely that communication with ATC will not occur prior to the commencement of the maneuver. Given the absence of an out-the-window view, the detection and presentation to the UAS pilot of traffic or other threats must be performed by technology. However the subsequent

steps may be assigned to either automation or the pilot, depending upon system design. Because a lost-link condition may prevent the pilot from performing a human-in-the-loop role during collision avoidance, some UAs may be capable of executing autonomous collision avoidance maneuvers. Collision avoidance can be seen as the final stage of DAA and will only be necessary when self-separation has not kept the UA well-clear of other traffic. Self-separation relates to the maintenance of a well-clear distance from traffic, and may occur while the aircraft are still some distance from each other. Guidelines that apply to the self-separation elements of detect and avoid (and the early steps of collision avoidance) can be found in section 2.3 “Self-Separation”. It should also be noted that because this document is focused on the unique requirements of unmanned aviation, standards for manned aviation that will also be relevant to unmanned aviation are not generally reproduced here. For more information the reader can refer to existing requirements for Traffic Alert and Collision Avoidance (TCAS) systems (RTCA, 2008) and Cockpit Displays of Traffic Information (RTCA, 2014). * *The self-separation element of DAA will be covered under the “Navigate” responsibility.*
The GCS should enable the pilot to accomplish the following tasks
The following tasks must be accomplished by the pilot in situations that require the UA to avoid a collision. T_1.4.1 The GCS should enable the pilot to identify the threat of an impending collision of the UA with other aircraft, terrain, or objects. T_1.4.2 The GCS should enable the pilot to recognize the need for a UA evasive maneuver to avoid an impending collision of the UA with other aircraft, terrain, or objects. T_1.4.3 The GCS should enable the pilot to determine an appropriate maneuver to avoid a collision of the UA with other aircraft, terrain, or objects. T_1.4.4 The GCS should enable the pilot to execute a UA collision avoidance maneuver. T_1.4.5 The GCS should enable the pilot to communicate with ATC about a collision avoidance maneuver and other departures from the assigned flight path. T_1.4.6 The GCS should enable the pilot to return the UA to the assigned flight path after

maneuvering to avoid a collision.

T_1.4.7 If the UA is capable of making an autonomous collision avoidance maneuver, the GCS should enable the pilot to monitor the maneuver.

T_1.4.8 If the UA executes an autonomous collision avoidance maneuver, the GCS should enable the pilot to smoothly regain control of the UA at the conclusion of the maneuver.

Information that GCS must provide for the pilot to accomplish the tasks

I_1.4.1 The GCS should provide an alert to the pilot when there is a threat of the UA colliding with another aircraft, terrain, or objects. The alert must be provided in time for the pilot to effectively respond to make the UA avoid the collision.

I_1.4.2 The GCS should provide information about terrain or ground-based objects within proximity of the projected UA flight path and may become a threat for UA collision.

I_1.4.3 The GCS should provide the pilot with the information necessary to detect aircraft, obstructions or people while the UA is moving on the ground. This information may be provided through a camera located on the aircraft, or Closed Circuit Television (CCTV) cameras located on the ground.

I_1.4.4 The GCS should provide the pilot with the information necessary to detect obstructions that may affect launch or takeoff. This information may be provided through a camera located on the aircraft, or CCTV cameras located on the ground.

I_1.4.5 The GCS should provide the pilot with the information necessary to detect obstructions that may affect approach and landing. This information may be provided through a camera located on the aircraft, or CCTV cameras located on the ground.

I_1.4.6 The GCS should provide the pilot information about the likelihood of the UA colliding with the upcoming threat so that the pilot will be able to make a decision about the need to take evasive action to avoid a collision.

I_1.4.7 The GCS should provide the pilot with a prediction of the time available until the UA would collide with the threat aircraft, object, or terrain.

I_1.4.8 The GCS should provide information about the aircraft surrounding the UA and the collision threat to help in making a decision about maneuvers that would not cause additional risks for collision.

I_1.4.9 The GCS should provide information about the capabilities of the UA for making evasive maneuvers in the current UA situation. This information should include at least the following:

> I_1.4.9a Possible maneuvers that can be made by the UA in the current situation – e.g. climb, descend, turn within a certain radius.

I_1.4.9b Time for the UA to accomplish the maneuvers – e.g. how long until the UA reaches a certain turn radius or climb attitude.

I_1.4.10 The GCS should provide the pilot with information necessary to quickly identify the current state, mode, or setting of all controls that are used to send flight commands to the UA.

I_1.4.11 The GCS should provide the pilot with information on the flight path that had been assigned to the UA prior to the evasive maneuver.

I_1.4.12 The GCS should provide information about the necessary UA trajectory needed to return to the assigned flight path. This should include the necessary UA heading and altitude changes.

I_1.4.13 If an autonomous collision avoidance maneuver is carried out, the GCS should alert the pilot that the maneuver is underway, and must notify the pilot when the maneuver is concluded.

Control inputs

C_1.4.1 The GCS should provide a control to cancel the collision alert if it will be ongoing and distract the pilot in accomplishing other tasks.

C_1.4.2 Flight controls should be provided to enable the pilot to rapidly command the UA to execute an effective maneuver to avoid an impending collision. The controls should be readily available at all times and must be designed to enable the pilot to make the command to the UA in the time needed to perform the collision avoidance maneuver. The flight controls must include means to control:

C_1.4.2a UA attitude.

C_1.4.2b UA heading.

C_1.4.2c UA speed and/or thrust.

Properties of displays and controls

The following properties are important to consider when designing the GCS displays and controls for the pilot to accomplish collision avoidance maneuvers.

P_1.4.1 Information and controls should be readily accessible for the pilot to recognize and accomplish collision avoidance maneuvers.

P_1.4.2 Collision avoidance alerts must attract the pilot's attention in all expected lighting and operating conditions.

P_1.4.3 Time-consuming or complicated sequences of actions (e.g. involving multiple levels of menu structures) must not be necessary to accomplish collision avoidance maneuvers.

P_1.4.4 Primary flight controls should be designed in a manner for the pilot to quickly execute critical collision avoidance maneuvers in all expected operating conditions.

Related Special UAS Considerations
A. Loss of natural sensing.

Responsibility 1.5: Manage status of control links
The control and communications (C2) link is an integral part of the UAS. The link may utilize a combination of technologies, including terrestrial radio (stand-alone or networked), satellite radio (geostationary or low earth orbit), air-to-air relays, and ground-based communication infrastructure. As well as managing the aircraft, the flight crew of a UAS operating in the NAS must maintain an awareness of the status of the C2 link, and will require the ability to manage the link. Link management will be particularly critical during control handovers, lost link and link resumption, when operating towards the limits of the signal, and during frequency changes. The use of the word "link" in the following guidelines includes uplink and downlink.
Pilot tasks that must be performed using the interface
T_1.5.1 The GCS should enable the pilot to confirm spectrum availability before selecting link. T_1.5.2 The GCS should enable the pilot to select the appropriate communication mode (e.g. terrestrial/satellite, frequency). T_1.5.3 The GCS should enable the pilot to maintain awareness of selected communication mode. T_1.5.4 The GCS should enable the pilot to confirm that communication link is effective, and established with the correct UA. T_1.5.5 The GCS should enable the pilot to identify if more than one control station is linked with the UA. T_1.5.6 The GCS should enable the pilot to maintain awareness of link strength, or link abnormalities. T_1.5.7 The GCS should enable the pilot to maintain awareness of link latency, where relevant. T_1.5.8 The GCS should enable the pilot to anticipate link degradations or diminished link strength.

T_1.5.9 The GCS should enable the pilot to maintain an awareness of the geographic limits of the link and potential obstructions to signal.

T_1.5.10 The GCS should enable the pilot to maintain awareness of crew actions or control inputs that could interrupt or degrade the link.

T_1.5.11 The GCS should enable the pilot to respond to interference with the signal, (e.g. other users of frequency, jamming attempts).

T_1.5.12 The GCS should enable the pilot to change the link during flight operations as necessary.

T_1.5.13 The GCS should enable the pilot to assess link strength and quality before switching link.

T_1.5.14 The GCS should enable the pilot to define the duration of a loss of link that must occur before the lost link alert is activated, or the UA enters its lost link procedure.

T_1.5.15 The GCS should enable the pilot to manage resumption of the signal after a lost link.

Information content of displays

I_1.5.1 The GCS should be capable of providing the pilot with predictive information on the quality and strength of a C2 link before the link is actively used to control the UA.

I_1.5.2 The GCS should provide information to enable the pilot to identify which C2 link settings are active (e.g. selected frequency, satellite vs terrestrial).

I_1.5.3 The GCS should provide the pilot with information to confirm that effective control is established with the correct UA.

I_1.5.4 The GCS should provide the pilot with information on the geographic limits of the link.

I_1.5.5 The GCS should provide the pilot with information on spectrum activity from a spectrum analyzer.

I_1.5.6 The GCS should alert the pilot when the UA is approaching an area where link is likely to be lost.

I_1.5.7 The GCS should alert the pilot when the link is lost.

I_1.5.8 The UA will transmit a pre-determined transponder code when the link is lost.

I_1.5.9 The GCS should provide information to enable the pilot to monitor the strength of the link.

I_1.5.10 The GCS should alert the pilot whenever the C2 link experiences interference, whether resulting from natural phenomena, payload or other equipment associated with the UAS, or human activities (such as jamming or other users on frequency).

I_1.5.11 The GCS should display to the pilot the source of downlink transmissions.

(Access 5,2006)

I_1.5.12 Where relevant, the GCS should provide the pilot with information on link latency, in milliseconds.

I_1.5.13 The GCS should provide information to enable the pilot to anticipate link degradations or diminished link strength. This information may include link footprint, including areas that may be affected by terrain masking.

I_1.5.14 The GCS should provide information to enable the pilot to manage link security.

I_1.5.15 The GCS should inform the pilot when a lost link is resumed.

Control inputs

C_1.5.1 The GCS should enable the pilot to select the communication mode (e.g. terrestrial/satellite, frequency, transmission power).

C_1.5.2 The GCS should provide a control to enable the pilot to request a link status report.

C_1.5.3 If antenna selection is performed by the pilot, then the GCS should support an external command to set the antenna used for communication.

C_1.5.4 The GCS should enable the pilot to set the duration of a link outage that must occur before a lost link response is triggered.

Properties of displays and controls

P_1.5.1 "There must be an alert for the UAS crew, via a clear and distinct aural and visual signal, for any total loss of the command and control data link".
(NATO, 2009)

P_1.5.2 The aural warning for lost control link should be a unique sound, not also used to signify other conditions.

P_1.5.3 The maximum range of the C2 datalink (datalink footprint) for all altitudes and directions relative to the signal source should be presented visually to the pilot, overlaid on a map display.

P_1.5.4 Areas where the C2 link (datalink footprint) are predicted to be masked by terrain should be displayed on the C2 datalink display.

P_1.5.5 If the datalink footprint can be suppressed, it should be automatically displayed when the UA is approaching a location where a loss of link is likely.

P_1.5.6 The C2 datalink footprint should be easily distinguishable from other footprints that may be present on the operator map display.
(NATO, 2004).

P_1.5.7 If the payload utilizes a link separate to the aircraft control link, any display of payload

link quality should be separate and clearly distinguishable from displays for the aircraft control link. P_1.5.8 If an aural warning is used to indicate loss of payload link, the sound should be dissimilar to that used to indicate loss of control link. P_1.5.9 Security features designed to prevent unapproved access (logon and logoff functions) should not result in inadvertent lockouts of authorized personnel. P_1.5.10 The GCS, in combination with the other elements of the UAS should comply with control link latency (time from initiation of a maneuver to a measurable response by the UA) requirements that are established at a level similar to manned aircraft. (FAA, 2013b)
Related special considerations
B. Control and communication via radio link .

Navigate

The navigate responsibility involves largely strategic, or longer-term, control of the air vehicle and its ground-based equipment.

