National Aeronautics and
Space Administration

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Human Factors Guidelines for Remotely Piloted Aircraft System Remote Pilot Stations

Addressing the unique human factors considerations associated with beyond visual line-of-sight operation of remotely piloted aircraft in civil airspace.

Guidelines Version 1.1

Supersedes *Human Factors Guidelines for Unmanned Aircraft System Ground Control Stations, Preliminary Guidelines 1.0*

Contractor report prepared for NASA Unmanned Aircraft Systems in the National Airspace System Project

July 2016

Authors' Note

This document has been prepared for NASA's Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS) Project. It contains a list of human factors guidelines for remote pilot stations (RPS) arranged within an organizing structure.

The Federal Aviation Administration, the International Civil Aviation Organization, and other agencies are working to develop operational concepts and standards to enable remotely piloted aircraft (RPA) to operate routinely in the civil airspace system. Our objective was to compile human factors guidelines for RPA operations in U.S. airspace, however we hope that our work will also be useful internationally.

It was not our intention to list all human factors guidelines relevant to the RPS, as this would involve replicating a large number of existing guidelines for cockpit design and other human system interfaces. Instead, the guidelines contained in this document are intended to supplement the existing human factors literature by focusing on the unique aspects of remotely piloted aircraft systems (RPAS) and the capabilities and characteristics of the RPS that will be necessary to enable these aircraft to operate routinely in the civil airspace system.

The reader should note that these guidelines address remotely piloted aircraft systems (RPAS) that are capable of operating beyond visual line-of-sight (VLOS) in all classes of civil airspace. We do not address RPA that are operated under the FAA regulations for "small UAS" (14 CFR Part 107) or that are operated entirely by visual reference of the pilot.

These guidelines will be revised and updated periodically as information becomes available from research, reader comments, and operational experience. Comments or questions can be sent to us via the email addresses below.

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Summary

This document contains a list of human factors guidelines for remote pilot stations (RPS) arranged within an organizing structure. The guidelines are intended for the RPS of remotely piloted aircraft systems (RPAS) that are capable of operating beyond visual line-of-sight (VLOS) in all classes of civil airspace.

Numerous human factors guidelines and standards for technological systems have been published by standards organizations and regulatory authorities. In compiling this document, the intent was not to reproduce or restate existing human factors material. Instead, this document focuses on the unique issues of civilian RPAS operations, and contains guidelines specific to this sector. As a result, it should be seen as a supplement to existing aviation human factors standards and guidance material.

Two constraints were used to focus the scope of this document. First, the assumptions contained in the FAA (2013a) roadmap for the integration of unmanned aircraft systems were used to define the responsibilities that will be assigned to the pilot of a RPAS operating beyond VLOS in civil airspace. This in turn helped to define the tasks that the remote pilot must perform via the RPS, and thereby the required features and characteristics of the RPS. Second, the points of difference between RPAS and conventional aviation were used to further focus the guidelines on the considerations that make piloting a RPA 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 RPS, (2) information content of displays, (3) descriptions of control inputs, (4) properties of the interface, and (5) general design considerations. Some of the guidelines in this document have been adapted from existing RPAS 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 research conducted under the National Aeronautics and Space Administration (NASA) 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 RPAS.

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
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
RPA	Remotely Piloted Aircraft
RPAS	Remotely Piloted Aircraft System
RPS	Remote Pilot Station
RTCA	RTCA Inc., *formerly Radio Technical Commission for Aeronautics*
STANAG	NATO Standardization Agreement
TCAS	Traffic Alert and Collision Avoidance System
UA	Unmanned Aircraft
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle
VHF	Very High Frequency
VLOS	Visual line-of-sight

Definition of Terms

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.

Conventional aviation and conventionally-piloted aircraft: Aircraft controlled by an onboard pilot.

Engineered system: The nonhuman components of the system, comprising facilities, parts, equipment, tools, materials, and software.

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

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

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.

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).

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.

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.

Remotely piloted aircraft (RPA): An unmanned aircraft which is piloted from a remote pilot station (ICAO, 2015).

Remote pilot station (RPS): The component of the remotely piloted aircraft system containing the equipment used to pilot the remotely piloted aircraft (ICAO, 2015).

Remotely piloted aircraft system (RPAS): A remotely piloted aircraft, its associated remote pilot station(s), the required command and control links, and any other components as specified in the type design (ICAO, 2015).

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).

1. Introduction

The terminology of the International Civil Aviation Organization (2015) is used throughout this document. The term "remotely piloted aircraft" (RPA) is used to refer to the aircraft, in both the singular and plural. The term "remotely piloted aircraft system" (RPAS) is used when the intent is to refer to the entire system, comprising the aircraft, its remote pilot station, communication links, and other elements. The workstation of the remote pilot is referred to as the "remote pilot station" (RPS). In several places, it has been necessary to refer to documents that include the terms "Unmanned Aircraft" (UA) and "Unmanned Aircraft System" (UAS). These terms are synonymous with RPA and RPAS, respectively.

RPA have generally experienced a higher accident rate than conventionally-piloted aircraft (Hobbs, 2017; Nullmeyer & Montijo, 2009). Many of these accidents appear to reflect the unique human challenges associated with piloting an aircraft remotely, in combination with RPS that were designed with insufficient regard for human factors engineering 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).

RPS range from commercial off-the-shelf (COTS) laptops, to sophisticated purpose-built interfaces housed in shelter trailers or control facilities. Although some RPS 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, nonintuitive automation interfaces, a reliance on text displays, and complicated sequences of menu selection to perform minor or routine tasks (Cooke, Pringle, Pedersen, & Connor, 2006; Hobbs & Lyall, 2016). 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 emerging issues unique to RPAS that are not covered by existing regulatory or advisory material.

NASA has recognized that human factors guidelines for the RPS will be a key requirement for safe and reliable operation of civilian RPAS in the United States NAS. As part of the NASA UAS in the NAS Project, the agency is working with key stakeholders to develop recommendations for RPS human factors guidelines with a focus on RPA operating beyond VLOS.

