REMOTELY PILOTED AIRCRAFT SYSTEMS PANEL (RPASP)

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Human performance considerations for Remotely Piloted Aircraft Systems (RPAS)

R. Jay Shively, NASA Ames Research Center
Alan Hobbs, San Jose State University Research Foundation
Beth Lyall, Research Integrations, Inc.
Conrad Rorie, San Jose State University Research Foundation

SUMMARY

Successful integration of Remotely Piloted Aircraft Systems (RPAS) into civil airspace will not only require solutions to technical challenges, but will also require that the design and operation of RPAS take into account human limitations and capabilities.

Human factors can affect overall system performance whenever the system relies on people to interact with another element of the system. Four types of broad interactions can be described. These are (1) interactions between people and hardware, such as controls and displays; (2) human use of procedures and documentation; (3) impact of the task environment, including lighting, noise and monotony; and lastly, (4) interactions between operational personnel, including communication and coordination.

In addition to the human factors that have been identified for conventional aviation, RPAS operations introduce a set of unique human challenges. The purpose of document is to raise human factors issues for consideration by workgroups of the ICAO RPAS panel as they work to develop guidance material and additions to ICAO annexes. It is anticipated that the content of this document will be revised and updated as the work of the panel progresses.

Contents

Definitions

The following definitions are taken from the ICAO RPAS manual. *Note.— Terms followed by one asterisk* have no official status within ICAO. A term that is used differently from a formally recognized ICAO definition is noted with two asterisks**.*

Autonomous operation*. An operation during which a remotely piloted aircraft is operating without pilot intervention in the management of the flight.

Command and control (C2) link. The data link between the remotely piloted aircraft and the remote pilot station for the purposes of managing the flight.

Continuing airworthiness. The set of processes by which an aircraft, engine, propeller or part complies with the applicable airworthiness requirements and remains in a condition for safe operation throughout its operating life.

Detect and avoid. The capability to see, sense or detect conflicting traffic or other hazards and take the appropriate action.

Handover*. The act of passing piloting control from one remote pilot station to another.

Human performance. Human capabilities and limitations which have an impact on the safety and efficiency of aeronautical operations.

Remote crew member**. A crew member charged with duties essential to the operation of a remotely piloted aircraft system during a flight duty period.

Remote flight crew member**. A licensed crew member charged with duties essential to the operation of a remotely piloted aircraft system during a flight duty period.

Remote pilot. A person charged by the operator with duties essential to the operation of a remotely piloted aircraft and who manipulates the flight controls, as appropriate, during flight time.

Remote pilot-in-command**. The remote pilot designated by the operator as being in command and charged with the safe conduct of a flight.

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

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

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.

RPA observer. A trained and competent person designated by the operator who, by visual observation of the remotely piloted aircraft, assists the remote pilot in the safe conduct of the flight.

Visual line-of-sight (VLOS) operation. An operation in which the remote pilot or RPA observer maintains direct unaided visual contact with the remotely piloted aircraft.

1 Introduction

Successful integration of Remotely Piloted Aircraft Systems (RPAS) into civil airspace will not only require solutions to technical challenges, but will also require that the design and operation of RPAS take into account human limitations and capabilities. The purpose of document is to raise human factors issues for consideration by workgroups of the ICAO RPAS Panel as they work to develop guidance material and additions to ICAO annexes.

1.1 Definition and scope of human factors

Safe and efficient aviation requires that human performance be considered at all stages of the system lifecycle, from design, construction, training of personnel, operation and maintenance. Human performance is sometimes considered when referring solely to the negative impacts of errors, procedure violations, physiological limitations and the like. However, there is increasing recognition that unique human characteristics, such as flexibility and the capacity for problem solving, can make a significant positive contribution to system performance. In developing standards and recommended practices for RPAS, it is important to recognize that the people in the system can have both negative and positive contributions to system performance.

The ICAO Human Factors Digest contains the following definition of the discipline of Human Factors:

> "Human Factors is about people … [and]… their relationship with machines, with procedures and with the environment about them; and also about their relationships with other people". (Page 1.2). ICAO Human Factors Digest 1. 216 AN/131

This definition makes it clear that a consideration of Human Factors for RPAS must include the human interactions in four broad areas:

1. Human interaction with machines (also called "hardware")
    - Examples include the interface between the RPS and pilots, support technicians, and maintenance personnel.

2. Operational procedures
    - Including checklists, policies, and procedures for pilots and air traffic control.

3. Environment
    - Including lighting, time of day, and the presence or absence of noise, vibration or other sensory cues.

4. Interactions with other people
    - Examples include crew coordination, and communication between pilots and air traffic control.

This view of human factors is also expressed in the SHEL model that has been promoted by ICAO (See figure 1).

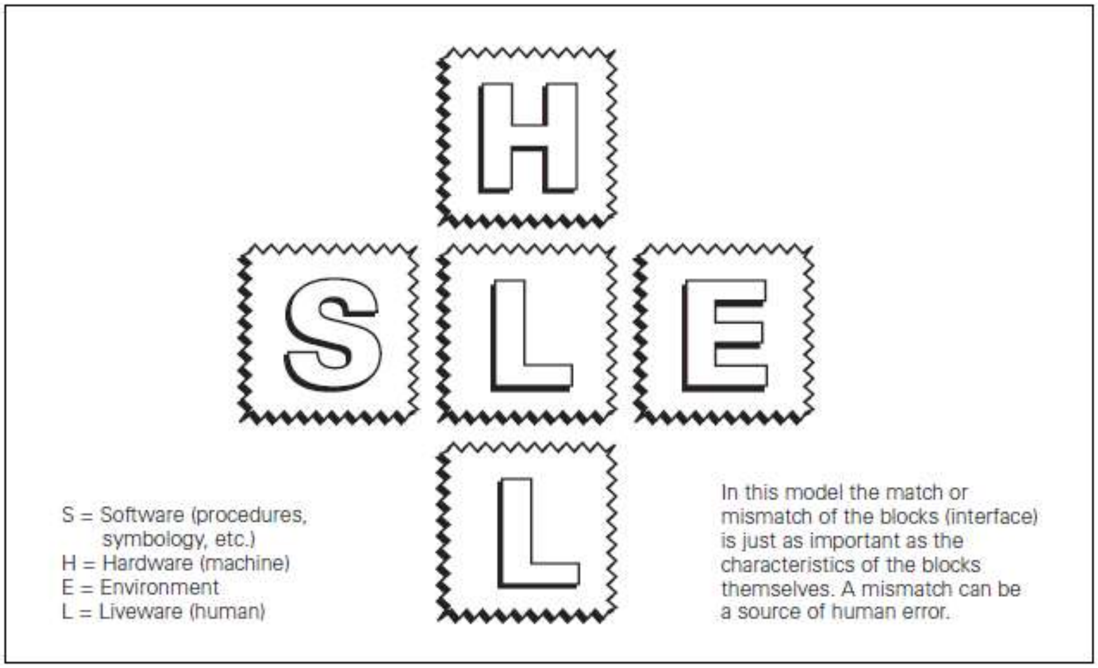

Figure 1. The SHEL model. From ICAO Human Factors Digest 216 AN/131.

In this document, we identify human factors considerations that deserve the attention of the RPAS Panel Workgroups. Using the workgroup tasks as the focus and the general framework described by the SHEL model as a guide, we have identified areas where the design of hardware, procedures, the environment, or interactions between people have the potential to significantly impact the performance of operational personnel. For each potential issue, we include a brief description, a list of standards or regulations where relevant, and recommendations for action to address the issue.

1.2 Human factors and RPAS

Remotely Piloted Aircraft have generally experienced a higher accident rate than conventionally piloted aircraft (Nullmeyer & Montijo, 2009). Many of these accidents appear to reflect the unique human challenges associated with piloting an RPAS, and design issues with the human/system interface (Williams, 2004). Some general human factors challenges of RPAS flight and operation include the following:

> Reduced sensory cues – The rich sensory cues available to the pilot of a conventional aircraft include visual, auditory, proprioceptive and olfactory sensations. The absence of these cues 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 self-correction more difficult.

Design of the Remote Pilot Station (RPS) –Some current RPS have included pilot interfaces that would not comply with design standards for aircraft cockpits, and fall short of general industry standards for ergonomics and human/system integration. Some RPS are already starting to resemble control rooms more than cockpits. Human factors design standards will be necessary to ensure that this change occurs safely with a focus on the tasks of the pilot and others conducting the RPAS operations.

Handovers – Control of a RPAS may be transferred in-flight between pilots at the same control station console, between consoles at the same control station, or between physically separated control stations (Williams, 2006). Handovers can be a time of particular risk, associated with system mode errors and coordination breakdowns. Where the aircraft is capable of remaining airborne for an extended period, multiple pilot handovers may occur during the course of a single flight (Tvaryanas, 2006), with each handover contributing to a cumulative level of risk.

Collision avoidance and separation assurance – In the absence of an out-the-window view, the pilot must rely on alternative sources of information, and is unable to comply with ATC visual clearances in the usual way. In collaboration with RTCA Special Committee 228,NASA is conducting studies to define the requirements for RPAS traffic situational displays for separation and collision avoidance..

Human factors implications of link performance – The transmission of radio signals, and the associated processing, may introduce operationally significant delays between pilot control input, RPA 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 latencies. If pilot voice communications are transmitted via the control link, delays in voice communication may become noticeable in some circumstances. 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.

Flight termination considerations – In an emergency, the pilot of a remotely piloted aircraft may be required to attempt an off-airport landing, or destroy the aircraft by a controlled impact, ditching, or other method. Although no lives are at stake on board the aircraft, the pilot is still responsible for the protection of life and property on the ground or in other aircraft. The information pilots will require to carry out such an action has to be determined when considering designs to support these tasks. The risk of inadvertent activation of the flight termination system must also be considered (Hobbs, 2010).

Management of the command and control (C2) link - 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 diagnose and respond to any changes that occur.

Workload management – 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 the possibility that workload may increase rapidly.

Maintenance considerations – Maintenance personnel will require the skills and knowledge to interact with a complex distributed system containing elements not typically supported by aviation maintenance personnel. Troubleshooting and fault rectification of the RPAS may also have to occur while a flight is underway.

1.3 Guiding assumptions

In identifying potential human factors issues relevant to RPAS, we have been guided by the following assumptions.

- A person will be in command of each RPAS. Fully autonomous RPAS operations will not be considered.
- The simultaneous operation of more than one RPAS by one person will not be considered.
- Risk management approaches may differ between RPAS and conventional aircraft due to the absence of human life on board RPAs.
- RPAS operations will comply with existing air traffic procedures, except where a specific difference has been agreed upon.

2 Discussion of human factors considerations

In the following sections we describe potential human factors considerations that relate to the work of the RPAS Panel. For ease of presentation, we have associated each consideration with a workgroup, however we acknowledge that in many cases the consideration will have implications for more than one workgroup. The RPAS Panel may decide that some of the considerations raised here will not require the attention of ICAO, however wherever in doubt, we erred on the side of including potential issues. We have developed this as a working document. We will continue to work with the RPAS Panel workgroups and modify the list, removing items that are no longer relevant, and adding newly identified concerns.