Responsibility 2.1: Control and monitor location and flight path of aircraft.
Controlling and monitoring the location and flight path of the aircraft includes ensuring that the aircraft keeps to its flight plan, taking into account airspace boundaries, terrain and other considerations. This responsibility includes ground taxiing and complying with all requirements for navigating airport taxiways and runways.
Pilot tasks that must be performed using the interface
T_2.1.1 The GCS should enable the pilot to monitor and control the position of the UA when on the ground and in the air. T_2.1.2 The GCS should enable the pilot to ensure that both the runway and approach path are clear of traffic before taxiing onto the active runway. (FAA, 2013b) T_2.1.3 “The UAS shall be capable of transitioning from an instrument approach procedure to a safe landing, either by visual reference of a flight crewmember at the airport or by other means acceptable to the FAA”. (FAA, 2013b)

Information content of displays
I_2.1.1 UA position in airspace. The GCS should provide a representation of the UA within the airspace. This information should provide: I_2.1.1a Representation of UA within the airspace. I_2.1.1b Heading of UA. I_2.1.1c Altitude of UA. I_2.1.1d Speed of UA. I_2.1.1e Attitude of UA. I_2.1.1f Position of UA relative to other aircraft, terrain, and obstacles. I_2.1.2 Programmed flight plan and predicted flight path of UA. The GCS should provide a representation of the predicted flight path of the UA based on the flight plan programmed into the flight management system based on the assigned flight clearance. This information should include: I_2.1.2a Indication of UA current position along programmed flight path. I_2.1.2b.Predicted flight path relative to UA and other traffic, terrain, and obstacles. I_2.1.2c Distance to waypoints along flight path. I_2.1.2d Indication of position in flight path when new commanded altitude will be attained. I_2.1.2e Indication of turning radius and path when making turns along flight path.
Control inputs
C_2.1.3 The GCS should enable the pilot to maneuver the UA.
Properties of displays and controls
P_2.1.1 The map display should be able to support a variety of map types including aeronautical charts and presentations of Digital Terrain Elevation Data (DTED). P_2.1.2 The presentation scale of the map should be selectable. Continuous scaling is preferred to discrete. (NATO, 2004) P_2.1.3 The pilot should be able to derive the scale of the map from the display. (NATO, 2004)

P_2.1.4 The map display should enable the pilot to customize the Aircraft's Information Trail.
(NATO, 2004)

P_2.1.5 The map display should be configurable to "North up" or "Track up".

P_2.1.6 If control is via a terrestrial radio, the location of (or direction to) the ground transmitter/receiver should be shown on the map.

P_2.1.7 Primary flight controls for controlling the UA (heading, attitude, speed) should be available at all times through dedicated physical controls. If the use of software-based controls cannot be avoided, then the controls should be immediately accessible at the top level of the control interface.
(NATO, 2009).

P_2.1.8 Map displays should have means to select the scale of the map to be presented. The scales presented on the maps should be evident to the pilot.
(NATO, 2004)

P_2.1.9 The pilot should have the means to customize the information trail for an aircraft shown on the traffic display.
(NATO, 2004)

Related special considerations

A. Loss of natural sensing; C. Control station on ground; G. Reliance on automation.

Responsibility 2.2: Remain clear of terrain, airspace boundaries and weather

This responsibility covers the activities involved in remaining clear of undesired locations that can be identified during flight planning or may become apparent during the course of a flight. These locations may be undesired due to terrain, airspace boundaries, weather, or other operational restrictions.

Pilot tasks that must be performed using the interface

T_2.2.1 The GCS should enable the pilot to ensure that both the runway and approach path are clear of traffic before taxiing onto the active runway.
(FAA, 2013b)

T_2.2.2 The GCS should enable the pilot to "observe" and comply with signage and warning lights during surface operations.

(FAA, 2013b)

T_2.2.3 The GCS should enable the pilot to monitor weather that has the potential to affect the flight.
(RTCA, 2007)

T_2.2.4 The GCS should enable the pilot to avoid weather that has the potential to affect the flight.

T_2.2.5 The GCS should enable the pilot to avoid icing conditions.

Information content of displays

Display Airspace Coordination Information

I_2.2.1 "The operator should be able to display flight corridors, controlled airspace and any other relevant airspace co-ordination information".
(NATO, 2004)

I_2.2.2 The GCS should display weather information to the pilot.

I_2.2.3 The GCS should provide the pilot with information on the location of icing conditions , especially if the UA is not certificated for flight in icing conditions.

I_2.2.4 The GCS should alert the pilot when the UA enters icing conditions.

I_2.2.5 The GCS should alert the pilot when the UA encounters significant air turbulence.

Control inputs

TBA.

Properties of displays and controls

TBA.

Related special considerations

A. Loss of natural sensing; E. Unique characteristics of UAS flight.

Responsibility 2.3: Self- separate from other aircraft

This responsibility includes the strategic separation assurance function of Detect and Avoid (DAA), in which the UA remains well clear of other traffic*. The NASA *UAS in the NAS*

project is developing Minimum Operational Performance Standards (MOPS) for the human-machine interface (HMI) of DAA Systems. This material will focus on UAS-specific issues that are not covered in RTCA (2014) "Guidelines for Cockpit Displays of Traffic Information", and will be included in a forthcoming standard to be published by RTCA in 2016. The final approved RTCA guidelines, when publically released, will replace the preliminary self-separation guidelines included below. For the purposes of this document, guidelines that have general relevance to navigation are contained in Section 2.1 "Control and Monitor Location and Flight path of Aircraft". Guidelines that relate to communication with ATC that must occur to accomplish self-separation are contained in Section 2.0 "Communication". * Note that evasive maneuvers for immediate collision avoidance are included under "1.4: Maneuver to avoid imminent hazard – Collision Avoidance".
Pilot tasks that must be performed using the interface
T_2.3.1 The GCS should enable the pilot to monitor all traffic in the airspace around the UA to identify potential for upcoming well-clear violations. T_2.3.2 The GCS should enable the pilot to quickly identify any threat of an aircraft violating the well-clear airspace of the UA T_2.3.3 The GCS should enable the pilot to track the surrounding traffic flight paths, assess the risk of well-clear violations, and recognize the need for the UA to maneuver to maintain self-separation criteria T_2.3.4 The GCS should enable the pilot to determine the appropriate maneuver for the UA to make to maintain self-separation. T_2.3.5 The GCS should enable the pilot to command the UA to execute the evasive maneuver T_2.3.6 The GCS should enable the pilot to communicate with ATC about making the separation maneuver and departing from the assigned flight path T_2.3.7 The GCS should enable the pilot to return the UA to the assigned flight path after maneuvering for self-separation.
Information content of displays

Material from RTCA SC-228 Minimum Operational Performance Standards (MOPS) for Unmanned Aircraft Detect and Avoid to be added here. This MOPS is currently in draft form.
Control inputs
Material from RTCA SC-228 Minimum Operational Performance Standards (MOPS) for Unmanned Aircraft Detect and Avoid to be added here.
Guidelines for properties of displays and controls
Material from RTCA SC-228 Minimum Operational Performance Standards (MOPS) for Unmanned Aircraft Detect and Avoid to be added here.
Related Special UAS Considerations
A: Loss of natural sensing.

Responsibility 2.4: Ensure that lost link procedure is appropriate
The pilot must maintain an awareness of the aircraft's pre-programmed lost link maneuver, and ensure that the maneuver is updated as necessary as the flight progresses. If the lost link procedure becomes "stale", the aircraft may execute an unsafe maneuver in the event of a lost link, such as flying towards terrain in an attempt to reach a waypoint programmed earlier in the flight.
Pilot tasks that must be performed using the interface
T_2.4.1 The GCS should enable the pilot to remain aware of the aircraft's lost link procedure as the flight progresses. T_2.4.2 The GCS should enable the pilot to update the aircraft's lost link procedure as the flight progresses.
Information content of displays
I_2.4.1 The GCS should provide the pilot with a display indicating the future flightpath of the

aircraft should a lost link occur.

I_2.4.2 The GCS should alert the pilot whenever the execution of a lost link procedure would create a hazard (such as directing the aircraft towards terrain, or into non-authorized airspace).

Control inputs

TBA.

Properties of displays and controls

P_2.4.1 The flightpath that would be taken by the aircraft in the event of a lost link should be clearly distinguishable from the programmed normal flightpath of the aircraft.

P_2.4.2 Information on the programmed lost link behavior of the aircraft should be readily available to the pilot, without the need for complex interactions with the human-machine interface.

Related special considerations

B. Control and communication via radio link

Responsibility 2.5: Flight termination

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. Some UAS designs will make provision for an emergency recovery system, such as a parachute. Human factors considerations will include the information pilots will require to make this difficult decision and execute the action, as well as measures to protect against the inadvertent activation of the flight termination system.

Pilot tasks that must be performed using the interface

T_2.5.1 The GCS should enable the pilot to decide when to terminate the flight via controlled impact, ditching or parachute descent.

T_2.5.2 The GCS should enable the pilot to identify a suitable location for flight termination.

T_2.5.3 The GCS should enable the pilot to terminate the flight in a pre-designated area. (RTCA, 2007)

T_2.5.4 The GCS should enable the pilot to use real-time information to confirm that flight termination at the selected location will not present unacceptable risk to people or property.

Information content of displays

I_2.5.1 The GCS should provide the pilot with real-time imagery of the selected impact, ditching or parachute descent site to confirm that a safe termination can be accomplished.

I_2.5.2 The GCS should provide an alert to the pilot to indicate that the flight termination system is about to be activated.

Control inputs

TBA.

Properties of displays and controls

P_2.5.1 When the UA is equipped with a flight termination system:

P_2.5.1a. The use of these controls should be intuitive and minimize the possibility of confusion and subsequent inadvertent operation.

P_2.5.1b. Two distinct and dissimilar actions of the UAS crew should be required to initiate the flight termination command.
(NATO, 2009)

Note: STANAG 4671 (NATO, 2009) specifies that flight termination controls "must be arranged and identified such that they are readily available and accessible". This text has been deleted from this document as it is believed that flight termination controls should not be readily accessible. STANAG 4671 did not contain requirement for dissimilar controls. This requirement is based on the experience contained in NASA procedural requirements related to two-fault tolerance).

P_2.5.2 Before the final step in activating the flight termination system is reached, the GCS should provide an aural and visual alert to the pilot that flight termination is about to be activated.

P_2.5.3 The aural alert warning of imminent flight termination should involve a unique sound. This should preferably take the form of a verbal message such as "Flight termination!"

P_2.5.4 When the UA is equipped with a flight termination system, flight termination controls should be safeguarded from interference that could lead to inadvertent operation.
(NATO, 2009).

Related special considerations

F. Flight termination

Communicate

The Pilot in command must communicate with ATC, other airspace users, other members of the flight crew or support team, and ancillary services such as weather briefers.

Responsibility 3.1: Communicate with ATC and other airspace users
Communication with ATC is typically via VHF voice communications transmitted from the UA, or in some cases, controller pilot data link (CPDL). If the UA is operating beyond radio line-of-sight from the ground transmitter, communications may be relayed using ground infrastructure or satellite. Additionally, air-to-air relays between UAs may be used in some cases. Relays have the potential to introduce time delays into communications. In addition to communicating with ATC, the pilot may be required to communicate with other airspace users. This includes direct pilot-to-pilot communications as well as "party line" communications that the pilot to maintain awareness of the location and intentions of other users of the airspace.
Pilot tasks that must be performed using the interface
T_3.1.1 When operating near a non-towered airport, the pilot should be able to exchange intent information with other airport traffic through standard communications on the airport common traffic advisory frequency (CTAF). (FAA, 2013b) T_3.1.2 The UAS pilot should be able to establish an alternate communications method with ATC if the duration of the communications loss exceeds requirements for the operating environment. (FAA, 2013b)
Information content of displays
I_3.1.1 The GCS should include alternate means for the pilot to communicate with ATC in the event of a loss of C2 link. I_3.1.2 Current settings of communication controls. The GCS should provide the pilot with information about the current state, mode, or setting of the controls used for communication with ATC.
Control inputs

TBA.
Properties of displays and controls
P_3.1.1 The voice communication delay between the pilot and ATC should have a mean less than or equal to 250 ms. (FAA, 2012) P_3.1.2 The voice communication delay between the pilot and ATC should be less than or equal to 300 ms. (99th percentile). (FAA, 2012) P_3.1.3 The voice communication delay between the pilot and ATC should be within a maximum of 350 ms. (FAA, 2012)
Related special considerations
B. Control and communication via radio link.

Responsibility 3.2: Communicate with other UAS flight crew and ground support personnel
Ground support personnel, external observers and other support personnel may be located remote from the GCS. Communication and coordination within the operating team will require special attention, and the human system interface must be designed to enable team situation awareness to be achieved. Some current UAS operators use closed circuit TV cameras to enable the pilot to monitor the aircraft during pre- and post-flight ground handling. Where control of the UA will be transferred in flight, communication must occur between the giving and receiving pilots. This may involve voice, or text based communications.
Pilot tasks that must be performed using the interface
T_3.2.1 The GCS should enable the UAS crewmembers to communicate with each other (co-located or not) in order to perform the necessary flight tasks. (FAA, 2013b) T_3.2.2 The GCS should enable the pilot to ensure that commands sent to the aircraft on the ground do not create a safety hazard for ground support personnel.