This document contains human factors guidelines that have been developed on the basis of data from simulations, accident and incident analysis, and the literature on RPAS human factors. The document also draws together existing RPAS guidelines previously developed by NATO, RTCA, Access 5, and other agencies. 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.

1.1 Scope of the Current Activity

The scope of the current activity is as follows:

a) The guidelines are intended for RPAS capable of operating beyond VLOS within all classes of civilian airspace.

b) RPAS operating entirely within VLOS or under the U.S. FAA regulation addressing "small UAS" (14 CFR Part 107) are out of scope.

c) The focus is the engineered system comprising the RPS and its immediate environment. Personnel training, crew qualifications, procedure design, and physical security of the RPS are beyond the scope of this document.

d) The scope is not limited to specific designs or technologies.

e) The control or management of operational mission or payload is out of scope, except where payload considerations may affect the safety of flight.

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

g) This document does not include material on Detect and Avoid (DAA) systems. Minimum Operational Performance Standards (MOPS) for DAA are currently being developed by RTCA Special Committee 228.

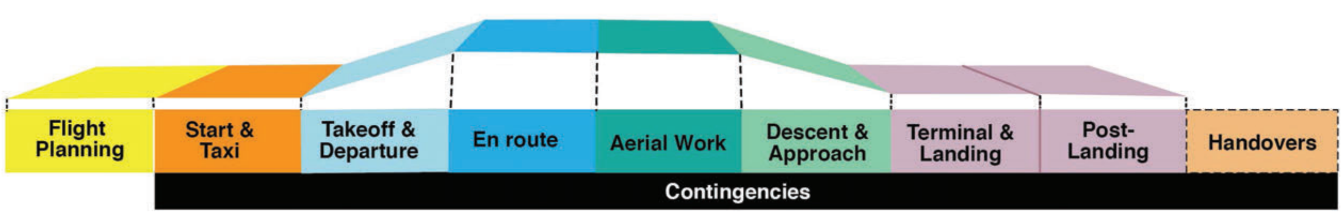

Figure 1. Stages-of-flight considered in the development of guidelines.

2. Guidelines and the Special Challenges of RPAS Operations

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

In compiling guidelines for the RPS, 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 RPAS in civil airspace systems. 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 RPAS-specific and deal with issues that are not covered by guidelines typically used in the aviation industry. In parts of this document, however, we have chosen to restate general human factors principles that have particular applicability to RPAS, especially when we have found evidence that the principle has been overlooked by the designers of existing RPS.

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 in the NAS. These assumptions determine the capabilities that RPAS must possess and the tasks that the pilot must be able to perform. Second, we have identified the special challenges presented by RPAS, and have focused on compiling guidelines relevant to these issues. These challenges are sometimes referred to as "deltas," meaning the additional considerations that apply to RPAS operations over and above those that apply to conventionally-piloted aircraft. A summary of the special challenges can be found in a following section.

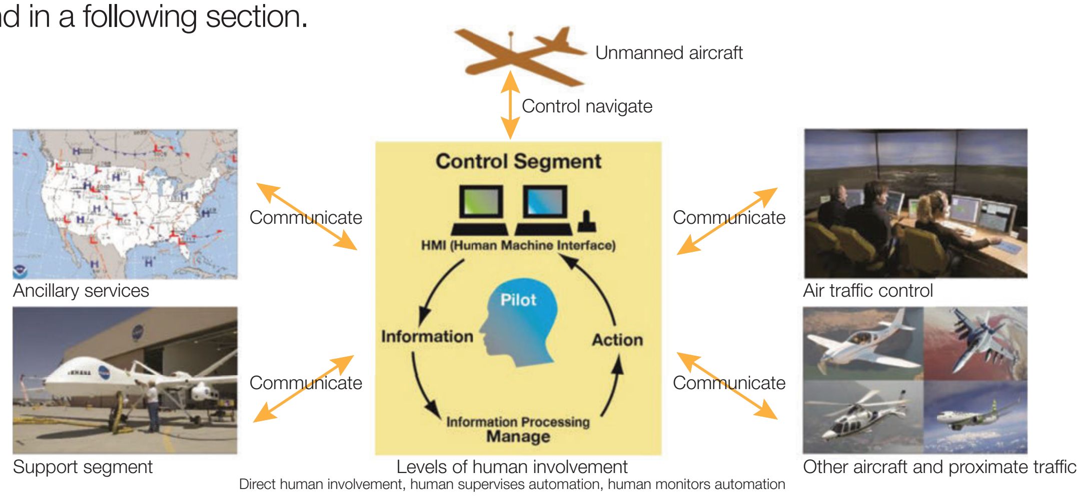

Figure 2. Control and communication responsibilities of a RPAS pilot operating in the NAS.

2.1 FAA Assumptions

The FAA (2013a) roadmap for integration of RPAS into the NAS includes a set of assumptions that will guide how civil RPAS operating beyond VLOS of the pilot will be integrated into the NAS. These assumptions are reproduced verbatim in Table 1 below. Several of the assumptions have direct implications for the role of the pilot. For example, from assumption 3, it follows that the pilot will comply with Instrument Flight Rules (IFR) procedures and will operate the aircraft on designated air routes. Assumption 6 makes it clear that there will be a role for a pilot in command, and that the control of multiple RPA by one pilot is not envisioned. Assumption 7 requires that the pilot will have on-the-loop or in-the-loop control authority. This in turn, implies that the RPS 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 conventionally-piloted aircraft. Figure 2 shows a simplified representation of the role of the remote pilot when 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.

FAA (2013a). Integration of Civil Unmanned Aircraft Systems (UAS) in the National Airspace System (NAS) Roadmap (pp 33-34).