2.1 Personnel licensing

2.1.1 Remote pilots and flight crewmembers

LIC1: Define licensing categories for remote pilots and other remote flight crewmembers.	
Description	Development of crew licensing categories will first require an analysis of the tasks that remote pilots and flight crewmembers will do to support a RPAS flight. The licensing categories that emerge may differ from those applicable to conventional aviation. Task categories include flight planning, ground preparation, takeoff or launch, cruise, and landing or recovery. Some key points of differences with conventional aviation are: • The preparation of flight plans may involve more specialist personnel for different types of missions and operations. • Ground support crew may have a larger role in pre-flight preparations because the pilot may not be with the RPA. • Pilots may be responsible for only one element of a flight. For example, one pilot may be responsible for takeoff or landing while other pilots may control the aircraft in the "cruise" phase of the operation. • The routine takeoff and landing may be highly automated, or completely automated. • Technical tasks, including the management of C2 links, may be performed by specialist personnel available to support the operation. • High levels of automation may reduce the need for manual flying tasks. • Sizes of aircraft can vary from very small to very large. • Operational missions include routings for surveillance around

	geographical areas instead of from point-to-point and very long flight durations. All of these factors should be considered when developing the appropriate classes for remote pilot licensing. An important part of this effort will be to identify tasks that should be performed by licensed personnel and tasks that can reasonably be assigned to unlicensed personnel and tasks that must be performed by the Remote Pilot In Command (PIC) and those that can be performed by other pilots.
Related regulations or standards	
Recommendations	Determine the tasks required to operate an RPAS considering all of the factors and differences from conventional aviation, and use these to identify operationally relevant categories for personnel licenses.

LIC2: Identify in detail the knowledge and skill requirements for remote PIC, remote pilots, and other licensed remote flight crewmembers.	
Description	Pilot knowledge and skills requirements will be somewhat different dependent on the operations that they perform. One consideration is whether they are conducting flights in visual line of sight (VLOS) or beyond visual line of sight (BVLOS), which require somewhat different sets of knowledge and skills. Other considerations include: • The designs of the RPA and their aerodynamic qualities • The decision making required to accomplish the operational tasks • The anticipated system management tasks and handling of malfunctions or functions that become unavailable • Communication and flight crew management tasks for different types of missions • Tasks that are particularly important for the Remote PIC • Mission needs for handing control of the RPA to other remote pilots within the same RPS or to a pilot in another RPS
Related regulations or standards	
Recommendations	Conduct research to determine the knowledge and skill requirements for different potential operational scenarios, RPA designs, and RPS configurations. Document these as input to training requirements and determine the differences in knowledge and skill requirements that can contribute to the development of separate classes of remote pilots and

	other licensed crewmembers.

2.1.2 RPA Observers

LIC3: Define licensing categories for RPA Observers.	
Description	Similar to the development of crew licensing categories, developing the licensing categories for RPA observers will require an analysis of the RPA Observer tasks that will be required to support RPAS operations. This is a new type of role not currently involved in conventional aviation operations so a thorough task and activity analysis will be important.
Related regulations or standards	
Recommendations	Conduct task and activity analyses to define and document the tasks required by an RPA Observer considering the anticipate range of RPAS operations, different designs of RPAs, and launch and recovery possibilities.
References	

LIC4: RPA Observer knowledge and skills.	
Description	The RPA observer is a role that is not included in the manned aircraft operations. The knowledge and skills for the RPA observer will need to be understood and documented as a basis for licensing and training.
Related regulations or standards	RPAS Manual Section 8.6
Recommendations	Conduct research to develop a description of the knowledge and skills required for RPA observers in all anticipated operating conditions. Use the results to develop the approach to RPA observer licensing and training and update the standards.

2.1.3 Maintenance personnel

LIC5: Define licensing categories for RPAS Maintenance personnel.	
Description	Similar to the development of crew licensing categories, developing the licensing categories for RPAS maintenance personnel will require an analysis of the maintainer tasks that will be required to support RPAS operations.

	Maintenance personnel will be required to maintain all components of the RPAS, including the RPA, RPS, communications equipment, and other elements required for RPAS operation. Maintenance personnel may specialize in one or more of these areas and it may be appropriate to license for a subset of components. Other issues to consider are: • Some maintenance tasks are likely to require software skills • It is possible that some maintenance may occur while RPA is in flight Maintenance personnel may have a real-time role in flight, similar to flight engineer.
Related regulations or standards	
Recommendations	Conduct task and activity analyses to define and document the tasks required by an RPA Observer considering the anticipated range of RPAS operations, different designs of RPAs, and launch and recovery possibilities. Identify whether other credentials like "system engineer" or flight engineer license are required.
References	

LIC6: Maintenance personnel knowledge and skills.	
Description	Knowledge and skills for maintainers will depend on the components of the RPAS they will be tasked with maintaining. These components include the RPA, RPS, communications equipment, launch and recovery equipment and anything else required for the particular RPAS operations. Maintenance personnel may specialize in one or more of these areas so it will be important to define the knowledge and skills for each one separately.
Related regulations or standards	
Recommendations	Identify the unique knowledge and skill requirements for RPAS maintenance personnel based on the tasks they may perform during anticipated RPAS operations.

2.1.4 RPAS Instructors

2.1.5 LIC7: Define licensing requirements for RPAS.	
Description	It may be important to develop licensing categories for the instructors who will be providing training for all roles related to RPAS operations including remote PICs and other remote pilots and flight crewmembers,

	RPA observers, and RPAS maintainers.
Related regulations or standards	
Recommendations	Conduct research to define the needs for licensing of instructors. The licensing requirements may be different based on what training the instructors will be providing.
References	

LIC8: RPAS instructor required knowledge, skills, and training.	
Description	The required knowledge, skills, and training for RPAS instructors may be different from the same instructor roles for conventional aviation operations. The differences should be considered when developing RPAS standards. The knowledge, skills, and training requirements will be different for training remote pilots, other remote flight crewmembers, RPA observers, and maintainers. Experience requirements should also be considered such as whether pilot instructors will need to have experience as pilots, maintainers as maintainer, etc.
Related regulations or standards	RPAS Manual Section 8.5
Recommendations	Conduct research to determine the RPAS instructor requirements based on the anticipated RPAS licensing classes and training to be conducted. Use results to update the appropriate standards or create new standards.

2.1.6 Validity periods

LIC9: Consideration of the degradation of knowledge and skill retention for different licensing classes when determining license validity periods.	
Description	Retention of knowledge and skills is dependent on the level of expertise of the pilot when they are first developed, the frequency at which they are used in daily activities, the importance that is placed on retention during the training process, and other factors. Consideration of retention of knowledge and skills expected to be in different licensing classes may lead to determination of different validity periods for the licenses. This applies to all licensing classes being developed (pilots, flight crewmembers, observers, maintainers, instructors).
Related regulations or standards	The validity period for the completion of the theoretical knowledge examination is described in paragraph 8.4.30 in the RPAS Manual.
Recommendations	Consider the potential for retention of the necessary knowledge and skills

	related to the different licensing classes being developed and use the results in determining appropriate validity periods for each license class. This should be considered in combination with developing the currency requirements.

2.1.7 Practical skills tests

LIC10: Description of practical skill tests for each licensing class.	
Description	Unique skills should be identified. In contrast to conventional aviation, these may be less likely to involve manual handling and more likely to relate to management of automation. The RPAS Manual paragraph 8.4.36 states: The applicant for the issue of a remote pilot license should demonstrate the ability to: a) recognize and manage threats and errors; b) operate the RPA within its limitations or those limitations imposed by regulation; c) complete all manoeuvres with smoothness and accuracy; d) exercise good judgement and airmanship; e) apply aeronautical knowledge; and f) maintain control of the RPA at all times in a manner such that the successful outcome of a procedure or manoeuvre is assured. Each of these skills may require different means of accomplishment, demonstration, and evaluation if they are applied to different types of operations (e.g. VLOS, BVLOS) and RPS configurations that may apply to separate Remote Pilot licenses. The resulting differences should be considered when describing the practical skill test requirements for each of the licensing classes. In assessing skills, it will be necessary to consider whether flight tests are necessary, or whether full simulations or part-task simulations will be sufficient. It is important to consider all skill requirements when determining the appropriate testing methods including the communication, decision-making, troubleshooting, and crew resource management skills.
Related regulations or standards	RPAS Manual 8.4.36
Recommendations	Consider the knowledge and skills related to the different licensing classes being developed and analyze each class for the appropriate practical skill test requirements. This should be considered in combination with the work on the knowledge, skills, retention, and currency requirements.

2.1.8 Experience and currency requirements

LIC11: Description of experience requirements based on the licensing classes.	
Description	The experience and currency requirements for different types of operations (e.g. VLOS, BVLOS) and RPS configurations should be considered when defining the basis for each licensing class. A pilot who only operates an RPAS in cruise may accumulate many flight hours, but never experience a takeoff or landing. Conversely, a pilot who is assigned takeoff and landing may accumulate significant experience with this phase of flight, while logging relatively few flight hours.
Related regulations or standards	RPAS Manual 8.4.38, 8.4.39
Recommendations	Conduct research to determine the differences in experience and currency requirements for the potential combinations of types of operations and RPS configurations that may be considered for licensing classes.

2.2 RPAS operations

2.2.1 Implications of lost link

No control link can be guaranteed to be available 100% of the time, and there will be occasions when either the forward link, return link, or both will be unavailable. Pre-programmed lost link procedures enable the RPA to continue flight until the link is resumed. Anecdotal reports indicate that RPA pilots must take into account the possibility that each command sent to the aircraft may be the pilot's last contact with the aircraft for some time, should a link interruption occur. Particular care must be taken if a command would produce an unsafe condition if not followed-up with additional commands. For example, it may be unsafe to turn an aircraft towards rising terrain if the safety of flight relies on successfully sending a subsequent command to turn away from the terrain.

OPS1: Predictability of lost link maneuvers.	
Description	The behavior of the aircraft in the event of a lost link must be predictable to the pilot and ATC. For example, the RPA lost link maneuver may involve climbing, or flying to a pre-determined position. Different maneuvers may be programmed to occur according to the stages of the flight, and/or the lost link maneuver may need to be manually updated as the flight progresses (Neville et al., 2012). Care must be taken to ensure that the pilot and ATC are not taken by surprise by the behavior of the aircraft during a lost link situation. It is likely that the aircraft flight plan will need to include information on the aircraft's lost link programming.
Related regulations or standards	
Recommendations	Best practices for the management of lost link maneuvers should be examined, and the characteristics that produce safe and predictable lost link behavior should be determined.

OPS2: Criteria for declaration of lost link.	
Description	A lost link situation is defined by the C2 link not being available for a defined period of time. It is unclear whether the duration of the link outages that triggers a lost link procedure should be specified in standards or guidance material, or should be left to the discretion of the pilot dependent on the particular operation. It is also possible that the trigger duration should be specified dependent on the phase of flight or operational environment. For example, in terminal areas, a brief link interruption may warrant the activation of a lost link procedure. In

	oceanic airspace, it may be acceptable to wait longer before the aircraft activates its lost link procedure. In some situations, pilots and ATC may prefer to have the certainty of an aircraft continuing along a planned flightpath even if the link is interrupted, than having the aircraft enter a lost link procedure.
Related regulations or standards	
Recommendations	The operations workgroup should consider whether there is a need to define the duration of a link loss necessary before a lost link is considered to have occurred. Consideration should be given to the role of the pilot in determining the duration for triggering the lost link situation, as well as the relevance of differing flight phases and operational environments.

OPS3: Frequently exceeding lost link threshold.	
Description	Frequent nuisance lost link occurrences may lead pilots to use workarounds to avoid triggering the lost link procedure. For example, anecdotal reports suggest that pilots have sometimes entered extended durations into lost link timers to ensure that the aircraft does not enter a lost link procedure. A balance may need to be reached between predictability of a flight and maintenance of control. In some cases it may be preferable to have an aircraft predictably maintain its planned flight path during a lost link, rather than execute a lost link procedure in order to re-establish link.
Related regulations or standards	
Recommendations	Research is needed on the operational impact of lost link occurrences and the strategies that may be adopted by pilots to prevent them and respond to them.