Information content of displays
I_3.2.1 The GCS should provide the pilot with imagery of the aircraft whenever the pilot has control of the aircraft on the ground and ground support personnel are interacting with the aircraft. I_3.2.2 The GCS should provide the pilot with a communication link with ground support personnel while they are interacting with the aircraft.
Control inputs
TBA.
Properties of displays and controls
TBA
Related special considerations
A. Loss of natural sensing; B. Control and communication via radio link; C. Physical characteristics of the control station

Responsibility 3.3: Communicate with ancillary services
Ancillary services include weather briefers, and other personnel providing external support to the UAS operation.
Pilot tasks that must be performed using the interface
T_3.3.1 The GCS should enable the pilot to communicate with weather information services and other ancillary services.
Information content of displays
TBA
Control inputs
TBA
Properties of displays and controls

TBA
Related special considerations
TBA

Manage Systems and Operations

Responsibility 4.1: Make decisions in normal conditions
Pilot tasks that must be performed using the interface
TBA.
Information content of displays
TBA.
Control inputs
TBA.
Properties of displays and controls
TBA.
Related special considerations
TBA.

Responsibility 4.2: Recognize and respond to non-normal conditions
Pilot tasks that must be performed using the interface
TBA.
Information content of displays

TBA.
Control inputs
TBA.
Properties of displays and controls
TBA.
Related special considerations
TBA.

Responsibility 4.3: Plan for normal and non-normal conditions
Pilot tasks that must be performed using the interface
TBA.
Information content of displays
TBA.
Control inputs
TBA.
Properties of displays and controls
TBA.
Related special considerations
TBA.

Responsibility 4.4: Transfer control
The ability to completely transfer control between or within control stations is one of the key differences between UAS operations and conventional aviation. Handovers have been identified as an area of increased risk in a range of industrial and transport settings, including aircraft maintenance, medicine, and air traffic control. Handovers require special attention to ensure that the crew of the "receiving" and "giving" GCS possess a shared understanding of the operational situation and that control settings are aligned between the two control stations.
Pilot tasks that must be performed using the interface
T_4.4.1 The GCS should enable control to be transferred between a giving and receiving GCS in a manner that is seamless and transparent to ATC. (FAA, 2013b) T_4.4.2 The GCS should enable continuity of pilot function to be maintained during the transfer of control between a giving and receiving GCS. (FAA, 2013b) T_4.4.3 "The GCS shall enable the pilot to ensure that operating parameters are identical before and after handover". (NATO, 2009) T_4.4.4 The GCS should enable the pilot to pass UA control (handover) to another GCS and monitor the status of the handover. (NATO, 2004) T_4.4.5 The GCS should enable the pilot to monitor which entity has control of the aircraft and to what extent the entity has control. (Access 5, 2006) T_4.4.6 The GCS should enable the giving and receiving pilots to confirm that control settings are appropriate and consistent before a handover is accomplished. T_4.4.7 The GCS should enable the receiving pilot to monitor the status of the UA by receiving telemetry from the UA before establishing control of the UA. T_4.4.8 The GCS should facilitate a handover briefing between the giving and receiving pilots. T_4.4.9 The GCS should provide the receiving pilot with a means of confirming that control has been established with the UA.
Information content of displays
I_4.4.1 The pilot should be presented with information necessary to confirm that flight-critical settings in the receiving GCS are consistent with settings in the giving GCS. I_4.4.2 The GCS should provide a level of involvement indicator to the pilot to show whether the GCS has been set to only receive telemetry from the UA, or to receive telemetry <u>and</u> transmit commands to the UA.

Control inputs
C_4.4.1 The GCS should enable the pilot to select the desired level of involvement with a UA, ranging from monitoring telemetry without an active uplink, to telemetry with full control via an active uplink. C_4.4.2 There should be a means for the giving and receiving pilots to communicate before, during and after the handover.
Properties of displays and controls
P_4.4.1 The GCS should provide suitable displays to enable briefings to be conducted between a seated pilot and a standing pilot during control handovers. This may include the use of large scale synoptic displays. P_4.4.2 The GCS should enable control to be transferred to another GCS without any gap in control occurring during the handover.
Related special considerations
D. In-flight transfer of control.

General guidelines

The guidelines listed in this section are broad principles that have general applicability to the GCS. Even though they may appear elsewhere in the human factors literature, these guidelines are listed here because they have special relevance to UAS in light of the human factors considerations listed in Table 2.

G_1 UAS developers should follow recognized human-centered design processes including the following:

> G_1a. Develop a full set of pilot tasks and intended operations for which the GCS will be used. These will help drive ensuring a thorough design that provides all systems, information, and controls that the pilots will need.
>
> G_1b. Develop an understanding of the potential safety critical errors that the pilots may make when accomplishing their tasks. These will provide the foundation for making trade-offs in design decisions by focusing on design attributes that will mitigate critical errors as needed.
>
> G_1c. Develop a full set of information requirements for the tasks the pilots will need to accomplish. These requirements should be developed with other design requirements at the

beginning of the systems engineering process. They will help ensure that the appropriate information is provided to the pilots and provide the foundation for making design decisions. G_1d. Develop a full set of requirements for controls that the pilot will need to accomplish their tasks. These requirements should be developed with other design requirements at the beginning of the systems engineering process. They will help ensure that all the pilot controls are planned for as design decisions are made. G_1e. Document all of the results of these processes so that they can be continually updated when design decisions and trade-offs are made during the design process. Good documentation will also help the human factors design processes to be integrated with the other systems engineering development and design processes.
Supporting notes: Many safety studies have concluded that design-related issues that lead to accidents or incidents were the result of inadequate attention to developing and documenting sound design requirements, not poor decisions about design characteristics. Following the processes presented in this guideline will help provide a foundation to ensure that human factors-related requirements are developed and documented as a basis for good human factors design decisions.
Related special considerations: General

G_2 The use of multi-mode functions on flight controls should be minimized. If modes are used, the system should clearly indicate the current mode, and other potential modes should be indicated.
Supporting notes: Flight-critical controls that can perform different functions based on mode selection have the potential to provoke control errors. In some GCS for example, a sidestick controller will control either pitch or speed, depending on the selected mode. Evidence from conventional aviation indicates that maintaining mode awareness can be difficult for pilots under some circumstances, and the resulting mode confusion can lead to accidents.
Related special considerations: G. Reliance on automation; H. Widespread use of interfaces based on consumer products.

G_3 If changing a mode selection of an automated system has a safety consequence, the action to select that mode should be alerted, and additional precautions should be taken to prevent inadvertent selection.
Supporting notes: Flight-critical controls that can perform different functions based on mode selection have the potential to provoke control errors. There have been cases where the UAS pilot has selected a mode in flight that renders the aircraft uncontrollable. The GCS design should make it difficult to perform such a mode selection action.
Related special considerations: G. Reliance on automation; H. Widespread use of interfaces based on consumer products.

G_4 Payload controls should be separate from controls with safety-of-flight functions.
Supporting notes: Some GCS designs have involved multi-function controls that can be configured to either control a safety-of-flight function or a non-critical payload function. A notable example was the accident to a MQ-9 in which the engine of the aircraft was shut down inadvertently. Although the accident was related to multiple causal factors, one issue was that a single lever in the GCS could be configured to either control an engine setting or control an iris setting on a camera (NTSB, 2006).
Related special considerations: General

G_5 It should not be possible to reconfigure a safety-of-flight control to perform a payload function.
Supporting notes: Some GCS designs have involved multi-function controls that can be configured to either control a safety-of-flight function or a non-critical payload function. The widespread use of consumer software interfaces in GCS make it possible to rapidly re-configure controls to perform functions that were not intended by the original designers.
Related special considerations: H. Widespread use of interfaces based on consumer products.

G_6 Activation of a key or button should provide tactile or auditory feedback to the pilot. (ANSI/HFES, 2007)
Supporting notes: TBA
Related special considerations: G. Reliance on automation; H. Widespread use of interfaces based on consumer products.

G_7 There should be a clear indication to the pilot when a command has been received by the UAS.
Supporting notes: The location of the UAS pilot, remote from the aircraft, can make it challenging for the pilot to maintain an awareness of system state and behavior of the aircraft. In the absence of other sensory cues, it is particularly important that the pilot receive feedback that a command has been received and is being acted upon.
Related special considerations: A. Loss of natural sensing; B. Control and Communication via radio link; G. Reliance on automation; H. Widespread use of interfaces based on consumer products.

G_8 Any unrecognized entry made by the pilot at the GCS should cause an informative error message to be displayed and not affect the status or operation of any system. (Access 5, 2006)
Supporting notes: The rich sensory cues available to the pilot of a conventional aircraft include visual, auditory, proprioceptive and olfactory sensations. The absence of these cues when operating a UAS can make it more difficult for the pilot to maintain an awareness of the aircraft's state. Observations of airline pilots have indicated that "pilot error" is a relatively frequent event, yet most of these errors are rapidly identified and corrected by the crews themselves (ICAO, 2002). The location of the UAS pilot remote from the aircraft may make pilot

error self-correction more difficult.
Related special considerations: A. Loss of natural sensing; B. Control and Communication via radio link; G. Reliance on automation; H. Widespread use of interfaces based on consumer products.

G_9 Flightcrew alerting. (Quoted verbatim from CFR § 25.1322)

G_9 "(a) Flightcrew alerts must: (1) Provide the flightcrew with the information needed to: (i) Identify non-normal operation or airplane system conditions, and (ii) Determine the appropriate actions, if any. (2) Be readily and easily detectable and intelligible by the flightcrew under all foreseeable operating conditions, including conditions where multiple alerts are provided. (3) Be removed when the alerting condition no longer exists.

G_9 (b) Alerts must conform to the following prioritization hierarchy based on the urgency of flightcrew awareness and response. (1) Warning: For conditions that require immediate flightcrew awareness and immediate flightcrew response. (2) Caution: For conditions that require immediate flightcrew awareness and subsequent flightcrew response. (3) Advisory: For conditions that require flightcrew awareness and may require subsequent flightcrew response.

G_9 (c) Warning and caution alerts must: (1) Be prioritized within each category, when necessary. (2) Provide timely attention-getting cues through at least two different senses by a combination of aural, visual, or tactile indications. (3) Permit each occurrence of the attention-getting cues required by paragraph (c)(2) of this section to be acknowledged and suppressed, unless they are required to be continuous.

G_9 (d) The alert function must be designed to minimize the effects of false and nuisance alerts. In particular, it must be designed to: (1) Prevent the presentation of an alert that is inappropriate or unnecessary. (2) Provide a means to suppress an attention-getting component of an alert caused by a failure of the alerting function that interferes with the flightcrew's ability to safely operate the airplane. This means must not be readily available to the flightcrew so that it could be operated inadvertently or by habitual reflexive action. When an alert is suppressed, there must be a clear and unmistakable annunciation to the flightcrew that the alert has been suppressed.

G_9 (e) Visual alert indications must: (1) Conform to the following color convention:(i) Red for warning alert indications. (ii) Amber or yellow for caution alert indications. (iii) Any color except red or green for advisory alert indications. (2) Use visual coding techniques, together with other alerting function elements on the flight deck, to distinguish between warning, caution, and advisory alert indications, if they are presented on monochromatic displays that are not capable of conforming to the color convention in paragraph (e)(1) of this section.
G_9 (f) Use of the colors red, amber, and yellow on the flight deck for functions other than flightcrew alerting must be limited and must not adversely affect flightcrew alerting".

Supporting notes: The presentation of warnings, cautions and advisories is an area where current GCS designs have been particularly deficient. Designs have tended to present information in textual format, which requires the pilot to receive the information through the limited channel of foveal vision. In the absence of a direct on-board experience of the aircraft's performance, the UAS pilot is entirely reliant on warning, caution and advisory alerts for critical information on system status. The above requirements are quoted directly from CFR part 25 due to their particular relevance to GCS designs.
Related special considerations: A. Loss of natural sensing

G_10 Systems that alert the pilot to a critical anomaly should not be subject to a silent failure.
Supporting notes: TBA.
Related special considerations: G. Reliance on automation.