2.2 Special Considerations of RPAS

RPAS share many of the same human factors considerations that apply in conventionally-piloted aircraft, however the points of difference have implications for RPS design (Hobbs & Lyall, 2016; 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 RPAS with implications for human factors guidelines.	
1.	Loss of natural sensing
2.	Control and communication via radio link
3.	The unique environment of the remote pilot station
4.	In-flight transfer of control
5.	Unique flight characteristics of remotely piloted aircraft
6.	Flight termination
7.	Reliance on automation
8.	Widespread use of interfaces based on consumer products

2.2.1 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 RPAS 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 remote 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 by direct visual reference. In the cruise flight phase, a remote 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 RPAS operations may not apply when the RPA is on the ground or in terminal airspace. The awareness of the surrounding environment 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 RPAS traffic displays to enable RPA to detect and avoid other aircraft.

Foveal bottleneck: Some RPAS designers have attempted to compensate for the lack of rich sensory cues with text-based displays in the RPS. However, this requires the remote pilot to use 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 onboard cameras: If an onboard 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. For example, if a moveable camera located on board a RPA is not aligned as expected by the pilot, or moves unexpectedly, there may be an illusion of yaw, or other undesired aircraft state.

2.2.2 Control and Communication (C2) Via Radio Link

Figure 3 illustrates the C2 links connecting the RPS with the RPA. The link may involve terrestrial radio or satellite links, or a combination of the two.

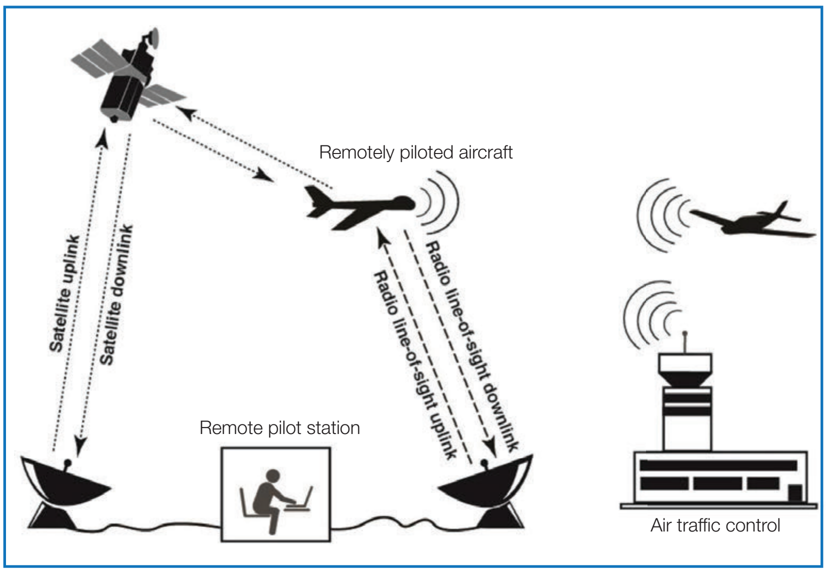

Figure 3. A representation of the links between the RPS and the RPA.

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 RPAS operations in the NAS will involve a digital relay of remote pilot voice communications from the ground to the RPA, from where the message will be converted to analog form, and rebroadcast over VHF radio. The transmissions of other pilots and controllers will be relayed to the remote pilot using the same system. The relay of voice communications from the RPS via the RPA will introduce a delay between the communications of the remote pilot with reference to other pilots on frequency. This delay will be most noticeable when a satellite link is involved. Most of this latency will be due to processing before and after signal transmission. In order to seamlessly integrate RPAS into civil airspace systems, it will be important that the latency introduced into the voice communications of remote pilots does not reach a level that disrupts communication.

Link management: In addition to flying the aircraft, the pilot must manage and monitor the 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 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 RPA or interfering with the control link. In the event of a link interruption, the RPA must be capable of continued flight in accordance with the expectations of the pilot and air traffic control.

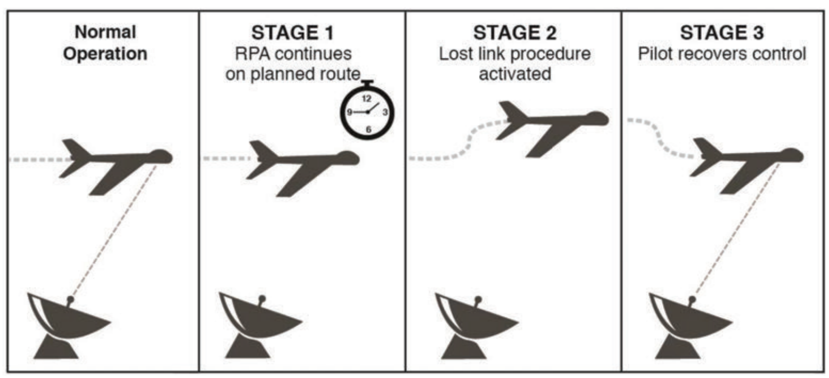

Figure 4. Stages of a lost link event.

A lost link event can consist of three stages, as shown in Figure 4. In Stage 1, the link has been interrupted, but the aircraft continues to fly in accordance with the last command received from the pilot. Some link outages will last a few milliseconds, whereas others may extend for minutes or even hours. It would be disruptive if the RPA started to fly its lost link procedure each time a brief link interruption occurred. Therefore, an onboard timer is needed to measure the duration of the outage and activate the lost link procedure after a preset interval has elapsed. In the terminal area, the lost link procedure may need to commence after an outage of a few seconds. Elsewhere, the RPA may be able to safely continue along its planned flightpath for an extended period before entering its lost link procedure. In Stage 2 of a lost link event, the RPA's preprogrammed lost link procedure is activated. Different lost link procedures will be appropriate according to the location of the aircraft and the stage of flight. The remote pilot must therefore remain aware of the current lost link procedure. In Stage 3 of the lost link sequence, the link is re-established and the aircraft transitions back to pilot control.

2.2.3 The Unique Environment of the RPS

The RPS, located remote to the aircraft, is likely to increasingly resemble a control room rather than a cockpit. Guidelines may cover not only the HMI, but also the physical environment of the RPS, including noise levels, access controls, temperature control, and lighting.