OPS4: Potential for multiple simultaneous lost links.	
Description	The RPAS manual section 4.4.4 considers the possibility that a widespread loss of C2 capabilities could result in multiple RPAs going lost link simultaneously. This could involve, for example, the failure of a communication facility being used by multiple RPAS.

Related regulations or standards	
Recommendations	The panel should give consideration to the causes and consequences of multiple RPAs entering lost link procedures simultaneously.

2.2.2 Pilot sensory considerations

The lack of sensory cues available to an RPAS pilot is well-recognized. The pilot may have limited visual information from a camera (or no camera view at all), and have no access to information from the aircraft via auditory, somatic or olfactory cues. From time to time, there have been suggestions that the control station should provide a richer variety of cues, perhaps via on-board microphones or haptic cues. The reduced sensory cues make it more difficult for the pilot to detect undesired aircraft states such as unusual attitudes, turbulence or weather conditions. In addition to these well-covered issues, the following considerations deserve attention.

OPS5: Flight crew interaction with aircraft.	
Description	ICAO Annex 6 specifies that the pilot must ensure that the aircraft is airworthy before flight. In some circumstances, the pilot of a RPA may not see or physically interact with their aircraft, before, during, or after a flight. If the pilot does not have an opportunity for a pre-flight walk-around, they are reliant on other personnel for information on the state of the aircraft.
Related regulations or standards	
Recommendations	The operations workgroup should consider how the absence of pilot physical examination of the aircraft may affect flight operations and safety. If considered necessary, alternative approaches should be identified.

OPS6: Perceptual illusions of RPAS operations.	
Description	The pilot of an RPAS may be exposed to a range of perceptual illusions and conflicts that do not occur in conventional aviation. A complete review of this topic has not been conducted, however the following examples are illustrative: Control-consequence incompatibility. If the pilot is in visual contact with the aircraft, and is facing in the direction of flight, or if the aircraft is shown on a map display aligned with the aircraft track shown as “up”,

	control inputs will result in an aircraft maneuver that is consistent with the pilot's point of view. For example, a left input will turn the aircraft to the pilot's left. However if the track of the aircraft is not aligned with the pilot's point of view, for example, if the aircraft is flying *towards* a visual pilot, or a map display is *not* aligned with track up, then control inputs may result in the aircraft turning in a manner that is inconsistent with the pilot's point of view. Depth cues. The difficulties in judging depth from periscopes and cameras have been studied for many years (Roscoe et al., 1966). Camera views can produce misleading depth cues, some of which may be related to the lack of binocular cues. These may be particularly noticeable during landing. Camera direction. If a moveable camera located on board an RPA is not aligned as expected by the pilot, there may be an illusion of yaw, or other undesired aircraft state.
Related regulations or standards	
Recommendations	The potential for perceptual illusions in RPAS operations should be examined, and their impact on flight operations and safety evaluated.

OPS7: Landing/recovery at aerodromes.	
Description	In the cruise flight phase, an RPAS pilot lacking information from an out-the-window view may be in a comparable situation to the pilot of a conventional aircraft during a flight in instrument conditions. 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 situational awareness provided by an out the window view may be particularly critical during taxiing and takeoff, and during the approach and landing phase. Unless an aircraft is capable of a fully automated landing, the pilot currently requires visual reference with the runway (14 CFR 91.175). A subgroup of the RTCA SC228 C2 Working Group evaluated the needs for visual information to be available to the remote pilot in different phases of flight and operating environments.
Related regulations or standards	14 CFR 91.175 Takeoff and Landing under IFR.
Recommendations	The workgroup should address the information needs of an RPAS pilot when making an instrument approach, and consider whether visual information is needed, or whether the necessary information can be

	provided by other means. Consider using the working paper from the SC228 visual considerations subgroup as input to build upon.

2.2.3 Vigilance and fatigue

Considerations of workload often focus on excessive task demands, however under-load can also create hazardous situations. Highly automated aircraft, long duration flights, low workload, and a sleep-inducing control station environment may make it difficult for RPAS pilots to maintain task engagement. Interventions such as rest breaks bring their own hazards that must be managed.

OPS8: Vigilance, low workload and monotony.	
Description	The RPAS pilot may experience extended periods of low workload, particularly when the pilot's role is only to perform 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. As a result, fatigue management may be particularly relevant to RPAS pilots. Well-meaning efforts to control distraction, such as eliminating windows or prohibiting visitors to the control station, may only serve to increase the monotony of the piloting task, thereby increasing risk.
Related regulations or standards	
Recommendations	The potential effects of low workload and monotony should be examined. Countermeasures to maintain vigilance should be identified. Care should be taken to ensure that interventions intended to reduce distractions do not have the unintended consequence of increasing monotony.

OPS9: Rest breaks and crew rotations.	
Description	During long-duration missions, rest breaks for RPAS pilots may be scheduled at appropriate intervals to manage fatigue and attend to biological needs. It is not clear how frequently breaks should occur. The

	rest pattern could be modeled on that currently used in long duration airline operations, or could follow a pattern similar to that of Air Traffic Control, where a break every two hours is typical. Rest breaks are likely to require the transfer of crew in and out of the crew position, with a resulting need for a handover briefing and the risks associated with breakdowns in communication.
Related regulations or standards	
Recommendations	Consideration must be given to the need for rest breaks and crew rotation. This will be related to the consideration of procedures for handovers between remote pilots in one RPS and from RPS to RPS.

2.2.4 Handovers

The ability to completely transfer control between or within control stations 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 (Lardner, 2000). Handovers require special attention to ensure that the incoming and outgoing crews possess a shared understanding of the operational situation and that control settings are aligned between the two RPS.

OPS10: Best practices for control handovers from RPS to RPS.	
Description	Control handover is likely to be an area of risk for communication breakdowns and mode management errors. Before control is transferred from one RPS to another, it is necessary to ensure that both control stations have consistent settings. Several RPAS accidents have occurred when control has been transferred between RPSs which were set to different modes or settings. There is a need to define best practices for control handovers between RPS. Issues to be considered include: • The use of intentional link interruptions during handovers. • Is it acceptable for the giving RPS to relinquish control before the receiving control station has established link with the RPA? • Is it preferable to have an overlap period during handover, when both giving and receiving RPS have an uplink to the RPA. • The acceptability of two RPS simultaneously linked with the RPA. • How should the receiving RPS confirm that it has gained control of an RPA? For example, switching lights on and off, or moving a control surface?

	• How should the receiving RPS confirm that it has gained control of the correct RPA? • Is voice communication between giving and receiving RPS necessary, or can handover be done safely with text-based communication? • Communication protocols to be used by crew during handovers. • Checklists and procedures to ensure that giving and receiving RPS are configured consistently.
Related regulations or standards	Section 2.2.3 of the ICAO RPAS Manual states that only one RPS should be in control of the RPA at a given time. This would appear to preclude overlapping handovers during which the giving RPS maintains control until the receiving RPS has demonstrated control.
Recommendations	There is a need to develop procedures and guidance to be used for control handovers from one RPS to another. Consideration should be given to the many varied factors involved with different types of operations and different operational environments encountered by the RPA at the time of handover.

OPS11: Transfer of control between adjacent consoles in same RPS.	
Description	Many RPS designs include side-by side consoles. It is not clear whether these should operate in a manner similar to a dual control aircraft (where at a given time, inputs can be made using either set of controls) or whether there should be a system to assign control to only one console at a time. If control is assigned, there must be a clear system to indicate which console has control.
Related regulations or standards	
Recommendations	The workgroup should consider the operational implications of transfer of control between adjacent consoles, and identify how this differs from the transfer of control between pilots in a conventional dual-control aircraft.

2.2.5 Flight planning

The pre-flight planning for an RPAS flight involves unique considerations. Three critical issues are outlined here: the impact of ultra-long duration flights, the need to plan for C2 link coverage, and planning for contingencies.

OPS13: Planning for ultra-long duration flights.

Description	Ultra-long flight endurance, ranging from days to weeks will change the nature of flight planning. A single flight may involve multiple crew members, some of whom may have had no involvement in flight planning. During flight planning, pilots may also need to consider longer-range weather forecasts, and must deal with the resulting reduction in forecast certainty when predicting weather conditions weeks into the future.
Related regulations or standards	
Recommendations	Consideration should be given to the implications for flight preparation of long-duration flights.

OPS14: Flight planning and C2 link considerations.	
Description	During the flight planning stage, consideration must be given to the predicted availability and quality of C2 links. This will include contingency plans for lost links throughout the flight. Other issues to be considered include: • The impact of aircraft location on C2 link availability and quality. • The impact of aircraft maneuvers on C2 link availability and quality • The need to change C2 mode or frequency throughout the flight. • Pre-arranged frequency changes. • Predicted signal strength throughout the flight and locations that may involve an increased risk of lost link. • The potential impact of weather (e.g. thunderstorms) or other natural events on link quality.
Related regulations or standards	
Recommendations	The operations group should consider the unique flight planning considerations associated with the C2 link for the anticipated operations.

OPS15: Planning for contingencies.	
Description	In addition to the usual planning required for the flight of a conventional aircraft, the RPAS pilot must plan for RPAS-specific contingencies. These may include loss of link (uplink, downlink or both), loss of Detect and Avoid system, off-airport landing or ditching with no external view,

	loss of on-board camera, and flight termination.
Related regulations or standards	
Recommendations	The operations group should identify the unique contingencies relevant to RPAS operations.

2.2.6 Flight termination considerations

In common with the pilot of a conventional aircraft, RPAS pilots will be faced with emergencies that require them to attempt an emergency landing, off-airport landing or ditching. Unlike the pilot of a conventional aircraft however, the RPAS pilot may also be required to intentionally destroy the aircraft in some critical situations. The absence of human life on board the aircraft markedly changes the nature of decision making in these circumstances. An important consideration is that the RPAS pilot and other personnel involved in the RPAS operation are exposed to virtually no safety hazards in this situation. The risks are borne instead by members of the general public. Research has established that the community tolerance of risk is greatly reduced in the case of hazards that are outside the control of the exposed population and where exposure to the hazard was involuntary (Slovic, 2000).

OPS16: Decision making for emergency landings, flight termination or ditching.	
Description	An RPAS pilot faced with an in-flight anomaly must decide on a course of action. The decision-making process may be complicated by a lack of direct sensory information from the aircraft. If the anomaly is considered to be inconsequential, the pilot may decide to continue the flight. However, if the anomaly has implications for the safety of flight or other people or property, the pilot may be faced with choices that may include: (1) landing at a nearby airfield (2) attempting a controlled off-airport landing or ditching (3) activation of a parachute system (if equipped) (4) destruction of the aircraft in flight, or an uncontrolled descent Each action may present hazards to people and property on the ground, and the pilot must balance a desire to preserve the aircraft and its payload with the need to protect the people and property on the ground. If time is available, the pilot may have an opportunity to consult with other operational personnel. This may be the case with High Altitude Long Endurance (HALE) operations. Some current RPAS flights involve range safety officers. Even when a team is involved in a decision, the PIC must bear ultimate responsibility for the decision.

	It is likely that some potential impact sites for flight termination will have been pre-selected. Nevertheless, the pilot may still require real-time information to ensure that the selected impact site is clear of people or property. Imagery from an on-board camera may enable the impact area to be confirmed as clear, however imagery that is transmitted over the C2 link will be unavailable if the anomaly also interrupts the C2 link. Furthermore, if a terrestrial C2 link is in use, a lost link may occur when the aircraft descends below radio line-of-sight from the ground transmitter. The C2 link may be lost as the aircraft descends towards the landing or impact site. If a loss of C2 link is anticipated as the aircraft descends to the landing or impact site, it will be necessary to make imagery-based decisions at an early stage in the descent, and take steps to ensure that inappropriate lost link actions are not activated when the link is lost.
Related regulations or standards	
Recommendations	The workgroup should consider the tasks that must be performed by an RPAS pilot conducting an emergency landing, flight termination or ditching. Consideration should include the information available to the pilot, the decisions that must be made, the timescale in which action must be taken, and the extent to which the pilot can control the RPA with the loss of the C2 link.