G_11 The GCS should provide a work environment that maintains pilot engagement, and minimizes the negative impact of extended periods of low workload.
Supporting notes: The UAS pilot may experience extended periods of low workload, particularly when the pilot's role is limited to the supervisory control of automation (Cummings, Mastracchio, Thornburg, & Mkrtchyan, 2013). It is well-established that humans have difficulty maintaining vigilance on tasks that involve long periods of monotonous monitoring. The pilot may have to make a rapid transition from an unstimulating period of monitoring to a period of high workload and quick decision-making. Control stations tend to be relatively quiet, air conditioned environments with low levels of noise. The experience of settings such as industrial control rooms and locomotive cabs indicates that such unstimulating environments can make it

more difficult for personnel to remain alert, especially when fatigued. Control stations must be designed to maintain pilot engagement even during extended periods of uneventful operation. This guideline does not specify how pilot engagement should be maintained, or how losses of vigilance should be detected. It should be noted that there is a long history in the railroad industry of "vigilance control devices" or "deadman's handles" designed to maintain operator vigilance. Some road vehicles now include devices intended to detect sleep episodes in drivers, by monitoring eye closures or detecting reduced control inputs.
Related special considerations: C; Control station on ground; E. Unique characteristics of UAS flight

G_12 The GCS should provide consistency of operation for common functions.
Supporting notes: TBA.
Related special considerations: G. Reliance on automation.

G_13 The functions needed to safely control the aircraft under usual flight situations should be located in the pilot's primary field-of-view.
Supporting notes: TBA.
Related special considerations: C. Physical characteristics of the control station; G. reliance on automation.

G_14 Warnings and cautions should not be obscured by other GCS displays.
Supporting notes: TBA.
Related special considerations: C. Physical characteristics of the control station ; G. Reliance on

automation.

G_15 “Part-time display. If it is desired to inhibit some parameters from full-time display, an equivalent level of safety to full-time display should be demonstrated. Criteria to be considered include the following: (a) Continuous display of the parameter is not required for safety of flight in all normal flight phases. (b) The parameter is automatically displayed in flight phases where it is required. (c) The inhibited parameter is automatically displayed when its value indicates an abnormal condition, or when the parameter reaches an abnormal value. (d) Display of the inhibited parameter can be manually selected by the UAV crew without interfering with the display of other required information. (e) If the parameter fails to be displayed when required, the failure effect and compounding effects must meet the requirements of USAR.1309. The analysis is to clearly demonstrate that the display(s) of data is consistent with safe operation under all probable operating conditions. (f) The automatic, or requested, display of the inhibited parameter should not create unacceptable clutter on the display; simultaneous multiple "pop-ups" must be considered. (g) If the presence of the new parameter is not sufficiently self-evident, suitable alerting must accompany the automatic presentation”. STANAG 4671 AMC.1722
Supporting notes: This material is taken verbatim from NATO (2009).
Related special considerations: G. Reliance on automation; H. Widespread use of interfaces based on consumer products.

G_16 Wherever possible, text messages, whether in dialog boxes, warning messages or other screen displays, should be presented in plain language, or using standard aviation terminology.
Supporting notes: Some GCS interfaces based on textual presentation of information have used unnecessarily complicated or counter-intuitive language.
Related special considerations: G. Reliance on automation; H. Widespread use of interfaces based on consumer products.

G_17 Controls intended to be operated by the pilot should be reachable from a seated position
Supporting notes: This principle has been violated in some current GCS designs.
Related special considerations: C: Control station on ground

G_18 The GCS should provide a bookrest to enable the pilot to refer to documents without risk that the document will come into contact with a keyboard or other flight controls.
Supporting notes: UAS incidents have occurred where keyboard commands have been inadvertently activated by contact with documents and other materials.
Related special considerations: C: Control station on ground

G_19 Appropriate priority controls should be available for UAS functions that require either quick accessibility or constant availability. Priority control devices can include, but are not limited to: (a) Touch panels, (b) Buttons, (c) Switches, (d) Joysticks, (e) Keyboard shortcuts. (NATO, 2004)
Supporting notes: Pilot actions that must be performed rapidly range from safety-critical actions such as collision avoidance maneuvers to less critical, but important routine actions such as responding to an ATC request to "Ident" (Pestana, 2008). Some GCS designs have required pilots to perform complicated sequences of actions to perform time-critical or routine actions. Guidelines calling for GCS to enable pilots to rapidly perform such actions appear in Access 5 (2006), NATO (2004) and NATO (2009). NATO (2009) states "Where the interface with UAV crew is based on a "pull down menus" architecture, the controls that necessitate a prompt reaction of the UAV crew must be accessible at the first level of the pull down menus, otherwise, safety critical controls in the UCS must have dedicated knobs or levers".
Related special considerations: A. Loss of natural sensing; B. Control and Communication via radio link; G. Reliance on automation; H. Widespread use of interfaces based on consumer

products.

G_20 If a display screen enables the pilot to move or rearrange display or control windows, it should not be possible to place a window so as to obscure primary flight controls or displays.
Supporting notes: The use of reconfigurable and moveable screen windows and dialog boxes introduces the possibility that critical displays could be obscured behind less-critical interfaces.
Related special considerations: H. Widespread use of interfaces based on consumer products.

Summary list of guidelines

Note that in the following summary list, the type of guideline can be ascertained from the first letter in the title as follows:

T_ Task guidelines
I_ Information content
C_ Control inputs
P_ Properties of the interface
G_ General guidelines

T_1.1.1 The GCS should enable the pilot to monitor which entity has control of the aircraft and to what extent the entity has control.

T_1.1.2 If an on-board camera is used for flight control tasks, the GCS should enable the pilot to center the field of view of the camera.

P_1.1.1 The GCS should not enable the pilot to disengage automation in flight if the aircraft will depart from controlled flight as a result.

P_1.1.2 The GCS should prevent multiple operators from operating the same application/procedures at any one time.

P_1.1.3 The GCS should provide the ability to allow other operators to view the status of aircraft systems.

T_1.2.1 The GCS should enable the pilot to monitor the status of consumable resources.

I_1.2.1 The GCS should provide the pilot with information on the status of consumable resources.

T_1.3.1 The GCS should enable the pilot to perform ground station performance checks.

T_1.3.2 The GCS should enable the pilot to perform a pre-flight check on an alternate control station, or confirm that this check has been performed.

T_1.3.3 The GCS should enable the pilot to check the control station for damage and function.

T_1.3.4 The GCS should enable the pilot to monitor the performance of GCS support services, e.g. air conditioning and electrical power.

I_1.3.1 The GCS should provide the pilot with health and status information on the GCS.

T_1.4.1 The GCS should enable the pilot to identify the threat of an impending collision of the UA with other aircraft, terrain, or objects.

T_1.4.2 The GCS should enable the pilot to recognize the need for a UA evasive maneuver to avoid an impending collision of the UA with other aircraft, terrain, or objects.

T_1.4.3 The GCS should enable the pilot to determine an appropriate maneuver to avoid a collision of the UA with other aircraft, terrain, or objects.

T_1.4.4 The GCS should enable the pilot to execute a UA collision avoidance maneuver.

T_1.4.5 The GCS should enable the pilot to communicate with ATC about a collision avoidance maneuver and other departures from the assigned flight path.

T_1.4.6 The GCS should enable the pilot to return the UA to the assigned flight path after maneuvering to avoid a collision.

T_1.4.7 If the UA is capable of making an autonomous collision avoidance maneuver, the GCS should enable the pilot to monitor the maneuver.

T_1.4.8 If the UA executes an autonomous collision avoidance maneuver, the GCS should enable the pilot to smoothly regain control of the UA at the conclusion of the maneuver.

I_1.4.1 The GCS should provide an alert to the pilot when there is a threat of the UA colliding with another aircraft, terrain, or objects. The alert must be provided in time for the pilot to effectively respond to make the UA avoid the collision.

I_1.4.2 The GCS should provide information about terrain or ground-based objects within proximity of the projected UA flight path and may become a threat for UA collision.

I_1.4.3 The GCS should provide the pilot with the information necessary to detect aircraft, obstructions or people while the UA is moving on the ground. This information may be provided through a camera located on the aircraft, or Closed Circuit Television (CCTV) cameras located on the ground.

I_1.4.4 The GCS should provide the pilot with the information necessary to detect obstructions that may affect launch or takeoff. This information may be provided through a camera located on the aircraft, or CCTV cameras located on the ground.

I_1.4.5 The GCS should provide the pilot with the information necessary to detect obstructions that may affect approach and landing. This information may be provided through a camera located on the aircraft, or CCTV cameras located on the ground.

I_1.4.6 The GCS should provide the pilot information about the likelihood of the UA colliding with the upcoming threat so that the pilot will be able to make a decision about the need to take evasive action to avoid a collision.

I_1.4.7 The GCS should provide the pilot with a prediction of the time available until the UA would collide with the threat aircraft, object, or terrain.

I_1.4.8. The GCS should provide information about the aircraft surrounding the UA and the collision threat to help in making a decision about maneuvers that would not cause additional risks for collision.

I_1.4.9. The GCS should provide information about the capabilities of the UA for making evasive maneuvers in the current UA situation. This information should include at least the following:

> I_1.4.9a Possible maneuvers that can be made by the UA in the current situation – e.g. climb, descend, turn within a certain radius.
>
> I_1.4.9b Time for the UA to accomplish the maneuvers – e.g. how long until the UA reaches a certain turn radius or climb attitude.

I_1.4.10 The GCS should provide the pilot with information necessary to quickly identify the current state, mode, or setting of all controls that are used to send flight commands to the UA.

I_1.4.11 The GCS should provide the pilot with information on the flight path that had been assigned to the UA prior to the evasive maneuver.

I_1.4.12 The GCS should provide information about the necessary UA trajectory needed to return to the assigned flight path. This should include the necessary UA heading and altitude changes.

I_1.4.13 If an autonomous collision avoidance maneuver is carried out, the GCS should alert the pilot that the maneuver is underway, and must notify the pilot when the maneuver is concluded.

C_1.4.1 The GCS should provide a control to cancel the collision alert if it will be ongoing and distract the pilot in accomplishing other tasks.

C_1.4.2 Flight controls should be provided to enable the pilot to rapidly command the UA to execute an effective maneuver to avoid an impending collision. The controls should be readily available at all times and must be designed to enable the pilot to make the command to the UA in the time needed to perform the collision avoidance maneuver. The flight controls must include means to control:

C_1.4.2a UA attitude.

C_1.4.2b UA heading.

C_1.4.2c UA speed and/or thrust.

P_1.4.1 Information and controls should be readily accessible for the pilot to recognize and accomplish collision avoidance maneuvers.

P_1.4.2 Collision avoidance alerts must attract the pilot's attention in all expected lighting and operating conditions.

P_1.4.3 Time-consuming or complicated sequences of actions (e.g. involving multiple levels of menu structures) must not be necessary to accomplish collision avoidance maneuvers.

P_1.4.4 Primary flight controls should be designed in a manner for the pilot to quickly execute critical collision avoidance maneuvers in all expected operating conditions.

T_1.5.1 The GCS should enable the pilot to confirm spectrum availability before selecting link.

T_1.5.2 The GCS should enable the pilot to select the appropriate communication mode (e.g. terrestrial/satellite, frequency).

T_1.5.3 The GCS should enable the pilot to maintain awareness of selected communication mode.

T_1.5.4 The GCS should enable the pilot to confirm that communication link is effective, and established with the correct UA.

T_1.5.5 The GCS should enable the pilot to identify if more than one control station is linked with the UA.

T_1.5.6 The GCS should enable the pilot to maintain awareness of link strength, or link abnormalities.

T_1.5.7 The GCS should enable the pilot to maintain awareness of link latency, where relevant.

T_1.5.8 The GCS should enable the pilot to anticipate link degradations or diminished link strength.

T_1.5.9 The GCS should enable the pilot to maintain an awareness of the geographic limits of the link and potential obstructions to signal.

T_1.5.10 The GCS should enable the pilot to maintain awareness of crew actions or control inputs that could interrupt or degrade the link.

T_1.5.11 The GCS should enable the pilot to respond to interference with the signal, (e.g. other users of frequency, jamming attempts).

T_1.5.12 The GCS should enable the pilot to change the link during flight operations as necessary.

T_1.5.13 The GCS should enable the pilot to assess link strength and quality before switching link.

T_1.5.14 The GCS should enable the pilot to define the duration of a loss of link that must occur before the lost link alert is activated, or the UA enters its lost link procedure.

T_1.5.15 The GCS should enable the pilot to manage resumption of the signal after a lost link.