Potential to add displays: The relative spaciousness of the RPS 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 RPS. It will be necessary to determine whether the addition of a display to the RPS should be considered a significant or minor modification for RPS design and certification purposes.

Ability of maintenance personnel to access the RPS during flight: Current RPAS 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, RPAS maintenance personnel have the opportunity to gain access to the RPS during flight operations to perform nonscheduled maintenance, and may have hands-on interactions with the RPS while a flight is underway. As a result, maintenance errors may have an immediate operational impact (Hobbs & Herwitz, 2008).

2.2.4 In-Flight Transfer of Control

Control of a RPA may be transferred during flight operations between pilots at the same RPS console, between consoles at the same RPS, or between physically separated RPS (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 RPS due to controls set in error. The control of a long-endurance 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.

2.2.5 Flight Characteristics of RPA

Compared to conventionally-piloted aircraft, RPA 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. The human factors implications of these characteristics may include a reduced ability to rapidly comply with ATC instructions, and a need for "north up" moving map displays suitable for flights with frequent changes of track. RPAS operations may also start and end with launch and recovery systems rather than conventional runways, changing the nature of the pilot's task.

Extended periods of low workload: A challenge for the designer of the RPS 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.

2.2.6 Flight Termination

In an emergency, the pilot of a RPA may be required to perform an off-airport landing, or otherwise terminate the flight by a controlled impact, ditching, parachute descent, or other method. Although no lives are at stake onboard 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 RPS 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).

2.2.7 Reliance on Automation

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

2.2.8 Widespread Use of Interfaces Based on Consumer Products

RPS 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 RPS 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.

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

3. Sources and Types of Guidelines

3.1 Overview of Existing Guidelines

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

3.2 Types of Guidelines

Several areas where guidelines may be useful can be identified by asking the questions shown in Figure 5. The process leads to five broad types of guidelines, described in further detail in the following sections.

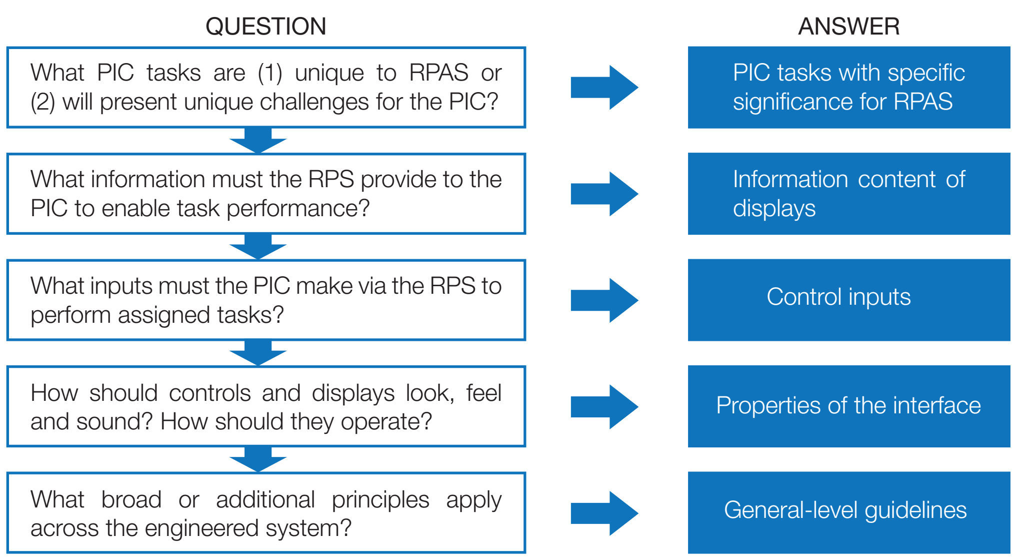

Figure 5. Questions about human-system interaction that lead to five types of guidelines.

3.2.1 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 remote pilot may be required by ATC to direct the aircraft on to a magnetic heading. Therefore, the RPS must provide displays and controls to support this task. In general, a guideline that takes the form of a task statement is a type 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 RPAS operations, or tasks that present significant additional challenges for remote pilot compared to the pilot of a conventional aircraft.

3.2.2 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.

3.2.3 Control Inputs

These are inputs that the RPS 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.

3.2.4 Properties of the HMI

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 RPS. Several analyses of RPS 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 (Hobbs, 2017).

3.2.5 General Guidelines

General design guidelines are "overarching" principles that have general applicability to the RPS and relevance to multiple displays and controls. In most cases, these are agnostic with respect to the form of the HMI. Examples are design principles dealing with issues such as the internal consistency of the HMI, 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 RPS, including characteristics that emerge from the operation of all subsystems together. For example, visual clutter, display competition for attention, and the prioritization of information.

3.3 Remote Pilot Responsibilities

Figure 6 presents a high-level model of the responsibilities of the remote 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 HMI. In some cases, broad areas of responsibility are common to both conventional aviation and RPAS, yet may present special challenges for the remote pilot. These include monitoring and controlling the status of radio links, control hand-offs, and flight termination. The model shown in Figure 6 is used to organize the guidelines included in this document. Note that standards for DAA systems are currently being developed by RTCA Special Committee 228. Consequently, this document does not include guidelines relating to collision avoidance maneuvers, or maneuvers to remain well-clear of other aircraft.

