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DOT/FAA/AR-xx/xx

Federal Aviation Administration
William J. Hughes Technical Center
Aviation Research Division
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New Jersey 08405

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A10 – Human Factors Considerations of Unmanned Aircraft System Procedures & Control Stations: Tasks CS-1 through CS-5

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October 16, 2017

Final Report

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/AR-xx/xx		

4. Title and Subtitle	5. Report Date
PROJECT A10 FINAL REPORT: TASKS CS-1 THROUGH CS-5	October 2017
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Carl Pankok, Jr., Ellen J. Bass, Philip J. Smith, Ronald Storm, Joel Walker, Andrew Shepherd, and Amy Spencer	
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
	11. Contract or Grant No.
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Directorate Address Here	Final Report
	14. Sponsoring Agency Code

15. Supplementary Notes

The Federal Aviation Administration Aviation William J. Hughes Technical Center Research Division COR was

16. Abstract

The objective of the work was to develop recommendations for minimum unmanned aircraft system (UAS) control station standards and guidelines. The recommendations focused on operation of fixed-wing unmanned aircraft (UA) larger than 55 lb. operated beyond visual line of sight in an integrated National Airspace System (NAS). The research approach included (1) development of recommendations for minimum human-automation function allocation, (2) identification of minimum information requirements for safe UAS operation in the NAS, (3) storyboard development, and (4) cognitive walkthrough of the storyboards by pilot subject matter experts (SMEs). In addition to serving as the participants in the cognitive walkthroughs, SMEs with experience in unmanned operation reviewed the technical content of the function allocation, information requirements, storyboard development, and resulting recommendations. The results of the work are expected to inform the development of regulations for UAS operation in the NAS.

17. Key Words	18. Distribution Statement
Cognitive Walkthrough Controls and Displays Design Guidelines Human-Automation Function Allocation Human Factors Information Requirements Storyboards Unmanned Aircraft Systems Unmanned Aircraft System Control Station	This document is available to the U.S. public through the National Technical Information Service (NTIS), Springfield, Virginia 22161. This document is also available from the Federal Aviation Administration William J. Hughes Technical Center at actlibrary.tc.faa.gov.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

ACKNOWLEDGEMENTS

Acknowledgements for individual efforts are included within sections of the report. In addition, the authors would like to thank Ashley Awwad for her assistance and guidance in directing the research. They would also like to thank individuals who reviewed earlier versions of this document, including Richard S. Stansbury, Stephen “Lux” Luxion, Andrew Abbate, and Ali Jazayeri. Finally, the authors want to express their gratitude to the subject matter experts who participated in the research: Amanda Brandt, Reuben Burch, Kurt Carraway, Joe Cerreta, Joseph Millette, Sean Moulton, Paul Snyder, and Gary Ullrich.

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LIST OF ACRONYMS

AC	Advisory Circular
ACAS	Airborne Collision Avoidance System
ACS	Airman Certification Standards
ADI	Attitude Director Indicator
ADM	Aeronautical Decision Making
ADS-B	Automatic Dependent Surveillance-Broadcast
AFM	Aircraft Flight Manual
AGL	Above Ground Level
AIAA	American Institute of Aeronautics and Astronautics
AIM	Aeronautical Information Manual
AIRMET	Airmen's Meteorological Information
ALTS	Automatic Landing/Take-off System
AO	Aircraft Operator
AOA	Angle of Attack
ARTCC	Air Route Traffic Control Center
ASSURE	Alliance for System Safety of UAS through Research Excellence
ASTM	American Society for Testing Materials
ATC	Air Traffic Control
ATIS	Automatic Terminal Information Service
ATOL	Auto Takeoff and Landing
ATS	Air Traffic Service
AVO	Air Vehicle Operator
BVLOS	Beyond Visual Line of Sight
CASA	Civil Aviation Safety Authority
CFIT	Controlled Flight Into Terrain
CFR	Code of Federal Regulation
CGCS	Common Ground Control System
CL	Checklist
COTS	Commercial Off-the-Shelf
CRM	Crew Resource Management
CS	Control Station
CTAF	Common Traffic Advisory Frequency
DAA	Detect and Avoid
DOD	Department of Defense
DVI	Direct Voice Input
EASA	European Aviation Safety Agency
EO	Electro-Optical
EVLOS	Extended Vision Line of Sight
FA	Aviation Area Forecast
FAA	Federal Aviation Administration