I_1.5.1 The GCS should be capable of providing the pilot with predictive information on the quality and strength of a C2 link before the link is actively used to control the UA.

I_1.5.2 The GCS should provide information to enable the pilot to identify which C2 link settings are active (e.g. selected frequency, satellite vs terrestrial).

I_1.5.3 The GCS should provide the pilot with information to confirm that effective control is established with the correct UA.

I_1.5.4 The GCS should provide the pilot with information on the geographic limits of the link.

I_1.5.5 The GCS should provide the pilot with information on spectrum activity from a spectrum analyzer.

I_1.5.6 The GCS should alert the pilot when the UA is approaching an area where link is likely to be lost.

I_1.5.7 The GCS should alert the pilot when the link is lost.

I_1.5.8 The UA will transmit a pre-determined transponder code when the link is lost.

I_1.5.9 The GCS should provide information to enable the pilot to monitor the strength of the link.

I_1.5.10 The GCS should alert the pilot whenever the C2 link experiences interference, whether resulting from natural phenomena, payload or other equipment associated with the UAS, or human activities (such as jamming or other users on frequency).

I_1.5.11 The GCS should display to the pilot the source of downlink transmissions.

I_1.5.12 Where relevant, the GCS should provide the pilot with information on link latency, in milliseconds.

I_1.5.13 The GCS should provide information to enable the pilot to anticipate link degradations or diminished link strength. This information may include link footprint, including areas that may be affected by terrain masking.

I_1.5.14 The GCS should provide information to enable the pilot to manage link security.

I_1.5.15 The GCS should inform the pilot when a lost link is resumed.

C_1.5.1 The GCS should enable the pilot to select the communication mode (e.g. terrestrial/satellite, frequency, transmission power).

C_1.5.2 The GCS should provide a control to enable the pilot to request a link status report.

C_1.5.3 If antenna selection is performed by the pilot, then the GCS should support an external command to set the antenna used for communication.

C_1.5.4 The GCS should enable the pilot to set the duration of a link outage that must occur before a lost link response is triggered.

P_1.5.1 "There must be an alert for the UAS crew, via a clear and distinct aural and visual signal, for any total loss of the command and control data link".

P_1.5.2 The aural warning for lost control link should be a unique sound, not also used to signify other conditions.

P_1.5.3 The maximum range of the C2 datalink (datalink footprint) for all altitudes and directions relative to the signal source should be presented visually to the pilot, overlaid on a map display.

P_1.5.4 Areas where the C2 link (datalink footprint) are predicted to be masked by terrain should be displayed on the C2 datalink display.

P_1.5.5 If the datalink footprint can be suppressed, it should be automatically displayed when the UA is approaching a location where a loss of link is likely.

P_1.5.6 The C2 datalink footprint should be easily distinguishable from other footprints that may be present on the operator map display.

P_1.5.7 If the payload utilizes a link separate to the aircraft control link, any display of payload link quality should be separate and clearly distinguishable from displays for the aircraft control link.

P_1.5.8 If an aural warning is used to indicate loss of payload link, the sound should be dissimilar to that used to indicate loss of control link.

P_1.5.9 Security features designed to prevent unapproved access (logon and logoff functions) should not result in inadvertent lockouts of authorized personnel.

P_1.5.10 The GCS, in combination with the other elements of the UAS should comply with control link latency (time from initiation of a maneuver to a measurable response by the UA) requirements that are established at a level similar to manned aircraft.

T_2.1.1 The GCS should enable the pilot to monitor and control the position of the UA when on the ground and in the air.

T_2.1.2 The GCS should enable the pilot to ensure that both the runway and approach path are clear of traffic before taxiing onto the active runway.

T_2.1.3 "The UAS shall be capable of transitioning from an instrument approach procedure to a safe landing, either by visual reference of a flight crewmember at the airport or by other means acceptable to the FAA".

I_2.1.1 UA position in airspace. The GCS should provide a representation of the UA within the airspace. This information should provide:

I_2.1.1a Representation of UA within the airspace.

I_2.1.1b Heading of UA.

I_2.1.1c Altitude of UA.

I_2.1.1d Speed of UA.

I_2.1.1e Attitude of UA.

I_2.1.1f Position of UA relative to other aircraft, terrain, and obstacles.

I_2.1.2 Programmed flight plan and predicted flight path of UA. The GCS should provide a representation of the predicted flight path of the UA based on the flight plan programmed into the flight management system based on the assigned flight clearance. This information should include:

I_2.1.2a Indication of UA current position along programmed flight path.

I_2.1.2b Predicted flight path relative to UA and other traffic, terrain, and obstacles.

I_2.1.2c Distance to waypoints along flight path.

I_2.1.2d Indication of position in flight path when new commanded altitude will be attained.

I_2.1.2e Indication of turning radius and path when making turns along flight path.

C_2.1.3 The GCS should enable the pilot to maneuver the UA.

P_2.1.1 The map display should be able to support a variety of map types including aeronautical charts and presentations of Digital Terrain Elevation Data (DTED).

P_2.1.2 The presentation scale of the map should be selectable. Continuous scaling is preferred to discrete.

P_2.1.3 The pilot should be able to derive the scale of the map from the display.

P_2.1.4 The map display should enable the pilot to customize the Aircraft's Information Trail.

P_2.1.5 The map display should be configurable to "North up" or "Track up".

P_2.1.6 If control is via a terrestrial radio, the location of (or direction to) the ground transmitter/receiver should be shown on the map.

P_2.1.7 Primary flight controls for controlling the UA (heading, attitude, speed) should be available at all times through dedicated physical controls. If the use of software-based controls cannot be avoided, then the controls should be immediately accessible at the top level of the control interface.

P_2.1.8 Map displays should have means to select the scale of the map to be presented. The scales presented on the maps should be evident to the pilot.

P_2.1.9 The pilot should have the means to customize the information trail for an aircraft shown on the traffic display.

T_2.2.1 The GCS should enable the pilot to ensure that both the runway and approach path are clear of traffic before taxiing onto the active runway.

T_2.2.2 The GCS should enable the pilot to “observe” and comply with signage and warning lights during surface operations.

T_2.2.3 The GCS should enable the pilot to monitor weather that has the potential to affect the flight.

T_2.2.4 The GCS should enable the pilot to avoid weather that has the potential to affect the flight.

T_2.2.5 The GCS should enable the pilot to avoid icing conditions.

I_2.2.1 “The operator should be able to display flight corridors, controlled airspace and any other relevant airspace co-ordination information”.

I_2.2.2 The GCS should display weather information to the pilot.

I_2.2.3 The GCS should provide the pilot with information on the location of icing conditions , especially if the UA is not certificated for flight in icing conditions.

I_2.2.4 The GCS should alert the pilot when the UA enters icing conditions.

I_2.2.5 The GCS should alert the pilot when the UA encounters significant air turbulence.

T_2.3.1 The GCS should enable the pilot to monitor all traffic in the airspace around the UA to identify potential for upcoming well-clear violations.

T_2.3.2 The GCS should enable the pilot to quickly identify any threat of an aircraft violating the well-clear airspace of the UA

T_2.3.3 The GCS should enable the pilot to track the surrounding traffic flight paths, assess the risk of well-clear violations, and recognize the need for the UA to maneuver to maintain self-separation criteria

T_2.3.4 The GCS should enable the pilot to determine the appropriate maneuver for the UA to make to maintain self-separation.

T_2.3.5 The GCS should enable the pilot to command the UA to execute the evasive maneuver

T_2.3.6 The GCS should enable the pilot to communicate with ATC about making the separation maneuver and departing from the assigned flight path

T_2.3.7 The GCS should enable the pilot to return the UA to the assigned flight path after maneuvering for self-separation.

T_2.4.1 The GCS should enable the pilot to remain aware of the aircraft’s lost link procedure as the flight progresses.

T_2.4.2 The GCS should enable the pilot to update the aircraft’s lost link procedure as the flight progresses.

I_2.4.1 The GCS should provide the pilot with a display indicating the future flightpath of the aircraft should a lost link occur.

I_2.4.2 The GCS should alert the pilot whenever the execution of a lost link procedure would create a hazard (such as directing the aircraft towards terrain, or into non-authorized airspace).

P_2.4.1 The flightpath that would be taken by the aircraft in the event of a lost link should be clearly distinguishable from the programmed normal flightpath of the aircraft.

P_2.4.2 Information on the programmed lost link behavior of the aircraft should be readily available to the pilot, without the need for complex interactions with the human-machine interface.

T_2.5.1 The GCS should enable the pilot to decide when to terminate the flight via controlled impact, ditching or parachute descent.

T_2.5.2 The GCS should enable the pilot to identify a suitable location for flight termination.

T_2.5.3 The GCS should enable the pilot to terminate the flight in a pre-designated area.

T_2.5.4 The GCS should enable the pilot to use real-time information to confirm that flight termination at the selected location will not present unacceptable risk to people or property.

I_2.5.1 The GCS should provide the pilot with real-time imagery of the selected impact, ditching or parachute descent site to confirm that a safe termination can be accomplished.

I_2.5.2 The GCS should provide an alert to the pilot to indicate that the flight termination system is about to be activated.

P_2.5.1 When the UA is equipped with a flight termination system:

> P_2.5.1a The use of these controls should be intuitive and minimize the possibility of confusion and subsequent inadvertent operation.
>
> P_2.5.1b Two distinct and dissimilar actions of the UAS crew should be required to initiate the flight termination command.

P_2.5.2 Before the final step in activating the flight termination system is reached, the GCS should provide an aural and visual alert to the pilot that flight termination is about to be activated.

P_2.5.3 The aural alert warning of imminent flight termination should involve a unique sound. This should preferably take the form of a verbal message such as “Flight termination!”

P_2.5.4 When the UA is equipped with a flight termination system, flight termination controls should be safeguarded from interference that could lead to inadvertent operation.

T_3.1.1 When operating near a non-towered airport, the pilot should be able to exchange intent information with other airport traffic through standard communications on the airport common traffic advisory frequency (CTAF).

T_3.1.2 The UAS pilot should be able to establish an alternate communications method with ATC if the duration of the communications loss exceeds requirements for the operating environment.

I_3.1.1 The GCS should include alternate means for the pilot to communicate with ATC in the event of a loss of C2 link.

I_3.1.2 Current settings of communication controls. The GCS should provide the pilot with information about the current state, mode, or setting of the controls used for communication with ATC.

P_3.1.1 The voice communication delay between the pilot and ATC should have a mean less than or equal to 250 ms.

P_3.1.2 The voice communication delay between the pilot and ATC should be less than or equal to 300 ms. (99th percentile).

P_3.1.3 The voice communication delay between the pilot and ATC should be within a maximum of 350 ms.

T_3.2.1 The GCS should enable the UAS crewmembers to communicate with each other (co-located or not) in order to perform the necessary flight tasks.

T_3.2.2 The GCS should enable the pilot to ensure that commands sent to the aircraft on the ground do not create a safety hazard for ground support personnel.

I_3.2.1 The GCS should provide the pilot with imagery of the aircraft whenever the pilot has control of the aircraft on the ground and ground support personnel are interacting with the aircraft.

I_3.2.2 The GCS should provide the pilot with a communication link with ground support personnel while they are interacting with the aircraft.

T_3.3.1 The GCS should enable the pilot to communicate with weather information services and other ancillary services.

T_4.4.1 The GCS should enable control to be transferred between a giving and receiving GCS in a manner that is seamless and transparent to ATC.

T_4.4.2 The GCS should enable continuity of pilot function to be maintained during the transfer of control between a giving and receiving GCS.

T_4.4.3 "The GCS shall enable the pilot to ensure that operating parameters are identical before and after handover".

T_4.4.4 The GCS should enable the pilot to pass UA control (handover) to another GCS and monitor the status of the handover.

T_4.4.5 The GCS should enable the pilot to monitor which entity has control of the aircraft and to what extent the entity has control.

T_4.4.6 The GCS should enable the giving and receiving pilots to confirm that control settings are appropriate and consistent before a handover is accomplished.

T_4.4.7 The GCS should enable the receiving pilot to monitor the status of the UA by receiving telemetry from the UA before establishing control of the UA.

T_4.4.8 The GCS should facilitate a handover briefing between the giving and receiving pilots.

T_4.4.9 The GCS should provide the receiving pilot with a means of confirming that control has been established with the UA.

I_4.4.1 The pilot should be presented with information necessary to confirm that flight-critical settings in the receiving GCS are consistent with settings in the giving GCS.