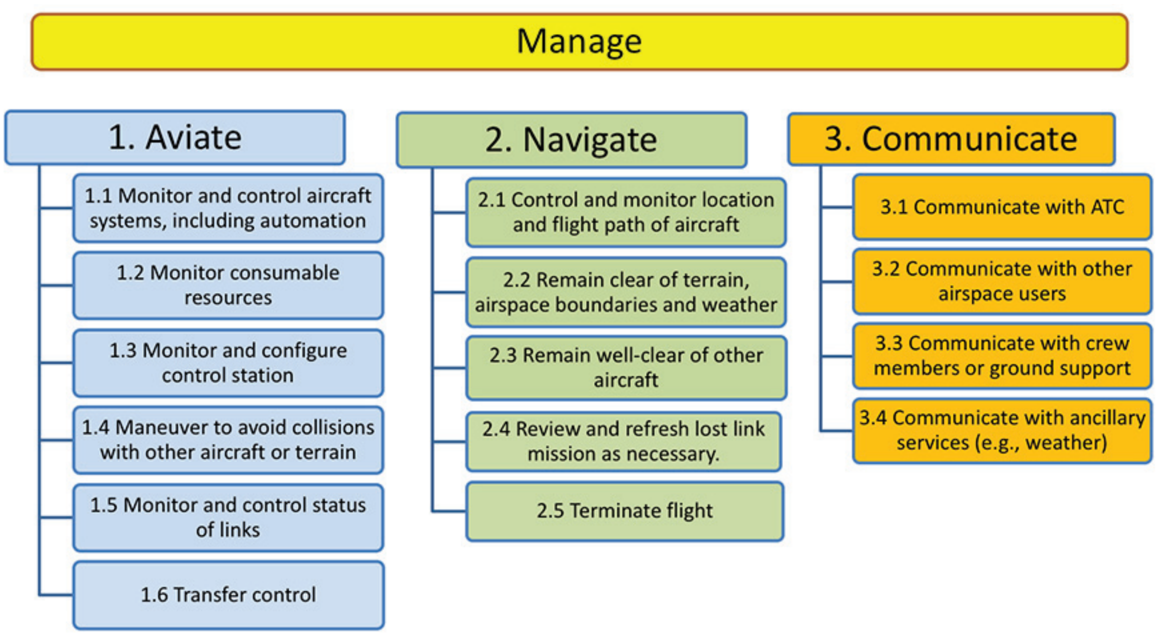

Figure 6. Responsibilities of the remote pilot.

Manage: The "Manage" category includes the overall planning, decision-making, and management responsibilities that must be accomplished by the pilot, supported by the HMI. For ease of presentation, management responsibilities are shown separately in Figure 6, 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 onboard automation, however the pilot is still required to provide supervisory oversight and control the configuration of systems. Maneuvers to avoid collisions with other aircraft are considered to be an aspect of "Aviate." However, as MOPS for DAA systems are currently being developed by RTCA Special Committee 228, they will not be covered in this document.

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 "remain well-clear" responsibility must be accomplished in the absence of an out-the-window view, necessitating reliance on a traffic situation display in the RPS. The two final responsibilities listed under "Navigate" are specific to RPAS. The pilot must maintain an awareness of the aircraft's preprogrammed 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 RPAS operating team is critical and the HMI must be designed to enable team situation awareness to be achieved. The relay of pilot-ATC voice communications via the RPA has the potential to introduce communication latencies that may be sufficient to disrupt verbal communication.

4. Guidelines

This section contains a set of preliminary human factors guidelines for RPAS. The guidelines in sections 4.1, 4.2, and 4.3 refer to specific characteristics or capabilities of the HMI, and are arranged using the model of pilot responsibilities shown in Figure 6. The letter at the beginning of each guideline code indicates the type of guideline. As shown in Table 3, guidelines with codes beginning with "T_" specify pilot tasks that must be facilitated by the RPS. 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 guidelines in section 4.4 deal with issues that have general applicability to the RPS, possibly across multiple pilot responsibilities. These guidelines are indicated by a "G_" code. General guidelines include human engineering activities that the RPS developer is expected to accomplish in order to produce a RPS that can be operated safely and reliably, considering human capabilities and limitations.

Table 3. Five types of guidelines are specified, in most cases relating to one or more pilot responsibilities.

	Manage	Aviate	Navigate	Communicate
T_ RPAS-specific pilot tasks that must be performed using the HMI				
I_ Information content of displays				
C_ Control inputs				
P_ Properties of displays and controls				
G_ General guidelines				

4.1 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 RPS.

4.1.1 Monitor and Control Aircraft Systems

In most cases, the continuous control functions necessary for the maintenance of stable flight are allocated to onboard 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.

RPAS-specific pilot tasks that must be performed using the HMI

T_1.1.1 If an onboard camera is used for flight control tasks, the RPS should enable the pilot to align the camera with the longitudinal axis of the aircraft.

Properties of displays and controls

P_1.1.1 The RPS 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 RPS should prevent multiple operators from operating the same application or procedure at any one time.
(Adapted from NATO, 2004)

P_1.1.3 It should be possible to set an RPS to a receive only mode, in which the RPS displays information downlinked from an RPA in the absence of an active command link.
(Adapted from NATO, 2004)

Related special considerations

A. Loss of natural sensing; B. C2 via radio link.

4.1.2 Monitor Consumable Resources

Consumable resources on the RPA 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 RPS must enable the pilot to monitor the status of these resources. The task of monitoring consumable resources may involve aspects unique to RPAS, 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.

RPAS-specific pilot tasks that must be performed using the HMI

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

Information content of displays

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

Related special considerations

E. Unique flight characteristics of RPA.

4.1.3 Monitor and Configure Control Station

Management of the RPS will require the pilot or other crewmembers to monitor and configure the status of the RPS, and identify and respond to abnormal conditions. This may include managing the performance of computer systems and power supplies. Unique considerations may include the need to manage uninterruptable power supplies and air conditioning required for computer systems. If a second RPS 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 that RPS.

RPAS-specific pilot tasks that must be performed using the HMI

T_1.3.1 The RPS should enable the pilot to perform checks on the status of RPS systems.

T_1.3.2 The RPS should enable the pilot to perform a preflight check on an alternate control station, or confirm that this check has been performed. (RTCA, 2007)

T_1.3.3 The RPS should enable the pilot to monitor the performance of RPS support services, for example, air conditioning, and electrical power.