OPS17: Insurance considerations and emergency decision-making.	
Description	Emergencies may arise where a pilot will be faced with the choice of (a) terminating a flight and destroying the aircraft with minimal risk to third parties, or (b) attempting to land the aircraft, with the possibility that doing so may increase third party risk. For example, attempting to land a partially disabled remotely piloted aircraft may present a hazard to people under the flight path of the aircraft. It is possible that insurance considerations (for aircraft, cargo, or payload) could influence the decision making of an RPAS pilot when faced with the choice of continuing a flight or intentionally terminating the flight.
Related regulations or standards	Current regulations and standards do not deal with situations where safety considerations warrant the intentional destruction of the aircraft.
Recommendations	The working group should examine current insurance practices for aircraft, and determine whether pilot decision making in the event of an emergency could be influenced by insurance considerations.

OPS18: Search and rescue.	
Description	Due to the absence of on-board occupants, the concept of "rescue" of survivors is not relevant to RPAS. However, there may still be a need to search for the downed RPA and conduct recovery operations.
Related regulations or standards	
Recommendations	Situations in which it will be necessary to search for and recover wreckage from an RPAS should be determined, and appropriate protocols for search and recovery should be developed.

2.2.7 Flight crew task responsibilities

The unique aspects of RPAS operations introduce new crew responsibilities. Unlike conventional transport category aircraft, RPAS are not typically engaged in point-to-point flight, and flights are more likely to include unconventional flight patterns such as high altitude loitering. Unique crew task issues are outlined below.

OPS19: Control of a domestic RPA by a crew members in another state.	
Description	An RPA conducting a flight entirely within the borders of a state could be operated by a pilot situated in a RPS located in another state. In some situations, crew members of a multi-crew operation could be located in different states.
Related regulations or standards	
Recommendations	The operations group should consider whether there are reasons to restrict domestic operations by crew members located in other states.

OPS20: Pilot interactions with payload.	
Description	The purpose of many RPAS operations is to carry a payload such as a camera or sensing equipment. It is unclear whether pilots should be permitted to perform payload-related tasks in addition to the task of operating the aircraft. Distraction of RPAS pilots by payload displays has been identified as a safety issue (Neville et al., 2012).
Related regulations or standards	
Recommendations	The impact of various types of payload operations on the pilot's primary

	tasks should be considered.

OPS21: Interaction with on-board autonomous systems.	
Description	Despite reluctance on the part of governments to permit autonomous RPAS, it is likely that future RPAs will be equipped with a number of fully automated features designed to recover from undesired aircraft states. In addition to pre-programmed lost link maneuvers, RPAs may be equipped with automated terrain avoidance systems, automated collision avoidance systems, and geofencing features. As these features will not typically activate during a normal flight, the pilot must maintain an awareness of the conditions that will trigger an autonomous aircraft maneuver, and the expected behavior of the aircraft in such situations must be anticipated.
Related regulations or standards	
Recommendations	The operations group should consider the pilot management of on-board autonomous features that will be activated during non-normal operational situations.

OPS22: Unique human factors training requirements for crew tasks.	
Description	RPAS crew may require human factors training tailored to RPAS operations. Topics could include: risk management, flight termination considerations, communication and coordination between remotely located RPS, teleoperation, illusions of teleoperation, fatigue, maintaining engagement during long duration flights, management of automation, transitioning from on-the-loop to in-the-loop. The ICAO Human Factors Training Manual provides information about training that is useful to pilot in conventional aviation and may provide relevant information for how to address the unique situations encountered by the remote pilots.
Related regulations or standards	ICAO Human Factors Training Manual (Doc 8683)
Recommendations	The operations group should identify human factors knowledge and skills relevant to RPAS operations. Consider providing input for updating the ICAO Human Factors Training Manual as well as the Annex 6.

2.2.8 Safety and security of the remote pilot station

The physical location of the RPS will introduce new procedural issues for the crew relating to safety, security and personnel access. Different issues may apply to fixed RPS located in buildings to mobile RPS located in trailers or on-board vessels. Consideration must also be given to crew interaction with security features intended to prevent unauthorized persons from taking control of an RPAS.

OPS23: Physical safety and accessibility of the RPS.	
Description	The physical location of the RPS presents new issues concerning safety and accessibility. Building access restrictions, security and safety features used in Air Traffic Control Facilities may provide a useful model. If multiple RPSs are located in a single facility, consideration must be given to the potential for a single failure to affect multiple RPS. Issues to consider include: • Procedures in the event of a fire or other emergency at the RPS. • How should access to the RPS be controlled? • Should the law allow a pilot to be arrested during a flight? (Morris, 2014).
Related regulations or standards	
Recommendations	The workgroup should identify the safety and accessibility differences between a RPS located in a control room and a conventional cockpit and develop new policies and procedures that account for different potential locations of RPS. The current policies and procedures used at air traffic control facilities may be useful during the evaluation.

OPS24: Electronic security procedures.	
Description	Electronic security features designed to prevent unapproved access (such as passwords or required logon credentials) could have unintended consequences. For example, security features create the potential for inadvertent electronic lockouts of authorized personnel. In such a scenario, the RPA might identify a genuine command from the RPS as an unauthorized command, or spoofing. An unintended electronic lockout of the pilot could be a form of contingency, alongside lost link, or pilot incapacitation.
Related regulations or standards	
Recommendations	Give consideration to the required level of electronic or software security,

	and the potential for security features to create unintended consequences. Consider appropriate procedures to respond to an unintended lock-out and other potential scenarios.

OPS25: Maintenance human factors.	
Description	Maintenance error has been recognized as a significant threat in conventional aviation. Human factors interventions include designing for maintainability, improved procedures, and human factors training for maintenance personnel. Compared to the pilot of a conventional aircraft, the RPAS pilot may have greater difficulty recognizing and responding rapidly to a maintenance-induced problem. RPAS involve unique challenges for maintenance personnel. The RPA, RPS, and associated equipment must each receive preventative and corrective maintenance, and maintenance personnel will require a wide skill-set to deal with diverse components including communication equipment, computer interfaces in the RPS, and potentially unconventional RPA components such as electric engines. Additional maintenance-related human factors considerations are: • Some RPA will require assembly and disassembly between flights, with a resulting increased potential for errors in assembly and connections. • Maintenance personnel could be called on to respond to faults in the RPS while the RPA is airborne. Procedures will be required to deal with this eventuality. • Systems are more likely to involve consumer electronics and computer systems, and maintainers must have the skills necessary to interact with these systems.
Related regulations or standards	The FAA has released extensive guidance material on human factors in airline maintenance.
Recommendations	ICAO should consider the unique challenges of RPAS maintenance and consider whether guidance material is needed on RPAS maintenance human factors.

OPS26: Intentional acts of operational personnel.	
Description	On several occasions, airline pilots have intentionally crashed or hijacked their own aircraft. These actions may stem from a variety of factors, including psychiatric conditions, personal grievances, or ideological motives.

	Remote pilots and other RPAS operational personnel could potentially carry out a malicious act without personal exposure to physical danger. The complex nature of an RPAS, with distributed interconnected elements supported by specialist personnel, may provide opportunities for a variety of individuals to carry out a malicious act without being immediately detected.
Related regulations or standards	
Recommendations	The RPAS panel should seek specialist expertise on this topic, and should consider appropriate measures to counter the risk of malicious acts by operational personnel.

2.3 Airworthiness

There are many human factors considerations that may be helpful when reviewing and updating the Airworthiness standards in Annex 8 and the related sections in the RPAS Manual. The issues presented here are organized by using the sections of Annex 8 starting with Initial Certification (with the relevant subsections from the Annex) and then Continuing Airworthiness. As such, these considerations do not include the detail that would be addressed by airworthiness regulations such as those in Parts 23 and 25 or the US and EASA regulations (see Jones et al 2012 and 2013 for a detailed review of US regulations related to RPAS design).

2.3.1 Initial certification

The human factors considerations related to Initial Certification are focused on the certification processes, then the certification of the RPAS as a whole, the RPA, RPS, and C2 link.

2.3.1.1 RPAS design and certification

The issues in this section impact the interaction of more than one of the RPAS components. In subsequent sections we will present issues that related to each of the RPAS components (e.g. RPA, RPS, C2 link). The primary human factors issue related to the full RPAS is the allocation of functions and tasks across the RPAS and the levels of automation employed in the design. This issue is presented first along with an issue about the PIC remaining aware of the automated systems. These are followed by issues associated with specific sections of Annex 8.

2.3.1.1.1 Function allocation and levels of automation

AIR1: Defining function allocation and pilot tasks.	
Description	Defining the role of the pilot within the RPAS is part of the decision for allocation between the functions of automated systems and the tasks remote PIC and other pilots, flight crew members, or remote observers. The function allocation decisions must be made in ways that allow the PIC to maintain the appropriate levels of control, authority, and responsibility for the RPA and the flight operations. This issue is related to the resolution of many of the other issues the come together to determine the design of the full suite of automated systems that comprise the RPAS. The types of control tasks that the pilot will perform will be important to address. When the pilot is required to perform continuous control tasks (like manually flying the RPA) it will require other parts of the system to be able to support those tasks. The timeliness of the interaction of the pilot inputs and the RPA responses through the C2 link will be higher for continuous control tasks.
Related regulations	

or standards	
Recommendations	Conduct research to define the expectations for minimum and maximum levels of automation that will be required in the safe design of an RPAS. The analyses should be accomplished to understand the approaches to automated system design for which the PIC has the level of control required for all anticipated operating conditions. One research strategy would be to define the following information for each approach to automated system design being considered: • Operating modes • Principles underlying mode transitions • Mode annunciation schemes • Automation engagement/disengagement principles • Preliminary logic diagrams These attributes of the candidate automated system design can be compared and evaluated to determine the boundaries of what will be acceptable in the standards and recommended practices.

AIR2: Ensure that the PIC will be able to maintain awareness of the state and behavior for all modes of the automated systems.	
Description	It is important for the PIC to be able to maintain awareness of the state and behavior of all automated systems that are included in the RPAS design. Three types of automated systems should be considered, not just control automation. • Control automation – The functions of control automation are to control and direct the airplane • Information automation – The functions of information automation are related to the management and presentation of flight-relevant information • Management automation – The functions of management automation are to permit strategic planning and control of the aircraft operation
Related regulations or standards	
Recommendations	Conduct research and analyses to determine the acceptable approaches to maintaining awareness of the state and behavior of the automated systems. One approach would be for the research should include the following.

	• Address 3 types of automation • Address all phases of flight and anticipate operational conditions • For each type of automation and phase of flight, assess the impact of automated system designs on potential PIC awareness

AIR3: Reduced sensory information.	
Description	The reduced sensory cues available to the RPAS pilot make it more challenging for the pilot to maintain awareness of the state of the aircraft, its operation, and environment. The extent to which conventional pilots rely on rich sensory cues, in addition to cockpit instruments, is difficult to quantify. However, such cues may play a significant role in maintaining pilot situational awareness. As noted in the RPAS Manual 13.6.1, the absent cues include: a) visual sensory information; b) auditory sensory information (noise environment including engine and airframe noise); c) proprioceptive sensory information (e.g. vibration and acceleration); d) olfactory sensory information (smell); e) tactile sensory information (e.g. heat and vibration); and f) other sensory information (e.g. heat and pressure). Some RPAS designers have attempted to compensate for the lack of rich sensory cues with text-based displays in the RPS. However, this risks overloading the visual channel of the pilot and requiring the pilot to invest the limited resource of foveal vision to obtain information that would be available to a conventional pilot via other sensory channels. The fovea of the eye perceives a few degrees of the visual field on either side of the direction of gaze, and sharp color vision only occurs in this area. Peripheral vision is useful for detecting cues such as movement, change, and optical flow, however text is not read with peripheral vision.
Related regulations or standards	RPAS Manual 13.6.1
Recommendations	Conduct research to define the impact of the loss of each type of sensory information and the compensating information that will be included in the standards to maintain safe operations.