I_4.4.2 The GCS should provide a level of involvement indicator to the pilot to show whether the GCS has been set to only receive telemetry from the UA, or to receive telemetry and transmit commands to the UA.

C_4.4.1 The GCS should enable the pilot to select the desired level of involvement with a UA, ranging from monitoring telemetry without an active uplink, to telemetry with full control via an active uplink.

C_4.4.2 There should be a means for the giving and receiving pilots to communicate before, during and after the handover.

P_4.4.1 The GCS should provide suitable displays to enable briefings to be conducted between a seated pilot and a standing pilot during control handovers. This may include the use of large scale synoptic displays.

P_4.4.2 The GCS should enable control to be transferred to another GCS without any gap in control occurring during the handover.

G_1 UAS developers should follow recognized human-centered design processes including the following:

G_1a. Develop a full set of pilot tasks and intended operations for which the GCS will be used. These will help drive ensuring a thorough design that provides all systems, information, and controls that the pilots will need.

G_1b. Develop an understanding of the potential safety critical errors that the pilots may make when accomplishing their tasks. These will provide the foundation for making trade-offs in design decisions by focusing on design attributes that will mitigate critical errors as needed.

G_1c. Develop a full set of information requirements for the tasks the pilots will need to accomplish. These requirements should be developed with other design requirements at the beginning of the systems engineering process. They will help ensure that the appropriate information is provided to the pilots and provide the foundation for making design decisions.

G_1d. Develop a full set of requirements for controls that the pilot will need to accomplish their tasks. These requirements should be developed with other design requirements at the beginning of the systems engineering process. They will help ensure that all the pilot controls are planned for as design decisions are made.

G_1e. Document all of the results of these processes so that they can be continually updated when design decisions and trade-offs are made during the design process. Good documentation will also help the human factors design processes to be integrated with the other systems engineering development and design processes.

G_2 The use of multi-mode functions on flight controls should be minimized. If modes are used, the system should clearly indicate the current mode, and other potential modes should be indicated.

G_3 If changing a mode selection of an automated system has a safety consequence, the action to select that mode should be alerted, and additional precautions should be taken to prevent inadvertent selection.

G_4 Payload controls should be separate from controls with safety-of-flight functions.

G_5 It should not be possible to reconfigure a safety-of-flight control to perform a payload function.

G_6 Activation of a key or button should provide tactile or auditory feedback to the pilot.

G_7 There should be a clear indication to the pilot when a command has been received by the UAS.

G_8 Any unrecognized entry made by the pilot at the GCS should cause an informative error message to be displayed and not affect the status or operation of any system.

G_9 Flightcrew alerting. (Quoted verbatim from CFR § 25.1322)

G_9 (a) Flightcrew alerts must: (1) Provide the flightcrew with the information needed to: (i) Identify non-normal operation or airplane system conditions, and (ii) Determine the appropriate actions, if any. (2) Be readily and easily detectable and intelligible by the flightcrew under all foreseeable operating conditions, including conditions where multiple alerts are provided. (3) Be removed when the alerting condition no longer exists.

G_9 (b) Alerts must conform to the following prioritization hierarchy based on the urgency of flightcrew awareness and response. (1) Warning: For conditions that require immediate flightcrew awareness and immediate flightcrew response. (2) Caution: For conditions that require immediate flightcrew awareness and subsequent flightcrew response. (3) Advisory: For conditions that require flightcrew awareness and may require subsequent flightcrew response.

G_9 (c) Warning and caution alerts must: (1) Be prioritized within each category, when necessary. (2) Provide timely attention-getting cues through at least two different senses by a combination of aural, visual, or tactile indications. (3) Permit each occurrence of the attention-getting cues required by paragraph (c)(2) of this section to be acknowledged and suppressed, unless they are required to be continuous.

G_9 (d) The alert function must be designed to minimize the effects of false and nuisance alerts. In particular, it must be designed to: (1) Prevent the presentation of an alert that is inappropriate or unnecessary. (2) Provide a means to suppress an attention-getting component of an alert caused by a failure of the alerting function that interferes with the flightcrew's ability to safely operate the airplane. This means must not be readily available to the flightcrew so that it could be operated inadvertently or by habitual reflexive action. When an alert is suppressed, there must be a clear and unmistakable annunciation to the flightcrew that the alert has been suppressed.

G_9 (e) Visual alert indications must: (1) Conform to the following color convention:(i) Red for warning alert indications. (ii) Amber or yellow for caution alert indications. (iii) Any color except red or green for advisory alert indications. (2) Use visual coding techniques, together with other alerting function elements on the flight deck, to distinguish between warning, caution, and advisory alert indications, if they are presented on monochromatic displays that are not capable of conforming to the color convention in paragraph (e)(1) of this section.

G_9 (f) Use of the colors red, amber, and yellow on the flight deck for functions other than flightcrew alerting must be limited and must not adversely affect flightcrew alerting.

G_10 Systems that alert the pilot to a critical anomaly should not be subject to a silent failure.

G_11 The GCS should provide a work environment that maintains pilot engagement, and minimizes the negative impact of extended periods of low workload.

G_12 The GCS should provide consistency of operation for common functions.

G_13 The functions needed to safely control the aircraft under usual flight situations should be located in the pilot's primary field-of-view.

G_14 Warnings and cautions should not be obscured by other GCS displays.

G_15 "Part-time display. If it is desired to inhibit some parameters from full-time display, an equivalent level of safety to full-time display should be demonstrated. Criteria to be considered include the following: (a) Continuous display of the parameter is not required for safety of flight in all normal flight phases. (b) The parameter is automatically displayed in flight phases where it is required. (c) The inhibited parameter is automatically displayed when its value indicates an abnormal condition, or when the parameter reaches an abnormal value. (d) Display of the inhibited parameter can be manually selected by the UAV crew without interfering with the display of other required information. (e) If the parameter fails to be displayed when required, the failure effect and compounding effects must meet the requirements of USAR.1309. The analysis is to clearly demonstrate that the display(s) of data is consistent with safe operation under all probable operating conditions. (f) The automatic, or requested, display of the inhibited parameter should not create unacceptable clutter on the display; simultaneous multiple "pop-ups" must be considered. (g) If the presence of the new parameter is not sufficiently self-evident, suitable alerting must accompany the automatic presentation".

G_16 Wherever possible, text messages, whether in dialog boxes, warning messages or other screen displays, should be presented in plain language, or using standard aviation terminology.

G_17 Controls intended to be operated by the pilot should be reachable from a seated position

G_18 The GCS should provide a bookrest to enable the pilot to refer to documents without risk that the document will come into contact with a keyboard or other flight controls.

G_19 Appropriate priority controls should be available for UAS functions that require either quick accessibility or constant availability. Priority control devices can include, but are not limited to: (a) Touch panels, (b) Buttons, (c) Switches, (d) Joysticks, (e) Keyboard shortcuts.

G_20 If a display screen enables the pilot to move or rearrange display or control windows, it should not be possible to place a window so as to obscure primary flight controls or displays.

Guidelines organized by type

Task-related guidelines

T_1.1.1 The GCS should enable the pilot to monitor which entity has control of the aircraft and to what extent the entity has control.

T_1.1.2 If an on-board camera is used for flight control tasks, the GCS should enable the pilot to center the field of view of the camera.

T_1.2.1 The GCS should enable the pilot to monitor the status of consumable resources.

T_1.3.1 The GCS should enable the pilot to perform ground station performance checks.

T_1.3.2 The GCS should enable the pilot to perform a pre-flight check on an alternate control station, or confirm that this check has been performed.

T_1.3.3 The GCS should enable the pilot to check the control station for damage and function.

T_1.3.4 The GCS should enable the pilot to monitor the performance of GCS support services, e.g. air conditioning and electrical power.

T_1.4.1 The GCS should enable the pilot to identify the threat of an impending collision of the UA with other aircraft, terrain, or objects.

T_1.4.2 The GCS should enable the pilot to recognize the need for a UA evasive maneuver to avoid an impending collision of the UA with other aircraft, terrain, or objects.

T_1.4.3 The GCS should enable the pilot to determine an appropriate maneuver to avoid a collision of the UA with other aircraft, terrain, or objects.

T_1.4.4 The GCS should enable the pilot to execute a UA collision avoidance maneuver.

T_1.4.5 The GCS should enable the pilot to communicate with ATC about a collision avoidance maneuver and other departures from the assigned flight path.

T_1.4.6 The GCS should enable the pilot to return the UA to the assigned flight path after maneuvering to avoid a collision.

T_1.4.7 If the UA is capable of making an autonomous collision avoidance maneuver, the GCS should enable the pilot to monitor the maneuver.

T_1.4.8 If the UA executes an autonomous collision avoidance maneuver, the GCS should enable the pilot to smoothly regain control of the UA at the conclusion of the maneuver.

T_1.5.1 The GCS should enable the pilot to confirm spectrum availability before selecting link.

T_1.5.2 The GCS should enable the pilot to select the appropriate communication mode (e.g. terrestrial/satellite, frequency).

T_1.5.3 The GCS should enable the pilot to maintain awareness of selected communication mode.

T_1.5.4 The GCS should enable the pilot to confirm that communication link is effective, and established with the correct UA.

T_1.5.5 The GCS should enable the pilot to identify if more than one control station is linked with the UA.

T_1.5.6 The GCS should enable the pilot to maintain awareness of link strength, or link abnormalities.

T_1.5.7 The GCS should enable the pilot to maintain awareness of link latency, where relevant.

T_1.5.8 The GCS should enable the pilot to anticipate link degradations or diminished link strength.

T_1.5.9 The GCS should enable the pilot to maintain an awareness of the geographic limits of the link and potential obstructions to signal.

T_1.5.10 The GCS should enable the pilot to maintain awareness of crew actions or control inputs that could interrupt or degrade the link.

T_1.5.11 The GCS should enable the pilot to respond to interference with the signal, (e.g. other users of frequency, jamming attempts).

T_1.5.12 The GCS should enable the pilot to change the link during flight operations as necessary.

T_1.5.13 The GCS should enable the pilot to assess link strength and quality before switching link.

T_1.5.14 The GCS should enable the pilot to define the duration of a loss of link that must occur before the lost link alert is activated, or the UA enters its lost link procedure.

T_1.5.15 The GCS should enable the pilot to manage resumption of the signal after a lost link.

T_2.1.1 The GCS should enable the pilot to monitor and control the position of the UA when on the ground and in the air.

T_2.1.2 The GCS should enable the pilot to ensure that both the runway and approach path are clear of traffic before taxiing onto the active runway.

T_2.1.3 "The UAS shall be capable of transitioning from an instrument approach procedure to a safe landing, either by visual reference of a flight crewmember at the airport or by other means acceptable to the FAA".

T_2.2.1 The GCS should enable the pilot to ensure that both the runway and approach path are clear of traffic before taxiing onto the active runway.

T_2.2.2 The GCS should enable the pilot to "observe" and comply with signage and warning lights during surface operations.

T_2.2.3 The GCS should enable the pilot to monitor weather that has the potential to affect the flight.

T_2.2.4 The GCS should enable the pilot to avoid weather that has the potential to affect the flight.

T_2.2.5 The GCS should enable the pilot to avoid icing conditions.

T_2.3.1 The GCS should enable the pilot to monitor all traffic in the airspace around the UA to identify potential for upcoming well-clear violations.

T_2.3.2 The GCS should enable the pilot to quickly identify any threat of an aircraft violating the well-clear airspace of the UA

T_2.3.3 The GCS should enable the pilot to track the surrounding traffic flight paths, assess the risk of well-clear violations, and recognize the need for the UA to maneuver to maintain self-separation criteria

T_2.3.4 The GCS should enable the pilot to determine the appropriate maneuver for the UA to make to maintain self-separation.

T_2.3.5 The GCS should enable the pilot to command the UA to execute the evasive maneuver

T_2.3.6 The GCS should enable the pilot to communicate with ATC about making the separation maneuver and departing from the assigned flight path

T_2.3.7 The GCS should enable the pilot to return the UA to the assigned flight path after maneuvering for self-separation.

T_2.4.1 The GCS should enable the pilot to remain aware of the aircraft's lost link procedure as the flight progresses.

T_2.4.2 The GCS should enable the pilot to update the aircraft's lost link procedure as the flight progresses.

T_2.5.1 The GCS should enable the pilot to decide when to terminate the flight via controlled impact, ditching or parachute descent.

T_2.5.2 The GCS should enable the pilot to identify a suitable location for flight termination.