Information content of displays

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

Related special considerations

C. The unique environment of the RPS.

4.1.4 Maneuver to Avoid Collisions With Other Aircraft or Terrain

This responsibility refers to tactical maneuvers to avoid collisions with proximate aircraft or objects. It can be seen as the final stage of DAA and will only be necessary when the RPA has failed to remain well-clear of other traffic. Guidelines for DAA systems are currently being developed by RTCA Special Committee 228 (Unmanned Aircraft Systems).

4.1.5 Monitor and Control Status of Links

The C2 link is an integral part of the RPAS. 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 pilot of a RPA 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.

RPAS-specific pilot tasks that must be performed using the HMI

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

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

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

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

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

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

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

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

T_1.5.9 The RPS 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 RPS 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 RPS should enable the pilot to respond to interference with the signal (e.g., other users of frequency, jamming attempts).

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

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

T_1.5.14 The RPS 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 RPA enters its lost link procedure.

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

Information content of displays

I_1.5.1 The RPS 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 RPA.

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

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

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

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

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

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

I_1.5.8 The RPA will transmit a predetermined transponder code when the link is lost.

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

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

I_1.5.11 The RPS should display to the pilot the source of downlink transmissions. (Access 5, 2006)

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

I_1.5.13 The RPS 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 RPS should provide information to enable the pilot to manage link security.

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

Control inputs

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

C_1.5.2 The RPS 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, the RPS should support an external command to set the antenna used for communication.

C_1.5.4 The RPS 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 [RPAS] 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 data link (data link 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 (data link footprint) are predicted to be masked by terrain should be displayed on the C2 data link display.

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

P_1.5.6 The C2 data link 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 RPS, in combination with the other elements of the RPAS, should comply with control link latency (time from initiation of a maneuver to a measurable response by the RPA) requirements that are established at a level similar to conventionally-piloted aircraft.
(FAA, 2013b)

Related special considerations

B. C2 via radio link.

4.1.6 Transfer Control

The ability to completely transfer control between or within RPS is one of the key differences between RPAS 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" RPS possess a shared understanding of the operational situation and that control settings are aligned between the two control stations.

RPAS-specific pilot tasks that must be performed using the HMI

T_1.6.1 The RPS should enable control to be transferred between a giving and receiving RPS in a manner that is seamless and transparent to ATC.
(FAA, 2013b)

T_1.6.2 The RPS should enable continuity of pilot function to be maintained during the transfer of control between a giving and receiving RPS.
(FAA, 2013b)

T_1.6.3 "The RPS shall enable the pilot to ensure that operating parameters are identical before and after handover."
(NATO, 2009) .

T_1.6.4 The RPS should enable the pilot to pass RPA control (handover) to another RPS and monitor the status of the handover.
(NATO, 2004)

T_1.6.5 In cases where more than one RPS could be linked with the RPA, each RPS will enable the pilot to monitor which entity has control of the aircraft and to what extent the entity has control.
(Adapted from Access 5, 2006)

T_1.6.6 The RPS should enable the giving and receiving pilots to confirm that control settings are appropriate and consistent before a handover is accomplished.

T_1.6.7 The RPS should enable the receiving pilot to monitor the status of the RPA by receiving telemetry from the RPA before establishing control of the RPA.

T_1.6.8 The RPS should facilitate a handover briefing between the giving and receiving pilots.

T_1.6.9 The RPS should provide the receiving pilot with a means of confirming that control has been established with the RPA.

Information content of displays

I_1.6.1 The pilot should be presented with information necessary to confirm that flight-critical settings in the receiving RPS are consistent with settings in the giving RPS.

I_1.6.2 The RPS should provide a level of involvement indicator to the pilot to show whether the RPS has been set to only receive telemetry from the RPA, or to receive telemetry and transmit commands to the RPA.

Control inputs

C_1.6.1 The RPS should enable the pilot to select the desired level of involvement with a RPA, ranging from monitoring telemetry without an active uplink, to telemetry with full control via an active uplink.

C_1.6.2 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_1.6.1 The RPS 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_1.6.2 The RPS should enable control to be transferred to another RPS without any gap in control occurring during the handover.

Related special considerations

D. In-flight transfer of control.

4.2 Navigate

The navigate responsibility involves largely strategic, or longer-term, control of the RPA. In many cases, the task of navigating the RPA is substantially the same as that for a conventionally-piloted aircraft. This section does not include requirements or guidelines that would apply equally to conventionally-piloted aircraft.

4.2.1 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.

RPAS-specific pilot tasks that must be performed using the HMI

T_2.1.1 The RPS 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_2.1.2 "The UAS [RPAS] 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 RPA ownship position. The RPS should provide a representation of the RPA's position. The display should provide:

I_2.1.1a Representation of RPA within the airspace.

I_2.1.1b Heading of RPA.

I_2.1.1c Altitude of RPA.

I_2.1.1d Airspeed of RPA.

I_2.1.1e Attitude of RPA.

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

I_2.1.2 Programmed flight plan and predicted flight path of RPA. The RPS should provide a representation of the predicted flight path of the RPA 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 RPA current position along programmed flight path.

I_2.1.2b Predicted flight path relative to RPA 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.

Properties of displays and controls

P_2.1.1 Map displays 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 Map displays should be configurable to "North up" or "Track up."

P_2.1.3 If control is via a terrestrial radio, the location of (or direction to) the ground transmitter/receiver should be shown on the map.

P_2.1.4 Primary flight controls for controlling the RPA (heading, attitude, and 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).

Related special considerations

A. Loss of natural sensing; C. The unique environment of the RPS; G. Reliance on automation.

4.2.2 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.

RPAS-specific pilot tasks that must be performed using the HMI

T_2.2.1 The RPS should enable the pilot to "observe" and comply with signage, painted markings, and warning lights during surface operations.
(FAA, 2013b)

T_2.2.2 The RPS should enable the pilot to monitor weather that has the potential to affect the flight.
(RTCA, 2007)

T_2.2.3 The RPS should enable the pilot to avoid weather that has the potential to affect the flight.

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 coordination information."
(NATO, 2004)

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

I_2.2.3 The RPS should provide the pilot with information on the location of icing conditions.