FAR	Federal Aviation Regulation
FD	Winds and Temperatures Aloft Forecast
FLIP	Flight Information Publication
FMS	Flight Management System
GCS	Ground Control Station
GPS	Global Positioning System
HMD	Head Mounted Display
HMI	Human Machine Interface
HSI	Human System Integration
HUD	Head Up Display
IAS	Indicated Airspeed
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
ITAR	International Traffic and Arms Regulations
KSA	Knowledge, Skills, and Abilities
LNAV	Lateral Navigation
LOA	Level of Automation
LOS	Line of Sight
MASPS	Minimum Aviation System Performance Standards
MCS	Mission Control Station
METAR	Meteorological Terminal Aviation Routine Weather Reports
MOPS	Minimum Operational Performance Standards
MTS	Multi-Spectral Targeting System
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
ODP	Obstacle Departure Procedures
PIC	Pilot in Command
PIREP	Pilot Weather Reports
POH	Pilots Operating Handbook
PTS	Practical Test Standards
RAIM	Receiver Autonomous Integrity Monitoring
RNAV	Radio Navigation
RPA	Remotely Piloted Aircraft
RPIC	Remote Pilot in Command
RTCA	Radio Technical Commission for Aeronautics
SAE	Society of Automotive Engineers
SARPS	Standards and Recommended Practices
SIGMET	Significant Meteorological Information
SME	Subject Matter Expert
sUAS	Small Unmanned Aircraft System

SVS	Synthetic Vision System
TAF	Terminal Aerodrome Forecast
TCAS	Traffic Collision Avoidance System
TCO	Training Course Outline
TIS-B	Traffic Information Service-Broadcast
TOC	Top of Climb
TOD	Top of Descent
TSO	Technical Standard Order
UA	Unmanned Aircraft
UAC	Unmanned Aircraft Commander
UAS	Unmanned Aircraft System
UMC	UAS Mission Commander
VFR	Visual Flight Rules
VLOS	Visual Line of Sight
VMC	Visual Meteorological Conditions
VNAV	Vertical Navigation
VO	Visual Observer
VOR	Very High Frequency Omni Directional Range
VSI	Vertical Speed Indicator
VTOL	Vertical Takeoff and Landing

EXECUTIVE SUMMARY

The objective of the work was to develop recommendations for minimum unmanned aircraft system (UAS) control station standards and guidelines. The recommendations focused on operation of fixed-wing unmanned aircraft (UA) larger than 55 lb. operated beyond visual line of sight in an integrated National Airspace System (NAS). The research approach included (1) development of recommendations for minimum human-automation function allocation, (2) identification of minimum information requirements for safe UAS operation in the NAS, (3) storyboard development, and (4) cognitive walkthrough of the storyboards.

The human-automation function allocation work focused on taxi, takeoff, landing, navigation, communication, contingency, and handover tasks. A task analysis was conducted, and for each task a minimum function allocation recommendation was identified, as well as rationale for the recommendations, potential higher and/or lower levels of automation, and a recommendation for an autonomous mode (which is recommended as a required mode to account for lost command and control link situations). The recommendations were refined via subject matter expert (SME) review; SMEs had experience in varying roles of UAS and traditional manned aircraft operation. While reviewing the recommendations, the SMEs were asked to consider what automation is necessary to compensate for any human factors implications associated with operating the aircraft remotely. Except for lost link, SMEs indicated that tasks necessary to operate the UAS safely in the NAS can be accomplished with regulations similar to those for manned operation; i.e., substantial automation assistance is not required as compared to manned aircraft operation. This input assumes timely and accurate delivery of information to the UAS control station.