T_2.5.3 The GCS should enable the pilot to terminate the flight in a pre-designated area.

T_2.5.4 The GCS should enable the pilot to use real-time information to confirm that flight termination at the selected location will not present unacceptable risk to people or property.

T_3.1.1 When operating near a non-towered airport, the pilot should be able to exchange intent information with other airport traffic through standard communications on the airport common traffic advisory frequency (CTAF).

T_3.1.2 The UAS pilot should be able to establish an alternate communications method with ATC if the duration of the communications loss exceeds requirements for the operating environment.

T_3.2.1 The GCS should enable the UAS crewmembers to communicate with each other (co-located or not) in order to perform the necessary flight tasks.

T_3.2.2 The GCS should enable the pilot to ensure that commands sent to the aircraft on the ground do not create a safety hazard for ground support personnel.

T_3.3.1 The GCS should enable the pilot to communicate with weather information services and other ancillary services.

T_4.4.1 The GCS should enable control to be transferred between a giving and receiving GCS in a manner that is seamless and transparent to ATC.

T_4.4.2 The GCS should enable continuity of pilot function to be maintained during the transfer of control between a giving and receiving GCS.

T_4.4.3 "The GCS shall enable the pilot to ensure that operating parameters are identical before and after handover".

T_4.4.4 The GCS should enable the pilot to pass UA control (handover) to another GCS and monitor the status of the handover.

T_4.4.5 The GCS should enable the pilot to monitor which entity has control of the aircraft and to what extent the entity has control.

T_4.4.6 The GCS should enable the giving and receiving pilots to confirm that control settings are appropriate and consistent before a handover is accomplished.

T_4.4.7 The GCS should enable the receiving pilot to monitor the status of the UA by receiving telemetry from the UA before establishing control of the UA.

T_4.4.8 The GCS should facilitate a handover briefing between the giving and receiving pilots.

T_4.4.9 The GCS should provide the receiving pilot with a means of confirming that control has been established with the UA.

Information-related guidelines

I_1.2.1 The GCS should provide the pilot with information on the status of consumable resources.

I_1.3.1 The GCS should provide the pilot with health and status information on the GCS.

I_1.4.1 The GCS should provide an alert to the pilot when there is a threat of the UA colliding with another aircraft, terrain, or objects. The alert must be provided in time for the pilot to effectively respond to make the UA avoid the collision.

I_1.4.2 The GCS should provide information about terrain or ground-based objects within proximity of the projected UA flight path and may become a threat for UA collision.

I_1.4.3 The GCS should provide the pilot with the information necessary to detect aircraft, obstructions or people while the UA is moving on the ground. This information may be provided through a camera located on the aircraft, or Closed Circuit Television (CCTV) cameras located on the ground.

I_1.4.4 The GCS should provide the pilot with the information necessary to detect obstructions that may affect launch or takeoff. This information may be provided through a camera located on the aircraft, or CCTV cameras located on the ground.

I_1.4.5 The GCS should provide the pilot with the information necessary to detect obstructions that may affect approach and landing. This information may be provided through a camera located on the aircraft, or CCTV cameras located on the ground.

I_1.4.6 The GCS should provide the pilot information about the likelihood of the UA colliding with the upcoming threat so that the pilot will be able to make a decision about the need to take evasive action to avoid a collision.

I_1.4.7 The GCS should provide the pilot with a prediction of the time available until the UA would collide with the threat aircraft, object, or terrain.

I_1.4.8. The GCS should provide information about the aircraft surrounding the UA and the collision threat to help in making a decision about maneuvers that would not cause additional risks for collision.

I_1.4.9. The GCS should provide information about the capabilities of the UA for making evasive maneuvers in the current UA situation. This information should include at least the following:

I_1.4.9a. Possible maneuvers that can be made by the UA in the current situation - e.g. climb, descend, turn within a certain radius.

I_1.4.9b. Time for the UA to accomplish the maneuvers - e.g. how long until the UA reaches a certain turn radius or climb attitude.

I_1.4.10 The GCS should provide the pilot with information necessary to quickly identify the current state, mode, or setting of all controls that are used to send flight commands to the UA.

I_1.4.11 The GCS should provide the pilot with information on the flight path that had been assigned to the UA prior to the evasive maneuver.

I_1.4.12 The GCS should provide information about the necessary UA trajectory needed to return to the assigned flight path. This should include the necessary UA heading and altitude changes.

I_1.4.13 If an autonomous collision avoidance maneuver is carried out, the GCS should alert the pilot that the maneuver is underway, and must notify the pilot when the maneuver is concluded.

I_1.5.1 The GCS should be capable of providing the pilot with predictive information on the quality and strength of a C2 link before the link is actively used to control the UA.

I_1.5.2 The GCS should provide information to enable the pilot to identify which C2 link settings are active (e.g. selected frequency, satellite vs terrestrial).

I_1.5.3 The GCS should provide the pilot with information to confirm that effective control is established with the correct UA.

I_1.5.4 The GCS should provide the pilot with information on the geographic limits of the link.

I_1.5.5 The GCS should provide the pilot with information on spectrum activity from a spectrum analyzer.

I_1.5.6 The GCS should alert the pilot when the UA is approaching an area where link is likely to be lost.

I_1.5.7 The GCS should alert the pilot when the link is lost.

I_1.5.8 The UA will transmit a pre-determined transponder code when the link is lost.

I_1.5.9 The GCS should provide information to enable the pilot to monitor the strength of the link.

I_1.5.10 The GCS should alert the pilot whenever the C2 link experiences interference, whether resulting from natural phenomena, payload or other equipment associated with the UAS, or human activities (such as jamming or other users on frequency).

I_1.5.11 The GCS should display to the pilot the source of downlink transmissions.

I_1.5.12 Where relevant, the GCS should provide the pilot with information on link latency, in milliseconds.

I_1.5.13 The GCS should provide information to enable the pilot to anticipate link degradations or diminished link strength. This information may include link footprint, including areas that may be affected by terrain masking.

I_1.5.14 The GCS should provide information to enable the pilot to manage link security.

I_1.5.15 The GCS should inform the pilot when a lost link is resumed.

I_2.1.1 UA position in airspace. The GCS should provide a representation of the UA within the airspace. This information should provide:

- I_2.1.1a Representation of UA within the airspace.
- I_2.1.1b Heading of UA.
- I_2.1.1c Altitude of UA.
- I_2.1.1d Speed of UA.
- I_2.1.1e Attitude of UA.
- I_2.1.1f Position of UA relative to other aircraft, terrain, and obstacles.

I_2.1.2 Programmed flight plan and predicted flight path of UA. The GCS should provide a representation of the predicted flight path of the UA based on the flight plan programmed into the flight management system based on the assigned flight clearance. This information should include:

- I_2.1.2a Indication of UA current position along programmed flight path.
- I_2.1.2b Predicted flight path relative to UA and other traffic, terrain, and obstacles.
- I_2.1.2c Distance to waypoints along flight path.

I_2.1.2d Indication of position in flight path when new commanded altitude will be attained.

I_2.1.2e Indication of turning radius and path when making turns along flight path.

I_2.2.1 "The operator should be able to display flight corridors, controlled airspace and any other relevant airspace co-ordination information".

I_2.2.2 The GCS should display weather information to the pilot.

I_2.2.3 The GCS should provide the pilot with information on the location of icing conditions , especially if the UA is not certificated for flight in icing conditions.

I_2.2.4 The GCS should alert the pilot when the UA enters icing conditions.

I_2.2.5 The GCS should alert the pilot when the UA encounters significant air turbulence.

I_2.4.1 The GCS should provide the pilot with a display indicating the future flightpath of the aircraft should a lost link occur.

I_2.4.2 The GCS should alert the pilot whenever the execution of a lost link procedure would create a hazard (such as directing the aircraft towards terrain, or into non-authorized airspace).

I_2.5.1 The GCS should provide the pilot with real-time imagery of the selected impact, ditching or parachute descent site to confirm that a safe termination can be accomplished.

I_2.5.2 The GCS should provide an alert to the pilot to indicate that the flight termination system is about to be activated.

I_3.1.1 The GCS should include alternate means for the pilot to communicate with ATC in the event of a loss of C2 link.

I_3.1.2 Current settings of communication controls. The GCS should provide the pilot with information about the current state, mode, or setting of the controls used for communication with ATC.

I_3.2.1 The GCS should provide the pilot with imagery of the aircraft whenever the pilot has control of the aircraft on the ground and ground support personnel are interacting with the aircraft.

I_3.2.2 The GCS should provide the pilot with a communication link with ground support personnel while they are interacting with the aircraft.

I_4.4.1 The pilot should be presented with information necessary to confirm that flight-critical settings in the receiving GCS are consistent with settings in the giving GCS.

I_4.4.2 The GCS should provide a level of involvement indicator to the pilot to show whether the GCS has been set to only receive telemetry from the UA, or to receive telemetry and transmit commands to the UA.

Control-related guidelines

C_1.4.1 The GCS should provide a control to cancel the collision alert if it will be ongoing and distract the pilot in accomplishing other tasks.

C_1.4.2 Flight controls should be provided to enable the pilot to rapidly command the UA to execute an effective maneuver to avoid an impending collision. The controls should be readily available at all times and must be designed to enable the pilot to make the command to the UA in the time needed to perform the collision avoidance maneuver. The flight controls must include means to control:

C_1.4.2a UA attitude.

C_1.4.2b UA heading.

C_1.4.2c UA speed and/or thrust.

C_1.5.1 The GCS should enable the pilot to select the communication mode (e.g. terrestrial/satellite, frequency, transmission power).

C_1.5.2 The GCS should provide a control to enable the pilot to request a link status report.

C_1.5.3 If antenna selection is performed by the pilot, then the GCS should support an external command to set the antenna used for communication.

C_1.5.4 The GCS should enable the pilot to set the duration of a link outage that must occur before a lost link response is triggered.

C_2.1.3 The GCS should enable the pilot to maneuver the UA.

C_4.4.1 The GCS should enable the pilot to select the desired level of involvement with a UA, ranging from monitoring telemetry without an active uplink, to telemetry with full control via an active uplink.

C_4.4.2 There should be a means for the giving and receiving pilots to communicate before, during and after the handover.

Guidelines relating to properties of the interface

P_1.1.1 The GCS should not enable the pilot to disengage automation in flight if the aircraft will depart from controlled flight as a result.

P_1.1.2 The GCS should prevent multiple operators from operating the same application/procedures at any one time.

P_1.1.3 The GCS should provide the ability to allow other operators to view the status of aircraft systems.

P_1.4.1 Information and controls should be readily accessible for the pilot to recognize and accomplish collision avoidance maneuvers.

P_1.4.2 Collision avoidance alerts must attract the pilot's attention in all expected lighting and operating conditions.

P_1.4.3 Time-consuming or complicated sequences of actions (e.g. involving multiple levels of menu structures) must not be necessary to accomplish collision avoidance maneuvers.

P_1.4.4 Primary flight controls should be designed in a manner for the pilot to quickly execute critical collision avoidance maneuvers in all expected operating conditions.

P_1.5.1 "There must be an alert for the UAS crew, via a clear and distinct aural and visual signal, for any total loss of the command and control data link".

P_1.5.2 The aural warning for lost control link should be a unique sound, not also used to signify other conditions.

P_1.5.3 The maximum range of the C2 datalink (datalink footprint) for all altitudes and directions relative to the signal source should be presented visually to the pilot, overlaid on a map display.

P_1.5.4 Areas where the C2 link (datalink footprint) are predicted to be masked by terrain should be displayed on the C2 datalink display.

P_1.5.5 If the datalink footprint can be suppressed, it should be automatically displayed when the UA is approaching a location where a loss of link is likely.

P_1.5.6 The C2 datalink footprint should be easily distinguishable from other footprints that may be present on the operator map display.

P_1.5.7 If the payload utilizes a link separate to the aircraft control link, any display of payload link quality should be separate and clearly distinguishable from displays for the aircraft control link.

P_1.5.8 If an aural warning is used to indicate loss of payload link, the sound should be dissimilar to that used to indicate loss of control link.

P_1.5.9 Security features designed to prevent unapproved access (logon and logoff functions) should not result in inadvertent lockouts of authorized personnel.

P_1.5.10 The GCS, in combination with the other elements of the UAS should comply with control link latency (time from initiation of a maneuver to a measurable response by the UA) requirements that are established at a level similar to manned aircraft.

P_2.1.1 The map display should be able to support a variety of map types including aeronautical charts and presentations of Digital Terrain Elevation Data (DTED).