I_2.2.4 The RPS should alert the pilot when the RPA enters icing conditions.

I_2.2.5 The RPS should alert the pilot when the RPA encounters significant air turbulence.

Related special considerations

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

4.2.3 Remain Well-Clear of Other Aircraft

This responsibility includes the strategic separation assurance function of DAA, in which the RPA remains well clear of other traffic. Guidelines for DAA systems are currently being developed by RTCA Special Committee 228 (Unmanned Aircraft Systems).

4.2.4 Review and Refresh Lost Link Mission as Necessary

The pilot must maintain an awareness of the aircraft's preprogrammed 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.

RPAS-specific pilot tasks that must be performed using the HMI

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

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

T_2.4.3 The RPS should enable the pilot to select the length of time that must elapse between the onset of a lost link event and the activation of the aircraft's lost link procedure.

Information content of displays

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

I_2.4.2 The RPS 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 nonauthorized airspace).

I_2.4.3 The RPS should display to the pilot the length of time that will elapse between the onset of a lost link event and the activation of the aircraft's lost link procedure.

I_2.4.4 In the event of a lost link, the RPS should display the time remaining until the activation of the aircraft's lost link procedure.

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 HMI.

Related special considerations

B. C2 via radio link.

4.2.5 Terminate Flight

In an emergency, the remote pilot may be required to terminate the flight by a controlled impact, ditching, parachute deployment, or other method. 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.

RPAS-specific pilot tasks that must be performed using the HMI

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

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

T_2.5.3 The RPS should enable the pilot to terminate the flight in a predesignated area.

(RTCA, 2007)

T_2.5.4 The RPS 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 RPS 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 RPS should provide an alert to the pilot to indicate that the flight termination system is about to be activated.

Properties of displays and controls

P_2.5.1 When the RPA 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 RPAS crew should be required to initiate the flight termination command.

(NATO, 2009)

Note: NATO Standardization Agreement 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 RPS 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 RPA 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

4.3 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.

4.3.1 and 4.3.2 Communicate With ATC and Other Airspace Users

Communication with ATC is typically via VHF voice communications transmitted from the RPA, or in some cases, controller pilot data link (CPDL). If the RPA is operating beyond radio line-of-sight of the ground transmitter, communications may be relayed using ground infrastructure or satellite. Additionally, air-to-air relays between RPA 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 so the pilot maintains awareness of the location and intentions of other users of the airspace.

RPAS-specific pilot tasks that must be performed using the HMI

T_3.1.1 When operating near a nontowered 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 remote 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 RPS should include alternate means for the pilot to communicate with ATC in the event of a loss of C2 link.

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

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. C2 via radio link.

4.3.3 Communicate With Other RPAS Flight Crew and Ground-Support Personnel

Ground-support personnel, external observers, and other support personnel may be located remote from the RPS. Communication and coordination within the operating team will require special attention, and the human machine-interface must be designed to enable team situation awareness to be achieved. Some current RPAS 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 RPA will be transferred in flight, communication must occur between the giving and receiving pilots. This may involve voice or text-based communications.

RPAS-specific pilot tasks that must be performed using the HMI

T_3.2.1 The RPS should enable the RPAS 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 RPS 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 RPS 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 RPS should provide the pilot with a communication link with ground-support personnel while they are interacting with the aircraft.

Related special considerations

A. Loss of natural sensing; B. Control and communication via radio link; C. The unique environment of the RPS.

4.3.4 Communicate With Ancillary Services

Ancillary services include weather briefers and other personnel providing external support to the RPAS operation.

RPAS-specific pilot tasks that must be performed using the HMI

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

4.4 General Guidelines

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

G_1 RPAS 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 RPS 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 pilots 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 multimode 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 RPS 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 remote pilot has selected a mode in flight that renders the aircraft uncontrollable. The RPS 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 RPS designs have involved multifunction controls that can be configured to either control a safety-of-flight function or a noncritical 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 RPS 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 RPS designs have involved multifunction controls that can be configured to either control a safety-of-flight function or a noncritical payload function. The widespread use of consumer software in RPS make it possible to rapidly reconfigure 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)

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 RPA.

Supporting notes: The location of the RPAS 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. C2 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 RPS 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 RPAS 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 RPAS pilot remote from the aircraft may make pilot error self-correction more difficult.

Related special considerations

A. Loss of natural sensing; B. C2 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 RPS 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 onboard experience of the aircraft's performance, the remote 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 RPS 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.

Related special considerations

G. Reliance on automation.

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

Supporting notes: The remote 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. The unique environment of the RPS; E. Unique characteristics of RPA flight.

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

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.

Related special considerations

C. The unique environment of the RPS; G. Reliance on automation.

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

Related special considerations

C. The unique environment of the RPS; 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 RPS 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 RPS designs.

Related special considerations

C: The unique environment of the RPS.

G_18 The RPS 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: RPAS incidents have occurred where keyboard commands have been inadvertently activated by contact with documents and other materials.

Related special considerations

C: The unique environment of the RPS.

G_19 Appropriate priority controls should be available for RPAS 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, and (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 RPS designs have required pilots to perform complicated sequences of actions to perform time-critical or routine actions. Guidelines calling for RPS 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. C2 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 screens or dialog boxes.

Related special considerations

H. Widespread use of interfaces based on consumer products.

4.5 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 If an onboard camera is used for flight control tasks, the RPS should enable the pilot to align the camera with the longitudinal axis of the aircraft.

P_1.1.1 The RPS 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 RPS should prevent multiple operators from operating the same application or procedure at any one time.

P_1.1.3 It should be possible to set an RPS to a receive only mode, in which the RPS displays information downlinked from an RPA in the absence of an active command link.

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

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

T_1.3.1 The RPS should enable the pilot to perform checks on the status of RPS systems.

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

T_1.3.3 The RPS should enable the pilot to monitor the performance of RPS support services, (e.g., air conditioning and electrical power).