The objective of the UAS control station information requirements work was to develop recommendations to support control station standards and guidelines for integrating UAS into the NAS. To inform the recommendations, the function allocation recommendations and a control station literature review conducted as part of Project A7 were leveraged. The function allocation recommendations and literature review were used to create a database of potential information elements necessary for UAS operation in the NAS. Two taxonomies were created to categorize the information elements: one reflecting the level of availability of the information element, and one identifying the agent(s) with control over changing the information element. All of the information elements identified from the function allocation recommendations and Project A7 literature review were categorized using the two taxonomies, and reviewed by SMEs with a range of experience in various manned and unmanned operational roles. The results yielded recommendations for control station standards and guidelines for minimum information elements for safe UAS operation in the NAS, as well as potential directions for future research.

Storyboards were developed to support the cognitive walkthrough work. In the first step of the work, a set of use cases representing UAS operation in the NAS were developed, including identification of the sequence of steps required to transition the system from its initial state to the goal state. This sequence of steps was used to develop the storyboards. Storyboards for three scenarios were developed, including (1) UAS operation departing from and arriving to the same airport with low traffic volume, (2) UAS diversion to an alternate airport with low traffic volume, and (3) a ferry UAS operation departing from one airport and arriving at another airport with low traffic volume.

The cognitive walkthroughs leveraged the storyboards to provide data to support the recommendations developed in the function allocation and information requirements work. SMEs were sent the storyboards via email, along with instructions and probes to solicit feedback for UAS control station design recommendations. In many cases, the SME feedback corroborated the recommendations developed in the function allocation and information requirements work. In other cases, the presentation of the specific contexts provided by the storyboards triggered input from the SMEs that was not consistent with the recommendations developed in the function allocation and control station work. The final recommendations were updated based on these results.

One theme that emerged from the work was that for many functions, UAS can be operated in the NAS with comparable function allocation strategies, automation, and information requirements to manned operation. One main difference is the use of a visual observer for obstacle avoidance when operating on the surface as well as during takeoff, initial climb out, final approach, and landing. Another main difference is what information should be presented for UAS operation at the control station. Key recommendations in this area include (1) presentation of obstacle information when flying close to the ground and for ground operations, including a dynamic surface display with overlaid ownship position during taxi, takeoff, and landing; (2) presentation of terrain information; and (3) presentation of altitude above ground level. Other differences involve contingency planning for situations unique to unmanned operation, such as lost command/control link, degraded UA position reporting, loss of contingency flight planning automation when the UA is airborne, and loss of communications with the visual observer. Other differences arise due to the unique procedures related to the ability to hand over control of a UA from one control station to another during flight.

The work performed to identify recommendations for minimum function allocation strategies and minimum information requirements, and the preliminary assessment of the recommendations via storyboard development and cognitive walkthroughs, represent a very early stage of the system design process. Future work needs to be conducted to validate the recommendations, including (but not limited to) more thorough cognitive walkthroughs with a broader range of SMEs and human-in-the-loop experimentation via part-task simulations and full-flight simulations. Beyond further testing of the recommendations developed as part of the present effort, future work should apply the methodology used to guide the present work to UAS operational areas beyond the scope of this work, such as other phases of flight, UA with alternate flight characteristics, platform-specific requirements, and alternate crew and control station configurations. More detailed areas of future work are contained in the *Future Work* section of this report and throughout the Appendices.