2.3.1.1.2 Controllability

AIR4: Ensuring controllability under all anticipated operating conditions, transitions between operating conditions, and all flight stages and aeroplane configurations.	
Description	The introduction of the C2 control link through which the PIC will be controlling the RPA impacts the means by which controllability is defined, evaluated, and tested. Appendix 8 Section 2.3.1 states that the aeroplane shall be controllable and manoeuverable under all anticipated operating conditions…without requiring exceptional skill, alertness or strength on the part of the pilot. It also states that a) *The PIC shall be able to make a smooth transition from one operating condition to another without requiring exceptional skill, alertness or strength on the part of the pilot*. It is important to consider all anticipated transitions as the pilot is controlling the RPA through the C2 link. b) *A technique for safely controlling the aeroplane shall be established for all stages of flight and aeroplane configurations for which performance is scheduled*. The technique may include the combination of PIC manual control, control through automation, or algorithms that reside on the RPA for autonomous control. Developing and describing what will be considered techniques for "safely controlling" the RPA in all conditions will be an important issue. c) *The pilot shall be able to safely control the aeroplane without requiring exceptional skill, alertness or strength on the part of the pilot even in the event of failure of any engine*. This includes when an engine is lost during take-off and all other flight stages. It will be important to ensure that the loss of an engine and any resulting power surges or other changes to the electrical system in the RPA does not impact the C2 radio and link such that it would impact the ability of the PIC to control the RPA.
Related regulations or standards	Appendix 8 Section 2.3.1 all paragraphs
Recommendations	Conduct research to understand the impact of the PIC controlling the RPA through the C2 link on the standards for designing, demonstrating, and testing controllability for the RPAS Airworthiness certification. It may be beneficial for the analyses to include controllability scenarios for all operating conditions, differing levels of automation and the range of expected performance for the C2 link. Specific attention needs to be paid

	to transitioning between operating conditions, conducting take-offs and landings, and handling engine failure situations. The analyses will need to ensure that the control of the RPA does not require exceptional skill, alertness or strength on the part of the remote pilot. It will also be important to address the impact of any engine failure on the ability of the pilot to control the airplane using the C2 link.

2.3.1.1.3 Control system

AIR5: Control system design.	
Description	Appendix 8 4.1.6 on systems design features states that Special consideration shall be given to design features that affect the ability of the flight crew to maintain controlled flight. This shall include at least the following: a) Controls and control systems. The design of the controls and control systems shall be such as to minimize the possibility of jamming*, inadvertent operations, and unintentional engagement of control surface locking devices. It is important to consider the impact of the C2 link on the design and evaluation of the control system to ensure that all aspects of this paragraph are addressed and the PIC can maintain control of the RPA. We note that the term “jamming” as used currently in Appendix 8, refers to a mechanical system becoming seized or stuck. There needs to be a clear distinction between this meaning of the word and “jamming” involving intentional interference with a radio signal.
Related regulations or standards	Appendix 8 paragraph 4.1.6 a
Recommendations	Analyze the impact of having the C2 link and as part of the control system related to the possibility of jamming (meaning seized or stuck), inadvertent operations, and unintentional engagement of control surface locking devices. The potential for the C2 link to fade or be susceptible to interference will be important aspects to consider in the analysis.

2.3.1.1.4 Stalling

AIR6: Ensuring timely detection and response to a stall with use of the C2 link.

Description	Response to a stall is a critical manoeuver to maintain safety or the RPA and any other aircraft or property that could be hit by the RPA if the stall was not recovered. There have been accidents documented that have resulted from the inability of the pilot to detect and recover from a stall. It is important to ensure that a stall condition is detected by the PIC in time to make a response to avoid or recover from the stall and this may be more difficult with control through the C2 control link is than in manned aircraft.
Related regulations or standards	Appendix 8 Section 2.3.4
Recommendations	Analyze the impact of controlling the RPA through the C2 link on recognizing and recovering from a stall. Use the analysis results to inform the design, procedures, and training related to stall recognition and recovery.

2.3.1.2 Remotely Piloted Aircraft (RPA) design and certification

AIR7: Minimize risk of unidentified damage to RPA due to ground handling.	
Description	Damage to the RPA that remains unnoticed can be a risk to safe operations. In many cases the PIC will not have an opportunity to conduct a pre-flight inspection of the aircraft, and so any damage must be evident to ground handling personnel. The use of composite materials may increase the possibility that structural damage may not be clearly evident during a general visual inspection. Technologies such as bruising materials or coatings may help to make damage clearly evident (Withey et al.,2012). Furthermore, RPAs that are disassembled between flight, or transported to the launch area via ground vehicles, may be more susceptible to damage and incorrect assembly. There have been cases of small UAVs that crashed after being incorrectly assembled when being prepared for flight (Hobbs & Herwitz, 2009). If elements of the RPA need to be routinely assembled before flight (e.g. wings connected to fuselage), the components should be designed to make incorrect assembly clearly evident. If the PIC does not conduct preflight inspections of the RPA, procedures should be in place for effective evaluation and communication of the RPA condition.
Related regulations or standards	Annex 8 paragraph 4.1.8
Recommendations	Consider the potential for RPA damage due to ground activities when developing updates to the RPAS manual and Annex 8. Updates should also address standards and best practices for ensuring that damage of any kind is identified, communicated to the PIC, and addressed appropriately.

2.3.1.3 Remote Pilot Station (RPS) design and certification

2.3.1.3.1 Reliability

AIR8: Reliability of RPS systems, displays, controls, instruments, and equipment.	
Description	The systems that have been used in existing RPS frequently contain equipment based on off-the-shelf consumer hardware and software that would not meet the software reliability standards required for manned aircraft. RPAS incidents have occurred in which screens have frozen, computer systems have slowed, and controls have become unresponsive. It will be important to ensure that the reliability of the systems in the RPS meet the requirements for the appropriate regulations for type certification.
Related regulations or standards	
Recommendations	Consider how the system reliability requirements in the manned aviation standards and regulations will be applied to the RPS airworthiness processes. The analyses should focus on whether there are reductions in reliability that are acceptable to include these types of systems or whether the RPS systems will need to comply by being developed on more reliable platforms.

2.3.1.3.2 RPS displays and controls

AIR9: Standards for RPS displays and controls.	
Description	There are currently no standards specifically for the design of displays and controls in the RPS. Pilot interfaces currently used in RPS differ significantly from those used in traditional cockpits. Many RPS designs utilize “point and click” input devices, keyboards, trackballs or mice, desktop computer screens, and computer interfaces based on menu structures and dialog boxes (Williams, 2007). Computer systems are frequently adapted from consumer off-the-shelf products, and sometimes use widely-available consumer operating systems. Duplicated, side-by-side consoles are common, enabling control to be switched between consoles. The relative spaciousness of the RPS compared to a traditional cockpit enables additional screens to be added easily when a need for an

	additional display is recognized. Not only may additional information displays affect the pilot's interaction with the RPS, but it is unclear whether the addition of a display to a control room should be considered a modification. Computer displays also provide a great deal of flexibility, enabling information displays to be rearranged, moved within a screen. Regulatory authorities must decide whether to apply existing cockpit design rules to RPS, or permit interfaces that have not traditionally been used in the aviation industry. Most existing RPS designs could not be approved under current manned aircraft certification regulations and requirements. Standards for display and controls are well established for manned aircraft, but they may not be appropriate for RPS controls, especially as RPS configurations are less similar to the manned flight deck. Among the issues to be considered are: • The need for feedback on crew inputs. • Error management with computer-based controls, including the ability to detect and recover from errors. • Design features necessary to support control transfers. • The extent to which individualization or modification of interfaces should be possible. • Approaches to compensate for reduced sensory cues.
Related regulations or standards	EASA CS 25.1302 and AMC 25.1302 FAA 14 CFR 25.1302 and AC 25.1302
Recommendations	Conduct research to define the modifications that could be appropriate for design standards without reducing the level of safety. Consider the information being developed by others, including RPS design guidelines being developed by NASA (Hobbs & Shively, 2013).

AIR10: PIC access to dedicated back up for critical controls.	
Description	There have been RPAS incidents in which the PIC has lost the functionality of the primary controls and switched to the secondary pilot station to control the RPA. It will be important to ensure that the PIC has access to all critical controls in normal, non-normal, and emergency situations, including loss of control station function necessitating switching to a secondary set of controls. This issue of availability of back up controls is related to the issue of ensuring the reliability of the control station functionality including all

	displays, controls, instruments, and equipment needed by the PIC to accomplish their tasks.
Related regulations or standards	
Recommendations	Consider the needs for dedicated back up controls for critical control functions. These activities should be coordinated with those related to the standards for reliability of systems and controls.

AIR11: Separate flight controls and payload controls.	
Description	Several existing RPS designs possess shared interface devices that can be switched to control either payload or flight controls. This arrangement has led to significant design-induced errors. Payload controls should be separate and distinct from aircraft controls.
Related regulations or standards	
Recommendations	Consider the need to ensure that payload controls are separate and distinct from aircraft controls.

2.3.1.3.3 RPS security

AIR12: Maintaining security of RPS and flight crew.	
Description	Unauthorized access to the RPS or RPS equipment may have security implications with the possibility of interference of control of the RPA in ways that could have safety consequences.
Related regulations or standards	Annex 8 Section 11.3
Recommendations	Conduct an assessment to define security-related design and procedure requirements for different types of RPS facilities and equipment. For example, are there security measures that need to be in place for RPS environments that are not in an enclosed facility and, if so, what are those requirements? The assessment must consider the potential for distraction of the RPA PIC to implement the security measures and ensure that there is no excessive impact on pilot tasks or attention. The resulting requirements should also consider procedures for handing over control from one RPA PIC to another.

2.3.1.4 C2 Link as part of certification

AIR13: Considering C2 link in RPAS design and certification.	
Description	RPAS design should take into account potential interruption of the C2 link and the impact it will have on the performance of the other system components. Duration of the interruption or the phase of flight may elevate the situation to an emergency. Appropriate abnormal or emergency procedures should be established to cope with any C2 link interruption commensurate with the probability of occurrence. This issue is related to the controllability of the full RPAS and the design of the control systems since the remote pilot will be controlling the RPA through the C2 link. There are also many operations-related human factors issues that are presented in the operations section of this document. The airworthiness implications of using a C2 link to pass control commands and information to and from the pilot and the RPA needs to be well understood and incorporated in the airworthiness standards.
Related regulations or standards	
Recommendations	Evaluate the impact on airworthiness certification of the inclusion of the C2 link as part of the control system and the systems to get information to the pilot from the RPA. Coordinate these efforts with that of those addressing other related issues including system reliability and controllability.

2.3.2 Continuing airworthiness

AIR14: Instructions for Continued Airworthiness.	
Description	Instructions for Continued Airworthiness (ICA) are part of the certification package delivered to and approved by the certification authorities. It will be important for the ICA to address all components that make up the RPAS (RPA, RPS, C2 link equipment and antennas, launch and recovery equipment, etc).
Related regulations or standards	RPAS Manual Section 4.7
Recommendations	Analyze the needs for continued airworthiness information to address all components of the RPAS when developing updates to the standards. Include the need for information by different roles in the continuing airworthiness processes: Remote PIC and other remote pilots and flight crewmembers, remote observers, and maintainers of the RPA, RPS, C2

	link, and other components.