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

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

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

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

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

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

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

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

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

T_1.5.9 The RPS 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 RPS 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 RPS should enable the pilot to respond to interference with the signal (e.g., other users of frequency and jamming attempts).

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

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

T_1.5.14 The RPS 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 RPA enters its lost link procedure.

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

I_1.5.1 The RPS 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 RPA.

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

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

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

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

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

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

I_1.5.8 The RPA will transmit a predetermined transponder code when the link is lost.

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

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

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

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

I_1.5.13 The RPS 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 RPS should provide information to enable the pilot to manage link security.

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

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

C_1.5.2 The RPS 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, the RPS should support an external command to set the antenna used for communication.

C_1.5.4 The RPS 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 [RPAS] 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 data link (data link 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 (data link footprint) are predicted to be masked by terrain should be displayed on the C2 data link display.

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

P_1.5.6 The C2 data link 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 RPS, in combination with the other elements of the RPAS, should comply with control link latency (time from initiation of a maneuver to a measurable response by the RPA) requirements that are established at a level similar to conventionally-piloted aircraft.

T_1.6.1 The RPS should enable control to be transferred between a giving and receiving RPS in a manner that is seamless and transparent to ATC.

T_1.6.2 The RPS should enable continuity of pilot function to be maintained during the transfer of control between a giving and receiving RPS.

T_1.6.3 "The RPS shall enable the pilot to ensure that operating parameters are identical before and after handover."

T_1.6.4 The RPS should enable the pilot to pass RPA control (handover) to another RPS and monitor the status of the handover.

T_1.6.5 In cases where more than one RPS could be linked with the RPA, each RPS will enable the pilot to monitor which entity has control of the aircraft and to what extent the entity has control.

T_1.6.6 The RPS should enable the giving and receiving pilots to confirm that control settings are appropriate and consistent before a handover is accomplished.

T_1.6.7 The RPS should enable the receiving pilot to monitor the status of the RPA by receiving telemetry from the RPA before establishing control of the RPA.

T_1.6.8 The RPS should facilitate a handover briefing between the giving and receiving pilots.

T_1.6.9 The RPS should provide the receiving pilot with a means of confirming that control has been established with the RPA.

I_1.6.1 The pilot should be presented with information necessary to confirm that flight-critical settings in the receiving RPS are consistent with settings in the giving RPS.

I_1.6.2 The RPS should provide a level of involvement indicator to the pilot to show whether the RPS has been set to only receive telemetry from the RPA, or to receive telemetry and transmit commands to the RPA.

C_1.6.1 The RPS should enable the pilot to select the desired level of involvement with a RPA, ranging from monitoring telemetry without an active uplink, to telemetry with full control via an active uplink.

C_1.6.2 There should be a means for the giving and receiving pilots to communicate before, during and after the handover.

P_1.6.1 The RPS 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_1.6.2 The RPS should enable control to be transferred to another RPS without any gap in control occurring during the handover.

I_2.1.1 RPA ownship position. The RPS should provide a representation of the RPA's position. The display should provide:

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

I_2.1.2 Programmed flight plan and predicted flight path of RPA. The RPS should provide a representation of the predicted flight path of the RPA 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 RPA current position along programmed flight path.
- I_2.1.2b Predicted flight path relative to RPA 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.

T_2.1.1 The RPS should enable the pilot to ensure that both the runway and approach path are clear of traffic before taxiing onto the active runway.

T_2.1.2 “The UAS [RPAS] 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.”

P_2.1.1 Map displays 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 Map displays should be configurable to “North up” or “Track up.”

P_2.1.3 If control is via a terrestrial radio, the location of (or direction to) the ground transmitter/receiver should be shown on the map.

P_2.1.4 Primary flight controls for controlling the RPA (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.

T_2.2.1 The RPS should enable the pilot to “observe” and comply with signage, painted markings, and warning lights during surface operations.

T_2.2.2 The RPS should enable the pilot to monitor weather that has the potential to affect the flight.

T_2.2.3 The RPS should enable the pilot to avoid weather that has the potential to affect the flight.

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

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

I_2.2.3 The RPS should provide the pilot with information on the location of icing conditions.

I_2.2.4 The RPS should alert the pilot when the RPA enters icing conditions.

I_2.2.5 The RPS should alert the pilot when the RPA encounters significant air turbulence.

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

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

T_2.4.3 The RPS should enable the pilot to select the length of time that must elapse between the onset of a lost link event and the activation of the aircraft's lost link procedure.

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

I_2.4.2 The RPS 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 nonauthorized airspace).

I_2.4.3 The RPS should display to the pilot the length of time that will elapse between the onset of a lost link event and the activation of the aircraft's lost link procedure.

I_2.4.4 In the event of a lost link, the RPS should display the time remaining until the activation of the aircraft's lost link procedure.

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 RPS should enable the pilot to decide when to terminate the flight via controlled impact, ditching or parachute descent.

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

T_2.5.3 The RPS should enable the pilot to terminate the flight in a predesignated area.

T_2.5.4 The RPS 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 RPS 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 RPS 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 RPA 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 RPAS 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 RPS 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 RPA 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 remote 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 RPS should include alternate means for the pilot to communicate with ATC in the event of a loss of C2 link.

I_3.1.2 The RPS 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 RPS should enable the RPAS crewmembers to communicate with each other (co-located or not) in order to perform the necessary flight tasks.

T_3.2.2 The RPS 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 RPS 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 RPS should provide the pilot with a communication link with ground support personnel while they are interacting with the aircraft.

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

G_1 RPAS 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 RPS 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 multimode 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 RPA.

G_8 Any unrecognized entry made by the pilot at the RPS 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 RPS should provide a work environment that maintains pilot engagement, and minimizes the negative impact of extended periods of low workload.

G_12 The RPS 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 RPS 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 RPS 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 RPAS 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, and (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.

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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)

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Documents with material covering the remote pilot station

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Department of Defense. MIL-STD-1472G: Human engineering.

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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/

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