1. INTRODUCTION

This project report focuses on the development of recommendations for minimum control station standards and guidelines for the operation of fixed-wing UAS greater than 55 pounds and capable of using the existing National Airspace System (NAS) infrastructure. It covers beyond line of sight (BLOS) operations for unmanned aircraft. The project leverages the functional allocation and workstation recommendations from Project A7, for which the goal was to help the FAA address the questions "What are the recommended function allocation strategies for UAS human-machine functions?" and "What are the recommended minimum standards and design guidelines for UAS control stations?" for aviate tasks (manage horizontal flight path, manage altitude, manage vertical speed, manage airspeed, and configure the unmanned aircraft (UA) to aviate during climb out, cruise, descent, and approach). This project report addresses the following contexts: taxi, takeoff, landing, navigate, communicate, four contingencies unique to unmanned operation, and handover of control. It addresses these contexts with five synergistic tasks:

- Task CS-1: Function allocation recommendations for taxi, takeoff, and landing tasks
- Task CS-2: Function allocation recommendations for navigation, communication, contingency, and handover tasks
- Task CS-3: Recommendations for minimum control station human factors considerations
- Task CS-4: Development of storyboards to support cognitive walkthroughs
- Task CS-5: Refinement and extension of workstation design requirements and guidelines based on cognitive walkthroughs

1.1 BACKGROUND

The use of automation is a key enabler for the integration of UAS into the NAS. Due to the remote location of the pilot and the wide array of uses of UAS, control stations may need to facilitate pilot control of a UAS via new and different automated functions (e.g., automation that controls the UA during lost command and control link situations). Function allocation is a process which examines a list of functions that the human-machine system needs to execute in order to achieve operational requirements, and determines whether the human, machine (i.e., automation), or some combination should implement each function. Function allocation has key implications on safety and performance and must be investigated first in order to address control station design. There is a large research base of information about human factors issues associated with automation systems and there is a need to identify the specific human factors requirements in certifying civil UAS automation systems. In Project A7, Pankok and Bass (2016) developed an enhanced function allocation taxonomy in the deliverable "Function Allocation Literature Review". The function allocation strategies taxonomy coupled with task analyses were applied in this project to help determine levels of automation across taxi, takeoff, landing, navigation, communication, contingencies.

The function allocation determines which functions should be accomplished via UAS control station automation, automation on the UA, the remote pilot in command (RPIC), and other system agents. From that analysis, one can develop recommendations for information requirements (as a result of function allocation) and design guidelines. That is, as a result of function allocation research, the information needed by the pilot to perform those functions can be determined and the strategies to display that information via the human-machine interface (HMI) can be developed. However, the control of UAS presents a set of human factors related challenges that should be considered in developing the recommended minimum standards and design guidelines for UAS control stations. As UAS pilots receive information regarding the state and health of their aircraft solely through electronic displays, they have reduced sensory cues as compared to pilots of conventional aircraft (Williams, 2008). Auditory information, visual and peripheral vision cues, spatial and vestibular information, proprioceptive and kinesthetic information, smell and related sources useful to conventional pilots are not easily available. This situation, coupled with communication latencies, makes it difficult for UAS pilots to recognize and diagnose anomalous flight events that could endanger the safety of the flight. In addition, information related to loss of data link, an anomalous event associated only with unmanned aircraft operation, is critical to UAS safety, so information such as strength of data link connection becomes critical.

In order to conduct evaluations early in the process, cognitive walkthrough using storyboards is helpful. Storyboards are realizations that can capture the human-automation interaction features across multiple use cases within individual scenarios. Completion of cognitive walkthroughs with UAS subject matter experts using the storyboards refine the information requirements. For the cognitive walkthrough, scripts define the goal to be accomplished. The participant then uses the storyboard to identify available actions, selects the action that seems likely to make progress toward the goal, and discusses what system feedback may be appropriate.

1.2 PROJECT SCOPE

The recommendations were developed under the following assumptions:

- The UA is a fixed-wing aircraft larger than 55 lb.
- The UAS is capable of flying instrument flight rules (IFR) in an integrated NAS, including standard takeoff and approach procedures.
- The UA flies beyond visual line of sight (BVLOS).
- The RPIC does not have visual sight lines of the airport taxiways and runways.
- A visual observer (VO) is required and is located at the airport to communicate with the RPIC and to monitor the UA as it performs taxi, takeoff, approach, and landing tasks.
- The *Integration of Unmanned Aircraft Systems into the National Airspace System: Concept of Operations* (Federal Aviation Administration, 2012) requires all UAS to be equipped with Automatic Dependent Surveillance-Broadcast (ADS-B) (Out) capability, so the recommendations assume that the UAS, at minimum, uses this technology for navigation.
- The UA is operated in Visual Meteorological Conditions (VMC), so the impact of weather conditions such as cloud coverage, cloud height, icing, precipitation, convective weather, and visibility are not addressed in the recommendations.
- Operation at both towered and non-towered airports is examined. Specifically, the work covers airport operations in Classes D and G airspace.
- The different types of turbulence (caused by the environment or other aircraft) are not accounted for in the recommendations.