2.3.2.1 Maintenance manual

AIR15: Maintenance Manual.	
Description	The Maintenance Manual is part of the certification package delivered to and approved by the certification authorities. It will be important to include information about maintenance requirements for all RPAS components.
Related regulations or standards	RPAS Manual Sections 4.12 and 4.16
Recommendations	Analyze the needs for maintenance information to be included in the Maintenance Manual for maintainers of all components of the RPAS (RPA, RPS, C2 link equipment and antennas, launch and recovery equipment) and consider the results when updating the standards.

AIR16: Maintenance Manual –In-flight troubleshooting and fault rectification.	
Description	There may be a need to perform troubleshooting and fault rectification of the RPAS while an RPA is airborne. Current RPAS operations sometimes involve in-flight troubleshooting such as diagnosing and correcting RPS console lock-ups, software problems, and problems with cable connections. The RPAS maintenance manual must include procedures for in-flight fault diagnosis and corrective actions that may be performed by maintenance personnel. It will need to be determined, on the basis of risk assessments, tasks that can reasonably be performed during a flight, and tasks that should not be undertaken during a flight. Scheduled or preventative maintenance should not occur while an RPA is airborne
Related regulations or standards	RPAS Manual Sections 4.12 and 4.16
Recommendations	Consider the need for the Maintenance Manual to include corrective maintenance procedures that may be safely performed during a flight.

2.3.2.2 Flight recorders and voice recorders

AIR17: Gathering useful flight recorder data.	
Description	With no human life at risk or bodies to be recovered, there may be less need to locate the wreckage of RPAS from oceans or remote areas. As a

	result, on-board flight recorders may be less likely to be retrieved, even though the information will still be valuable in understanding the causal factors of accidents.
Related regulations or standards	RPAS Manual Section 9.10
Recommendations	Where a record of data from on-board systems is needed for accident investigation purposes, consideration should be given to ground-based recorders instead of, or in combination with, on-board flight recorders. An evaluation should also be made about how to gather the information from the RPS that would typically be recorded on the FDR in a manned aircraft.

2.4 Command and control

It is sometimes proposed that a shift from conventionally piloted to remotely piloted aircraft is partially analogous to moving from “fly by wire” to “fly by wireless”. In light of the importance of the radio link to aircraft control, standards and practices that were developed for aviation radio communication systems may not be adequate when the radio becomes part of the aircraft control system.

The human factors associated with the C2 link can be divided into two broad types, as follows.

First, an understanding of the tasks performed by the pilot, and the operating environment in which these tasks will be performed, can help to define the capacity and required link performance (RLP) of the C2 link in terms of acceptable latency, availability, integrity and continuity (ICAO, 2006). For example, if the aircraft is to be controlled via direct manual inputs, then low latency may be a critical requirement. If the pilot will require video imagery from the aircraft, then the ability of the link to transmit large amounts of data becomes critical. In general, as the level of automation on board the RPA increases, the requirements for link performance are relaxed, and vice versa.

Second, in addition to managing the aircraft, the flight crew of a RPAS must manage the C2 link. Management and awareness of the link status may be particularly critical during control handovers, lost link and link resumption, when operating towards the limits of the signal, and during frequency changes.

2.4.1 Human factors with implications for required link performance

Before required link performance can be determined, it is necessary to understand the exchanges that must occur between the pilot and the RPA via the C2 link. The link must be capable of transmitting the necessary pilot control inputs to the aircraft and returning the information required for pilot displays. In each case, the exchange must be performed within a required time window and at the required quality.

A distinction can be made between continuous control tasks and non-continuous control tasks. A continuous control task is one that requires constant human monitoring and control inputs that must often be performed within very a limited time window. An example is manual control of ailerons in an aircraft that is not equipped with an autopilot.

Non-continuous control tasks involve discrete actions that do not involve constant monitoring or regular human inputs, and that can often be performed within a time window ranging from seconds to minutes. Examples are switching on landing lights, or supervisory control of automated systems via mode selections.

In general, continuous control tasks demand a higher level of link performance than non-continuous control tasks. It is important to note however, that an RPA can have systems with several levels of pilot control operating at once. For example, a stability augmentation system may require no pilot involvement, a waypoint-based navigation system may require pilot monitoring and occasional inputs, whereas gear extension may require a discrete pilot selection.

CC1: Link latency and manual control.	
Description	Some UAS designs have involved the direct manual control of flight surfaces, either by a pilot within visual line of sight of the aircraft, or a pilot located in a control station equipped with "stick and rudder" controls. Latencies between control input and response can impede direct manual control. Lags of a second or more make manual control extremely difficult, and even lags as brief as 50 milliseconds can produce noticeable degradations of performance and lead to pilot induced oscillations (Welch, 2003). Control latencies may be most problematic when the control is via a geostationary satellite link (Mouloua, Gilson, Daskarolis-Kring, Kring, & Hancock, 2001) or if the aircraft is being remotely piloted via a relay from another aircraft (Gawron, 1998). Although a proportion of the latency may result from over-the-air transmission time, processing at either end of the radio link can also contribute to latencies.
Related regulations or standards	United States MIL Standard 1472G (Department of Defense, 2012) states that UAS system transport delays between user input, system output, and display of system execution shall not exceed 100 milliseconds. However, it is not clear whether this requirement is intended to only apply to UAS under direct manual control.
Recommendations	UAS designs that rely on direct manual control of flight surfaces to ensure flight stability may not be feasible unless very small link latencies can be guaranteed. For most conditions, this will mean that some level of on-board flight control automation will be necessary. Where the stability of flight relies on on-board automation, protective measures should be taken to reduce the likelihood of inadvertent disengagement of the automation.

CC2: Back-channel communication between RPAS pilots.	
Description	RPAS operations may involve communication between geographically distributed personnel. An in-flight handover between RPS will require communication and coordination between personnel at each location. This may involve verbal or text-based communications. Flight crew may also need to communicate with support personnel located at the aircraft

	during pre-flight and post-flight stages.
Related regulations or standards	
Recommendations	The C2 workgroup should consider whether back-channel communication is within its scope. If so, it should be determined how this communication should occur.

CC3: Link latency may be sufficient to disrupt voice communications.	
Description	In controlled airspace, all pilots on the same frequency are able to monitor voice transmissions due to the "party line" nature of the radio. This provides situational 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 communication and control architecture for RPAS operations may involve the relay of pilot voice communications from the ground to the RPA via either a terrestrial radio or a satellite link. The message will then be re-broadcast from the RPA via VHF or HF radio. The transmissions of other pilots and controllers will be relayed to the RPA 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 RPAS pilot with reference to other pilots on frequency. Some of this latency will be due to processing before and after signal transmission. Care must be taken to ensure that the latency between RPAS voice communications with reference to other pilots on frequency communications does not reach a level that disrupts communication. Several studies have examined the impact of voice latency on ATC communications (Nadler et al. (1992); Rantanen et al. (2004); Sollenberger et al.(2003); Zingale et al. (2003)). However it has always been the case in conventional aviation that all pilots on frequency are communicating with no between-pilot delays. No studies to date have examined the impact of voice latency between pilots. Telecommunications research has identified that round-trip transmission delay in the range of 500 ms gives considerable subscriber difficulties in telecommunications, and on tasks requiring complex verbal exchanges,

	disruption can occur at significantly shorter latencies Kitawaki & Itoh (1991). ITU report G.114 notes that one-way transmission times below 150 ms will not significantly affect most voice communication.
Related regulations or standards	
Recommendations	Research is needed to determine the point at which latency starts to cause disruption when the voice communications of one pilot are delayed with reference to the voice communications of all other pilots on frequency.

CC4: Loss of command link may also mean loss of communications and loss of some DAA capabilities.	
Description	If the C2 link also carries pilot-ATC communications, and certain features of the DAA system are reliant on the link, then a loss of link may result in three abnormal conditions occurring simultaneously: (1) loss of pilot input to aircraft and loss of aircraft telemetry (2) loss of voice communications with ATC and (3) inability of pilot to interface with DAA system. If only the uplink or downlink is interrupted, some pilot tasks may be affected while others may remain unaffected. For example, if uplink is lost while downlink remains, it is conceivable that the pilot may be unable to send commands to the aircraft or make radio transmissions via the aircraft, but may still have the ability to receive telemetry data and hear communications on frequency.
Related regulations or standards	
Recommendations	In considering required link performance, all impacts of loss of links must be considered.

CC5: Imagery from on-board cameras.	
Description	Not all current RPAs are equipped with an on-board camera. Video downlinks can impose significant bandwidth requirements (International Telecommunications Union, 2010). Nevertheless, there are several potential uses of imagery from an on-board camera. (1) Assisting with pilot situational awareness, including detecting the presence of airframe ice. (2) During approach to land, confirming that the aircraft is lined-up correctly and that a safe landing can be accomplished. (3) Risk mitigation in the event of an off-airport landing or ditching.

Related regulations or standards	RTCA Special Committee 228 is considering the requirement for on-board visual imagery, and may recommend that C2 links have the capability to downlink imagery in certain situations.
Recommendations	Consider the suitability of the requirements for on-board video included in the Minimum Operational Performance Standards (MOPS) document to be released by RTCA Special Committee 228.

2.4.2 Human factors considerations for monitoring and management of link

In addition to controlling the aircraft, the crew of an RPAS must monitor and manage the C2 link, and their actions may positively or negatively impact the performance of the link.

It must be decided whether the pilot should have an active role in managing the link, such as by selecting frequencies or transmission power, or whether the operation of the link will be automated. In the latter case, the pilot may still perform a monitoring role, remaining aware of current and predicted link performance.

CC6: Crew actions and lost link.	
Description	A full consideration of link performance must take into account not only the technical characteristics of the link architecture, but also the fragility or robustness of the link in the face of predictable human error, procedure deviations, or other human actions that could lead to signal interruptions.
Related regulations or standards	
Recommendations	The C2 Workgroup should ensure that the human role in link management is considered.

CC7: Human role in frequency assignment.	
Description	It is unclear how frequencies will be assigned to each RPAS. A flight may involve the assignment of C2 frequencies during preflight planning, and further frequency assignments as the flight progresses. If frequency assignment will require human involvement, it will be necessary to examine the nature of this involvement and the potential for system performance to be affected by human errors or procedure violations.

Related regulations or standards	RPAS manual Section 11.4.1
Recommendations	In conjunction with the Operations Workgroup, the C2 workgroup should consider the human tasks that may be involved in frequency assignment, and how the performance of these tasks could affect safety and efficiency.

CC8: Lack of information on prevalence of lost link.	
Description	Although information on link losses is available from simulations and flight tests, there may be a need for statistical information on the frequency, duration and causes of link interruptions for current "real world" RPAS operations. It is expected that the patterns of link interruptions will vary according to the nature of the C2 link, terrain, environmental factors and flight characteristics. This information will have human factors implications for several areas including the design of operational procedures, DAA systems and procedures, pilot interactions with air traffic control, and risk assessments.
Related regulations or standards	
Recommendations	A request for information should be made to member states to provide information on lost links experienced by "real world" RPAS operations.

CC9: In-flight diagnosis of link degradation.	
Description	In the event of an in-flight loss of link, or degradation in link quality, it may be necessary for the pilot to understand the cause of the problem, in order to take appropriate action. For example, different responses may be necessary according to whether the problem is related to interference from payload, intentional jamming, masking of the signal by terrain, or other causes.
Related regulations or standards	
Recommendations	The C2 group should consult with the Operations group to consider whether the pilot will be expected to diagnose the cause of link degradations, and if so, what information is needed to enable this to occur.