P_2.1.2 The presentation scale of the map should be selectable. Continuous scaling is preferred to discrete.

P_2.1.3 The pilot should be able to derive the scale of the map from the display.

P_2.1.4 The map display should enable the pilot to customize the Aircraft's Information Trail.

P_2.1.5 The map display should be configurable to "North up" or "Track up".

P_2.1.6 If control is via a terrestrial radio, the location of (or direction to) the ground transmitter/receiver should be shown on the map.

P_2.1.7 Primary flight controls for controlling the UA (heading, attitude, speed) should be available at all times through dedicated physical controls. If the use of software-based controls cannot be avoided, then the controls should be immediately accessible at the top level of the control interface.

P_2.1.8 Map displays should have means to select the scale of the map to be presented. The scales presented on the maps should be evident to the pilot.

P_2.1.9 The pilot should have the means to customize the information trail for an aircraft shown on the traffic display.

P_2.4.1 The flightpath that would be taken by the aircraft in the event of a lost link should be clearly distinguishable from the programmed normal flightpath of the aircraft.

P_2.4.2 Information on the programmed lost link behavior of the aircraft should be readily available to the pilot, without the need for complex interactions with the human-machine interface.

P_2.5.1 When the UA is equipped with a flight termination system:

> P_2.5.1a The use of these controls should be intuitive and minimize the possibility of confusion and subsequent inadvertent operation.
>
> P_2.5.1b Two distinct and dissimilar actions of the UAS crew should be required to initiate the

flight termination command.

P_2.5.2 Before the final step in activating the flight termination system is reached, the GCS should provide an aural and visual alert to the pilot that flight termination is about to be activated.

P_2.5.3 The aural alert warning of imminent flight termination should involve a unique sound. This should preferably take the form of a verbal message such as "Flight termination!"

P_2.5.4 When the UA is equipped with a flight termination system, flight termination controls should be safeguarded from interference that could lead to inadvertent operation.

P_3.1.1 The voice communication delay between the pilot and ATC should have a mean less than or equal to 250 ms.

P_3.1.2 The voice communication delay between the pilot and ATC should be less than or equal to 300 ms. (99th percentile).

P_3.1.3 The voice communication delay between the pilot and ATC should be within a maximum of 350 ms.

P_4.4.1 The GCS should provide suitable displays to enable briefings to be conducted between a seated pilot and a standing pilot during control handovers. This may include the use of large scale synoptic displays.

P_4.4.2 The GCS should enable control to be transferred to another GCS without any gap in control occurring during the handover.

General guidelines

G_1 UAS developers should follow recognized human-centered design processes including the following:

G_1a. Develop a full set of pilot tasks and intended operations for which the GCS will be used. These will help drive ensuring a thorough design that provides all systems, information, and controls that the pilots will need.

G_1b. Develop an understanding of the potential safety critical errors that the pilots may make when accomplishing their tasks. These will provide the foundation for making trade-offs in design decisions by focusing on design attributes that will mitigate critical errors as needed.

G_1c. Develop a full set of information requirements for the tasks the pilots will need to accomplish. These requirements should be developed with other design requirements at the beginning of the systems engineering process. They will help ensure that the appropriate information is provided to the pilots and provide the foundation for making design decisions.

G_1d. Develop a full set of requirements for controls that the pilot will need to accomplish their tasks. These requirements should be developed with other design requirements at the beginning of the systems engineering process. They will help ensure that all the pilot controls are planned for as design decisions are made.

G_1e. Document all of the results of these processes so that they can be continually updated when design decisions and trade-offs are made during the design process. Good documentation will also help the human factors design processes to be integrated with the other systems engineering development and design processes.

G_2 The use of multi-mode functions on flight controls should be minimized. If modes are used, the system should clearly indicate the current mode, and other potential modes should be indicated.

G_3 If changing a mode selection of an automated system has a safety consequence, the action to select that mode should be alerted, and additional precautions should be taken to prevent inadvertent selection.

G_4 Payload controls should be separate from controls with safety-of-flight functions.

G_5 It should not be possible to reconfigure a safety-of-flight control to perform a payload function.

G_6 Activation of a key or button should provide tactile or auditory feedback to the pilot.

G_7 There should be a clear indication to the pilot when a command has been received by the UAS.

G_8 Any unrecognized entry made by the pilot at the GCS should cause an informative error message to be displayed and not affect the status or operation of any system.

G_9 Flightcrew alerting. (Quoted verbatim from CFR § 25.1322)

G_9 “(a) Flightcrew alerts must: (1) Provide the flightcrew with the information needed to: (i) Identify non-normal operation or airplane system conditions, and (ii) Determine the appropriate actions, if any. (2) Be readily and easily detectable and intelligible by the flightcrew under all foreseeable operating conditions, including conditions where multiple alerts are provided. (3) Be removed when the alerting condition no longer exists.

G_9 (b) Alerts must conform to the following prioritization hierarchy based on the urgency of flightcrew awareness and response. (1) Warning: For conditions that require immediate flightcrew awareness and immediate flightcrew response. (2) Caution: For conditions that require immediate flightcrew awareness and subsequent flightcrew response. (3) Advisory: For conditions that require flightcrew awareness and may require subsequent flightcrew response.

G_9 (c) Warning and caution alerts must: (1) Be prioritized within each category, when necessary. (2) Provide timely attention-getting cues through at least two different senses by a combination of aural, visual, or tactile indications. (3) Permit each occurrence of the attention-getting cues required by paragraph (c)(2) of this section to be acknowledged and suppressed, unless they are required to be continuous.

G_9 (d) The alert function must be designed to minimize the effects of false and nuisance alerts. In particular, it must be designed to: (1) Prevent the presentation of an alert that is inappropriate or unnecessary. (2) Provide a means to suppress an attention-getting component of an alert caused by a failure of the alerting function that interferes with the flightcrew's ability to safely operate the airplane. This means must not be readily available to the flightcrew so that it could be operated inadvertently or by habitual reflexive action. When an alert is suppressed, there must be a clear and unmistakable annunciation to the flightcrew that the alert has been suppressed.

G_9 (e) Visual alert indications must: (1) Conform to the following color convention:(i) Red for warning alert indications. (ii) Amber or yellow for caution alert indications. (iii) Any color except red or green for advisory alert indications. (2) Use visual coding techniques, together with other alerting function elements on the flight deck, to distinguish between warning, caution, and advisory alert indications, if they are presented on monochromatic displays that are not capable of conforming to the color convention in paragraph (e)(1) of this section.

G_9 (f) Use of the colors red, amber, and yellow on the flight deck for functions other than flightcrew alerting must be limited and must not adversely affect flightcrew alerting”.

G_10 Systems that alert the pilot to a critical anomaly should not be subject to a silent failure.

G_11 The GCS should provide a work environment that maintains pilot engagement, and minimizes the negative impact of extended periods of low workload.

G_12 The GCS should provide consistency of operation for common functions.

G_13 The functions needed to safely control the aircraft under usual flight situations should be located in the pilot's primary field-of-view.

G_14 Warnings and cautions should not be obscured by other GCS displays.

G_15 "Part-time display. If it is desired to inhibit some parameters from full-time display, an equivalent level of safety to full-time display should be demonstrated. Criteria to be considered include the following: (a) Continuous display of the parameter is not required for safety of flight in all normal flight phases. (b) The parameter is automatically displayed in flight phases where it is required. (c) The inhibited parameter is automatically displayed when its value indicates an abnormal condition, or when the parameter reaches an abnormal value. (d) Display of the inhibited parameter can be manually selected by the UAV crew without interfering with the display of other required information. (e) If the parameter fails to be displayed when required, the failure effect and compounding effects must meet the requirements of USAR.1309. The analysis is to clearly demonstrate that the display(s) of data is consistent with safe operation under all probable operating conditions. (f) The automatic, or requested, display of the inhibited parameter should not create unacceptable clutter on the display; simultaneous multiple "pop-ups" must be considered. (g) If the presence of the new parameter is not sufficiently self-evident, suitable alerting must accompany the automatic presentation".

G_16 Wherever possible, text messages, whether in dialog boxes, warning messages or other screen displays, should be presented in plain language, or using standard aviation terminology.

G_17 Controls intended to be operated by the pilot should be reachable from a seated position

G_18 The GCS should provide a bookrest to enable the pilot to refer to documents without risk that the document will come into contact with a keyboard or other flight controls.

G_19 Appropriate priority controls should be available for UAS functions that require either quick accessibility or constant availability. Priority control devices can include, but are not limited to: (a) Touch panels, (b) Buttons, (c) Switches, (d) Joysticks, (e) Keyboard shortcuts.

G_20 If a display screen enables the pilot to move or rearrange display or control windows, it should not be possible to place a window so as to obscure primary flight controls or displays.

Definitions of terms

System: An integrated collection of facilities, parts, equipment, tools, materials, software, personnel, and/or techniques which make an organized whole capable of performing or supporting a function (Stramler, 1993).

Engineered system: The non-human components of the system, comprising facilities, parts, equipment, tools, materials & software.

Human factors: A body of knowledge about human abilities, human limitations, and other human characteristics that are relevant to design (Chapanis, 1991).

Human factors engineering: The application of human factors information to the design of tools, machines, systems, tasks, jobs, and environments for safe, comfortable, and effective human use Chapanis (1991).

Human factors guideline: A statement describing a characteristic of the engineered system with the intention of promoting safe and effective human use (Adapted from Chapanis, 1991).

Human task: A task description is composed of an actor, a verb and an object. Qualifying phrases may be included if needed for clarification.

Information content of displays: Information that must be provided by the engineered system to the human to enable a task to be performed. The requirement may specify key attributes of the information, such as accuracy, timing, and usability, but will remain agnostic with respect to the medium used to transmit the information.

Control input: Inputs that the engineered system must be capable of receiving from the human. The requirement may specify key attributes of the input, such as timing and precision, but will remain agnostic with respect to the device used to make the input.

Property of the interface: Specifications of desired physical or functional properties of controls or displays. Physical properties are characteristics that are directly observable, such as shape and color. Functional properties refer to operational characteristics of the interface such as the order in which inputs must be made, or the ability to undo an input.

General guideline: A human factors principle that relates to whole-of-system functioning, or that has broad applicability across the engineered system.

Human-centered design process: An activity performed during the design and development phase to ensure that the system will operate safely and effectively, and will be consistent with the capabilities and limitations of the human operator.

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Appendix - Selected human factors regulations, guidance, and policy

Regulations and guidance material with relevance to cockpit design
Title 14 Code of Federal Regulations (14 CFR) http://www.faa.gov/aircraft/air_cert/design_approvals/human_factors/hf-air/cfr/
FAA Guidance and Policy http://www.faa.gov/aircraft/air_cert/design_approvals/human_factors/hf-air/policy/
European Aviation Safety Agency. CS 25.1302 & AMC 25.1302. Certification specifications for large aeroplanes. Installed systems and equipment for use by the flight crew.
Department of Defense. MIL-STD-1787B: Aircraft display symbology.
Department of Defense. MIL-STD-411F: Aircrew station alerting systems.
Human Factors Considerations in the Design and Evaluation of Flight Deck Displays and Controls. Yeh, M., Jo, Y, Donovan, C. & Gabree, S. (2013)
GAMA Publication No. 10 (2004). Recommended practices and guidelines for Part 23 cockpit/flight deck design.
Documents specifically covering the UAS pilot interface
North Atlantic Treaty Organization. (2007). STANAG 4586 Edition 2: Standard interfaces of UAV control systems (UCS) for NATO UAV Interoperability.
Department of Defense. MIL-STD-1472G: Human engineering.
Access 5 (2006). HSI003 Revision 2 (Draft): HSI guidelines outline for the air vehicle control station.
North Atlantic Treaty Organization. (2009). STANAG 4671 Edition 1: Unmanned aerial vehicles systems airworthiness requirements.
Office of the Under Secretary of Defense. (2012). Unmanned aircraft systems ground control station human-machine interface development and standardization guide.

Examples of documents with general relevance to HMI design
FAA. (2012). Human Factors Design Standard (HFDS). HF-STD-001. Available at: http://hf.tc.faa.gov/hfds/
Department of Defense. MIL-HDBK-759C: Human engineering design guidelines.
Research Integrations, Inc. (2012) *HFYI Design CoPilot* [online application and database]. Available at http://www.designcopilot.com.
National Aeronautics and Space Administration. (2010). Human integration design handbook (HIDH).
ANSI/HFES Standard 100-2007. Design of Computer Workstations