- Automation for ground and air sense-and-avoid tasks were not part of the scope of this work.

The team considered the general requirements and assumptions published in the Federal Aviation Administration (2013) *Integration of Civil Unmanned Aircraft Systems in the National Airspace System Roadmap* listed below (note that roadmap assumptions are designated by the letter *R* followed by the assumption number).

R1. RPICs comply with existing, adapted, and/or new operating rules or procedures as a prerequisite for NAS integration.
R2. Civil UAS operating in the NAS must obtain an appropriate airworthiness certificate while public users retain their responsibility to determine airworthiness.
R3. All UAS file and fly an Instrument Flight Rules (IFR) flight plan.
R4. All UAS are equipped with ADS-B (Out) and transponder with altitude-encoding capability. This requirement is independent of the FAA's rule-making for ADS-B (Out).
R5. UAS meet performance and equipage requirements for the environment in which they are operating and adhere to the relevant procedures.
R6. Each UAS has a flight crew appropriate to fulfill the operators' responsibilities, and includes a RPIC. Each RPIC controls only one UA.
R7. Fully autonomous operations are not permitted. The RPIC has full control, or override authority to assume control at all times during normal UAS operations.
R8. Communications spectrum is available to support UAS operations.
R9. No new classes or types of airspace are designated or created specifically for UAS operations.
R10. Federal Aviation Administration (FAA) policy, guidelines, and automation support air traffic decision-makers on assigning priority for individual flights (or flight segments) and providing equitable access to airspace and air traffic services.
R11. Air traffic separation minima in controlled airspace apply to UA.
R12. Air Traffic Control (ATC) is responsible for separation services as required by airspace class and type of flight plan for both manned and unmanned aircraft.
R13. The RPIC complies with all ATC instructions and uses standard phraseology per FAA Order 7110.65 and the Aeronautical Information Manual (Federal Aviation Administration, 2014).
R14. ATC has no direct link to the UAS for flight control purposes.

Based on input from the FAA and discussions about the document scope, additional assumptions were considered. These are listed below and are designated by the letter *A* preceding the assumption number.

A1. The RPIC does not simultaneously control any payload onboard the UA (note that activities related to aerial work are outside of the scope).
A2. VFR flight is permitted only when the UA is within visual line of sight (VLOS) of a VO (necessary for takeoff and landing at non-towered airports).

A3. Each UA has a maximum crosswind component capability that limits the conditions under which it can depart or land.
A4. The airport has sufficient infrastructure (e.g., reliable power source, ATC communication, etc.) for operating the UAS.
A5. While there may be UAS that use alternative methods for control, like differential engine output and rudder, this document assumes the use of traditional manned aircraft controls and control surfaces.

Additional assumptions are related to communication tasks. These assumptions are designated by the letter *C* preceding the assumption number.

C1. Communication with VO always occurs via voice communication.
C2. We do not specify a communication medium between the RPIC and ATC (i.e., datalink vs. radio frequency). Selecting a recipient and communicating with the recipient (either with datalink or radio frequency) is considered the lowest level of communication automation.
C3. VOs are not required to have direct transmit capability with ATC but may have receiving capabilities.