CC10: Do directional/tracking antennas (on the ground or in the air) change the nature of crew tasks?	
Description	Tracking antennas for terrestrial radio systems may offer advantages such as resistance to interference and greater signal strength than omnidirectional antennas. However tracking antennas are more complex than omnidirectional antennas, and may require more monitoring by the crew. A failure of the antenna's tracking system could lead to a lost link. It is unclear whether tracking antennas are more susceptible to human error than omnidirectional antenna systems.
Related regulations or standards	
Recommendations	Information should be gathered on the experience of RPAS operators with omnidirectional and directional antennas to identify if the operation of a directional antenna introduces additional human tasks or hazards.

CC11: Pilot awareness of link quality.	
Description	Pilots will require information showing link quality. This is likely to include link footprint and no-go areas where link will be masked by terrain or obstructions. The information will enable the pilot to monitor the current state of the C2 link and anticipate degradations.
Related regulations or standards	ICAO Manual section 13.2.6
Recommendations	In conjunction with the Operations group, the C2 workgroup should identify the information necessary to monitor and predict the performance of the C2 link.

2.5 Detect and avoid

Despite their removal from the cockpit, pilots of unmanned aircraft systems (UAS) will be the final authority in maintaining a safe level of separation (i.e., "well clear") between their aircraft and nearby traffic. The FAA and ICAO have thus far required pilots to 'see and avoid' other aircraft, where pilots rely on the visual acquisition of nearby traffic to ensure that they do not create a collision hazard. In response to this requirement, the UAS community has had to quantify well clear, a traditionally subjective concept, so that systems on board the aircraft and in the ground control station can help the ground pilot *detect* and avoid nearby traffic. The development of such a system requires careful design, with the abilities and limitations of the ground pilot taken into account. The rest of this section details eight considerations that need to be addressed before a viable detect and avoid system can be fielded. While the list is far from comprehensive, what follows are high-level issues that can be addressed by the community in the near term.

DAA1: Inability to visually acquire target.	
Description	It is unlikely that RPAs will be equipped with a camera that is capable of replacing the manned pilot's ability to visually acquire nearby traffic. Current traffic avoidance systems in manned aviation are intended to serve as a supplement to the pilot's ability to directly attend to traffic outside of their aircraft. The detect and avoid system, however, will be the pilot's sole source of traffic information. The heightened role of the traffic display should be reflected in its design.
Related regulations or standards	
Recommendations	A cockpit display of traffic information should be included in the ground control station that is capable of showing surrounding traffic at a sufficient range around ownship. The traffic display will also need to provide the pilot with sufficient information regarding nearby traffic, such as intruder position, direction, altitude, speed and vertical trend. It may also be necessary for the system to utilize a conflict detection and resolution algorithm that can provide the pilot with potential maneuver options, thereby reducing the cognitive load on the pilot.
References	

DAA2: Definition of Well Clear.	
Description	The self-separation (SS) function of a DAA system is a means of compliance with the regulatory requirements (14CFR Part 91, §91.111 and §91.113) to "see and avoid" and to remain well clear of other aircraft. The concept of well clear has been proposed as an airborne separation

	standard to which a DAA system must adhere, and performing SS correctly means remaining well clear of other aircraft. In order to build a DAA system that helps the pilot remain well clear, that separation standard must be defined quantitatively. Well clear is defined as the state of maintaining a safe distance from other aircraft that would not normally cause the initiation of a collision avoidance (CA) maneuver by either aircraft. A well clear separation standard should be large enough to (1) avoid corrective maneuvers by intruders (i.e., any aircraft detected in range of the RPAS's surveillance system) that are equipped with a CA system (e.g., Traffic Alert and Collision Avoidance System (TCAS)—or Airborne Collision Avoidance System (ACAS)), (2) minimize traffic alert issuances by air traffic control (ATC), and (3) avoid excessive concern for pilots of proximate piloted aircraft. However, a well clear separation standard also should be small enough to prevent the need for large deviations that potentially disrupt traffic flow and ATC separation management plans (Consiglio et al., 2013; Federal Aviation Administration, 2013; Johnson et al., 2015; Weibel et al., 2011) The separation standard now used as the means for RPAs to remain well clear of all traffic derives from the work performed by the UAS Sense and Avoid Science and Research Panel (Cook et al. 2015), which was then modified by the FAA to account for the existing VFR and IFR separation of 500 feet, and now has concurrence from RTCA Special Committee 228 (Walker, 2014). Its pedigree comes from the TCAS collision detection logic. In order for the RPA to remain well clear with another aircraft, the following must be true: • Modified tau <= 35 seconds (i.e. analogous to time to closest point of approach (CPA)) • Horizontal miss distance <= 4000 feet (i.e. horizontal separation as extrapolated CPA) • Z Threshold <= 450 (i.e. current altitude separation standard)
Related regulations or standards	United States Code of Federal Regulations 14CFR Part 91, §91.111 and §91.113
Recommendations	Investigate the suitability for ICAO purposes of the well clear definition proposed by the United States UAS Sense and Avoid Science and Research Panel (SARP).

DAA3: Alerting.	
Description	The pilot needs to be adequately alerted with respect to a potential loss of well clear and/or legal separation. This includes the logic as well as the alerts themselves. The type (severity, urgency) of these alerts needs to be defined. In addition, the parameters in which this alerts are activated need to be defined (see well clear). Once these parameters are

	established, the visual and auditory alerts need to be defined.
Related regulations or standards	RTCA DO 317b.
Recommendations	Review extant literature on this topic. Adopt or develop based on the specific ICAO mission and need. Evaluate in human in the loop simulations.

DAA4: Level of Guidance.	
Description	The guidance provided to pilots to remain well clear can take several forms of increasing information. A basic “informational” display may only contain basic traffic information and alerting (based on the scheme above. A “suggestive” display may provide the pilot with a range of potential solutions to solve the traffic conflict. Whereas a “directive” display would inform the pilot of a single point solution to be executed. The appropriate level of guidance needs to be determined for this application along with the information elements that constitute that display.
Related regulations or standards	
Recommendations	Once the constraints are well defined (e.g., well clear, alerting) determine the appropriate level of guidance by referring to previous evaluations or perform human in the loop simulations in this specific context.

DAA5: Assessing the severity of a threat.	
Description	The inability to look outside of the cockpit window places additional burden on the detect and avoid system, as the system must clearly convey the spatial relationship between the intruding aircraft and unmanned aircraft. The lack of in situ cues in the ground station must be taken into account when designing how and when the detect and avoid system attracts and orients the pilot’s attention.
Related regulations or standards	
Recommendations	The detect and avoid system should explicitly declare the predicted threat level of nearby traffic using a multi-level alert structure that categorizes nearby traffic according to their predicted spatial and temporal proximity from ownship. Caution and warning-level visual and auditory alerts should be issued for traffic that is predicted to require immediate pilot awareness and/or corrective action. Furthermore, each level of the alert structure should correspond to an expected pilot action.

References	

DAA6: Accommodating longer pilot response times.	
Description	Existing UAS platforms utilize a variety of input methods to enable the UAS pilot to control the aircraft. Some of these methods (e.g., point-and-click navigation controls) are associated with longer pilot response times than are seen with the standard method of control in manned aviation (i.e., hands-on stick-and-throttle). Paired with the inherent control link latencies found with the control on unmanned aircraft, UAS pilots may not be able to take positive control over the aircraft as quickly as can the pilots of manned aircraft.
Related regulations or standards	
Recommendations	The detect and avoid system should alert the pilot with sufficient time so as to allow the pilot to assess the conflict and determine an appropriate response. The alerting system should take into account the potential for longer pilot response times as a result of different input control methods and link latencies. Furthermore, to minimize pilot response times, it may be advisable to provide suggestive guidance to pilots to assist in the determination of an appropriate maneuver
References	

DAA7: Handling the transition between pilot-in-the-loop and fully autonomous response by the aircraft.	
Description	It is assumed that the pilot will be 'in-the-loop' (i.e., responsible for implementing the response to the threat) during the detect and avoid function. However, if the pilot fails to make an appropriate maneuver, or if the aircraft 'loses link' with the ground control station, the aircraft must ultimately be capable of responding to the threat autonomously in order to avoid a midair collision (or near midair collision).
Related regulations or standards	
Recommendations	The transition to autonomous response by the aircraft requires further study. The system should be designed to transition safely and to be viewed as acceptable and reliable by the pilot.
References	

DAA8: Presence of error in the surveillance sensors.	
Description	The surveillance sensors that are utilized by the detect and avoid system are subject to position and velocity errors. These errors, which impact the ability of the surveillance sensors to accurately track nearby targets, in turn, have an impact on the ability of the conflict detection and resolution algorithm to appropriately evaluate their relative threat level. This 'noisiness' can result in both higher rates of 'false alarms' and 'misses', both of which can negatively affect pilot's trust of the detect and avoid system.
Related regulations or standards	
Recommendations	The conflict detection and resolution algorithm(s) utilized by the detect and avoid system should utilize spatial and temporal buffers that can account for the presence of error in the surveillance systems. Further research is needed to optimize such buffers in the presence of real-world data.
References	

DAA9: The use of multiple surveillance sources.	
Description	Multiple surveillance sources are required by the detect and avoid system. A transponder on the unmanned aircraft will be required in order to pick up nearby aircraft that are broadcasting their position, while an on-board RADAR (or an equivalent technology) will be necessary in order to track nearby aircraft and objects that are not equipped with a transponder. Each of these sources has its own inherent error and bias, which has an impact on the sort of maneuvers that pilots can make in response to the information. (Maneuvers made against targets tracked by TCAS, for instance, must be in the vertical dimension since the horizontal error present in TCAS is deemed excessive.)
Related regulations or standards	
Recommendations	The detect and avoid system must be able to discern the source of the tracking information it is presenting to the pilot. It may be necessary to use different symbology in cases where the source of the information directly affects the pilot response.
References	

DAA10: Loss of command and control link.	
Description	The loss of the command and control link between the ground control station and the aircraft is an inherent risk of unmanned systems. It is therefore possible that link is lost while the pilot is performing the detect and avoid function. Without mitigating factors, this could lead to a loss of well clear or a collision avoidance scenario with the unmanned system and the threat aircraft (Fern, Rorie & Shively, 2014).
Related regulations or standards	
Recommendations	The detect and avoid system should be capable of assessing when a loss of link has occurred and communicate that information to the pilot. The system should also have the capacity to make autonomous maneuvers onboard the aircraft so as to avoid midair collision.
References	

2.6 ATM integration

The integration of RPAS operations into the Air Traffic Management system as a whole presents many challenges that may impact the tasks and responsibilities of air traffic control personnel and the policies and procedures that they use.

ATM1: Impact of C2 link latency on party line information used by pilots.	
Description	Several potential architectures may introduce latencies into RPA pilot voice communications. The impact of this on pilot-ATC and pilot-pilot (party line) communications is currently unknown. Latency in the delivery of RPAS communications to and from ATC through the C2 link may impact the flow of information with ATC and all the aircraft in their airspace. This includes the potential for anticipated timing of making radio calls and possible increased likelihood of stepping on or interrupting other communications.
Related regulations or standards	
Recommendations	Consider the potential impact of latency in the C2 link communications between ATC and pilots when updating best practices and required procedures. Include the impact on other pilots who will be in the airspace with the RPA and their need for relevant and timely party-line information.

ATM2: Potential loss of party line information.	
Description	RPA pilot – ATC voice architectures that rely on private ground connections may result in loss of "party line" communication where other pilots can maintain awareness.
Related regulations or standards	
Recommendations	Consider the potential for safety consequences if pilots of other aircraft in a particular controlled airspace do not have access to the ATC communications with the pilot of an RPA in their airspace. There may be a need for providing information to these other pilots about the state of the RPA or the fact that it has lost its communication link.

ATM3: Impact of loss of C2 link on voice communications.	
Description	If voice communications are also transmitted via C2 link, loss of C2 will also result in loss of voice communications until pilot establishes

	communication with ATC by other means.
Related regulations or standards	
Recommendations	Develop policies and procedures for alternate means of communication in the event of lost C2 link when it is the routine method for pilot-ATC communication.

ATM4: Potential for multiple RPAs going lost link simultaneously.	
Description	It is possible that loss of a portion of the C2 infrastructure could result in multiple RPAs going lost link simultaneously.
Related regulations or standards	
Recommendations	Conduct research to assess the risk of this occurring and develop ATM policies and procedures as necessary based on the results.

ATM5: ATM awareness of RPA lost link contingency options.	
Description	Pilot and ATM awareness of how the RPA will behave during a lost link is critical to maintain the safety of the airspace. It is important to have policies and procedures available to help the pilot and ATM personnel predict the behavior of the RPA and respond appropriately under a lost link situation. The procedures used for developing and communicating flight planning information and documents will be important to consider as well. The flight plan should include the planned contingency flight path that the RPA will follow if the link is lost at any particular point in the flight. However, this may create some complexity for the controllers to refer to the plan and understand the anticipated behavior for the point of flight when the link is lost.
Related regulations or standards	
Recommendations	Consider options for planning, documenting, communicating, and using lost link contingency information and develop policies and procedures that will have minimal impact on on-going workload of the ATM personnel involved.

ATM6: RPAS handling of ATM instructions including visual references.	
Description	It is common practice for ATM instructions to include following another airplane or using other visual references. The Remote PIC will need access to equivalent information about those visual references to comply with these requests or the requests will not be able to be made by ATM

	for RPAS. Controllers may not be able to expect to use these types of instructions with RPAS in their airspace. If they do, it will be important for them to have an understanding of the alternate information that is being used by the remote PIC to respond to the requests.
Related regulations or standards	RPAS Manual 2.3.6
Recommendations	Consider the potential for remote pilots to respond to common requests that include reference to visual information and develop procedures for handling RPAS that cannot comply.

2.6.1 Visual Flight Rules

ATM7: RPAS flights under VFR.	
Description	If an RPAS is operating under visual flight rules, the PIC must be able to ensure that the RPA stays in visual meteorological conditions. This means that they must be able to assess meteorological conditions during the flight and take the appropriate actions if conditions change. This is of particular importance during the take-off and landing phases.
Related regulations or standards	RPAS Manual 14.2.5, 14.2.7 "The remote pilot or RPAS operator must be able to assess the meteorological conditions throughout the flight. In the event the RPA, on a VFR flight, encounters IMC, appropriate action must be taken".
Recommendations	Consider the limitations of a remote pilot for conducting VFR operations and in particular the unlikelihood of them identifying when the RPA has gone from a VMC to IMC situation. Update the RPAS Manual and appropriate Annexes to disallow RPAS operations under VFR or require a means to maintain visual awareness of the meteorological conditions surrounding the RPA.

2.6.2 RPAS unique procedures

ATM8: Unique ATM procedures related to RPAS operations.	
Description	There will likely be ATM procedures unique to RPAS operations that will be required to be developed, documented, and implemented. It will be important to carefully consider these and include them in updates to

	the standards.
Related regulations or standards	RPAS Manual 14.2.11, 14.2.12
Recommendations	Conduct research to define the RPAS-unique ATM procedures and use the results to update the standards.

2.6.3 Flight rules

2.6.3.1 Right-of-way

ATM9: RPAS adherence to right-of-way rules.	
Description	RPAs will be required to follow all existing right-of-way rules to integrate with the current ATM system. This will require the PIC to have the appropriate information and awareness of other aircraft on a continuing basis throughout the flight.
Related regulations or standards	RPAS Manual 14.3.1
Recommendations	Conduct research to understand the information that will be needed by Remote PICs to follow right-of-way rules and update appropriate standards.

2.6.3.2 RPAS performance requirements

ATM10: ATM awareness of RPAS performance capabilities and limitations.	
Description	ATM providers are trained on the capabilities of different aircraft classes to be able to provide directions that are within their capabilities. This will be particularly important for RPAS because the range of capabilities is so wide.
Related regulations or standards	RPAS Manual Section 14.3
Recommendations	Develop a full description of the range of anticipated RPA performance characteristics. The minimum list of performance characteristics to consider from paragraph 14.3.4 of the RPAS Manual is a) speed; b) climb, descent or turn rates; c) wake turbulence; d) endurance; e) latency; and f) effect of bank angle on C2 and ATC communications link capability and reliability

	Use the results to update standards to include how air traffic providers will handle RPAS of differing capabilities and how they will gain the knowledge about the performance characteristics.

2.6.3.3 ATM procedures

ATM11: Integration of RPAS into ATM procedures.	
Description	Integration of RPAS may require modifications to current ATM procedures. It will be important to effectively update the procedures and not leave it to the controllers to develop work-around practices on their own.
Related regulations or standards	RPAS Manual 14.3.5, 14.3.6
Recommendations	Identify the ATM tasks that will need to be modified when integrating RPAS into their traffic management. Modify procedures to include those tasks and clearly specify when the procedures should be applied.

2.6.3.4 Flight plan

ATM12: Including lost link information in flight plan.	
Description	A standard method to include information about lost link procedures in the flight plan will need to be developed. The standard will need to take into account the needs of all those who will develop or use the flight plan.
Related regulations or standards	RPAS Manual Section 14.3
Recommendations	Develop a description of the needs of all those who will prepare, file, or use the flight plan that includes the use each of them will have for lost link procedure information. Use the description to update the standards in a way that will best work from all the varying perspectives.

3 List of considerations

For ease of reference, the human factors considerations contained in this document are listed below.

3.1.1 Personnel licensing

- **LIC1:** Define licensing categories for remote pilots and other remote flight crewmembers.
- **LIC2:** Identify in detail the knowledge and skill requirements for remote PIC, remote pilots, and other licensed remote flight crewmembers.
- **LIC3:** Define licensing categories for RPA Observers.
- **LIC4:** RPA Observer knowledge and skills.
- **LIC5:** Define licensing categories for RPAS Maintenance personnel.
- **LIC6:** Maintenance personnel knowledge and skills.
- **LIC7:** Define licensing requirements for RPAS.
- **LIC8:** RPAS instructor required skills and training.
- **LIC9:** Consideration of the degradation of knowledge and skill retention for different licensing classes when determining license validity periods.
- **LIC10:** Description of practical skill tests for each licensing class.
- **LIC11:** Description of experience requirements based on the licensing classes.

3.1.2 RPAS operations

- **OPS1:** Predictability of lost link maneuvers.
- **OPS2:** Criteria for declaration of lost link.
- **OPS3:** Frequently exceeding lost link threshold.
- **OPS4:** Potential for multiple simultaneous lost links.
- **OPS5:** Flight crew interaction with aircraft.
- **OPS6:** Perceptual illusions of RPAS operations.
- **OPS7:** Landing/recovery at aerodromes.
- **OPS8:** Vigilance, low workload and monotony.
- **OPS9:** Rest breaks and crew rotations.
- **OPS10:** Best practices for control handovers from RPS to RPS.
- **OPS11:** Transfer of control between adjacent consoles in same RPS.
- **OPS13:** Planning for ultra-long duration flights.
- **OPS14:** Flight planning and C2 link considerations.

- **OPS15:** Planning for contingencies.
- **OPS16:** Decision making for emergency landings, flight termination or ditching.
- **OPS17:** Insurance considerations and emergency decision-making.
- **OPS18:** Search and rescue.
- **OPS19:** Control of a domestic RPA by a crew members in another state.
- **OPS20:** Pilot interactions with payload.
- **OPS21:** Interaction with on-board autonomous systems.
- **OPS22:** Unique human factors training requirements for crew tasks.
- **OPS23:** Physical safety and accessibility of the RPS.
- **OPS24:** Electronic security procedures.
- **OPS25:** Maintenance human factors.
- **OPS26:** Intentional acts of operational personnel.

3.1.3 Airworthiness

- **AIR1:** Defining function allocation and pilot tasks.
- **AIR2:** Ensure that the PIC will be able to maintain awareness of the state and behavior for all modes of the automated systems.
- **AIR3:** Reduced sensory information.
- **AIR4:** Ensuring controllability under all anticipated operating conditions, transitions between operating conditions, and all flight stages and aeroplane configurations.
- **AIR5:** Control system design.
- **AIR6:** Ensuring timely detection and response to a stall with use of the C2 link.
- **AIR7:** Minimize risk of unidentified damage to RPA due to ground handling.
- **AIR8:** Reliability of RPS systems, displays, controls, instruments, and equipment.
- **AIR9:** Standards for RPS displays and controls.
- **AIR10:** PIC access to dedicated back up for critical controls.
- **AIR11:** Separate flight controls and payload controls.
- **AIR12:** Maintaining security of RPS and flight crew.
- **AIR13:** Considering C2 link in RPAS design and certification.
- **AIR14:** Instructions for Continued Airworthiness.
- **AIR15:** Maintenance Manual.
- **AIR16:** Maintenance Manual –In-flight troubleshooting and fault rectification.
- **AIR17:** Gathering useful flight recorder data.

3.1.4 Command and control

- **CC1:** Link latency and manual control.
- **CC2:** Back-channel communication between RPAS pilots.
- **CC3:** Link latency may be sufficient to disrupt voice communications.
- **CC4:** Loss of command link may also mean loss of communications and loss of some DAA capabilities.
- **CC5:** Imagery from on-board cameras.
- **CC6:** Crew actions and lost link.
- **CC7:** Human role in frequency assignment.
- **CC8:** Lack of information on prevalence of lost link.
- **CC9:** In-flight diagnosis of link degradation.
- **CC10:** Do directional/tracking antennas (on the ground or in the air) change the nature of crew tasks?
- **CC11:** Pilot awareness of link quality.

3.1.5 Detect and avoid

- **DAA1:** Inability to visually acquire target.
- **DAA2:** Definition of Well Clear.
- **DAA3:** Alerting.
- **DAA4:** Level of Guidance.
- **DAA5:** Assessing the severity of a threat.
- **DAA6:** Accommodating longer pilot response times.
- **DAA7:** Handling the transition between pilot-in-the-loop and fully autonomous response by the aircraft.
- **DAA8:** Presence of error in the surveillance sensors.
- **DAA9:** The use of multiple surveillance sources.
- **DAA10:** Loss of command and control link.

3.1.6 ATM integration

- **ATM1:** Impact of C2 link latency on party line information used by pilots.
- **ATM2:** Potential loss of party line information.
- **ATM3:** Impact of loss of C2 link on voice communications.
- **ATM4:** Potential for multiple RPAs going lost link simultaneously.

- **ATM5:** ATM awareness of RPA lost link contingency options.
- **ATM6:** RPAS handling of ATM instructions including visual references.
- **ATM7:** RPAS flights under VFR.
- **ATM8:** Unique ATM procedures related to RPAS operations.
- **ATM9:** RPAS adherence to right-of-way rules.
- **ATM10:** ATM awareness of RPAS performance capabilities and limitations.
- **ATM11:** Integration of RPAS into ATM procedures.
- **ATM12:** Including lost link information in flight plan.

4 Action by the meeting

The meeting is invited to:

a) note and review the contents of this working paper;

b) refer the identified human factors considerations to Workgroups ; and

c) agree that this document should be revised and updated periodically.

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