Additional assumptions are related to handover tasks: transfer of control from one remote pilot at a control station (i.e., transferring CS) to a second remote pilot located at a second control station (i.e., receiving CS). The recommendations related to handover (designated by the letter *H* preceding the assumption number) are subject to the following assumptions with respect to the roles and communication:

H1. Voice communication is used to coordinate the handover.
H2. Synchronous communication occurs between the transferring and receiving control stations.
H3. Only the RPICs are actively involved in the handover. If the crew contains any sensor/mission operators, their workstations do not contain any critical functionality that would be required during a handover.
H4. At no point during the handover is there a loss of voice communication between the control stations.
H5. A CS performing a handover contains, at minimum, three independent communication systems: one for communication with ATC, one for communication with VO, and one for communication with other CSs. The system for communicating with other CSs may not be required for UASs that do not perform handover of control.

The recommendations related to handover also assume that transfers will only occur under the following flight and airspace conditions:

H6. The UA is on straight and level flight; handover must be completed before the UA initiates any turns or changes in altitude.
H7. There should be a minimum altitude only above which transfer of control is permitted (except in the case of an emergency).

H8. There are no ATC instructions or compliance issues that need to be resolved.
H9. Handovers do not occur in congested airspace.
H10. Handovers do not occur during emergency or critical situations (unless the handover itself is part of the emergency or critical checklist sequence).

The handover recommendations assume limited UAS capability:

H11. The UA contains only one uplink and downlink connection and thus the handover of control and the transfer of relevant UA state information must be performed predominately via two-way communication between the RPICs located at the transferring and receiving CSs.
   a. If there are two links, then the UAS has a primary and secondary link, and the links would need to be identified as such (i.e., primary link and secondary link).
   b. The UA does not contain automation that checks the accuracy of the settings on the receiving CS. Procedures are required to ensure safety.
H12. The receiving UA does not have transfer of control override authority.

1.3 DOCUMENT STRUCTURE

Section 2 of this document contains a high-level overview of the methodology used to complete the work, Section 3 contains potential directions for future research, and Section 4 contains key points from the work. Following the key points, appendices contain the details of the work conducted as part of Project A10. Each appendix serves as a stand-alone document, with its own introduction, detailed description of the methodology, results, and recommendations (where applicable).

2. METHODOLOGY

The methodology used to develop recommendations for minimum control station standards and guidelines for the operation of fixed-wing UAS larger than 55 pounds and capable of using the existing NAS infrastructure in BLOS operations followed a multiple research task process. Each research task benefitted from review from subject matter experts (SMEs) with traditional manned aircraft and unmanned aircraft experience.

For each set of functions (i.e., taxi, takeoff, and landing for task CS-1 and navigation, communication, contingency, and handover for task CS-2), the first research task involved development of recommended function allocation strategies for UAS human-machine functions. The generic strategies were identified during Project A7 (Pankok, Bass, Smith, Dolgov, & Walker, 2017). Then, for each function considered in Project A10, a task analysis was developed and the Project A7 taxonomy was applied. The results were reviewed by SMEs. SME comments were incorporated into the results. Details of the methods for taxi, takeoff, and landing tasks appear in Appendix A, and details of the methods for navigation, communication, contingency, and handover tasks appear in Appendix B.

The second research task was to identify potential information elements. A taxonomy was developed to refine the notion of “minimum” to categorize the information elements with respect to recommended availability. In addition, the information elements were analyzed with respect to control and feedback, and a second taxonomy was developed to categorize information elements for this purpose. Recommendations were reviewed by a collection of SMEs with a range of manned and unmanned experiences. SME comments were incorporated into the results. Details of the methods appear in Appendix C.

The third research task was the development of storyboards to support cognitive walkthroughs. An approach defined by Lewis and Wharton (1997) and refined by Smith, Stone, and Spencer (2006) was utilized, which included (1) identification of use cases, (2) defining the process used to meet the system goal state, and (3) translating the process into a storyboard. Details of the methods appear in Appendix D.

The fourth research task was refinement and extension of the recommendations for minimum control station standards and guidelines based on the results from the walkthroughs. In this research task, SMEs were asked to review the storyboards individually and answer questions about potential scenarios. SME responses were recorded, and their recommendations for control station design were compared to the recommendations solicited in the function allocation recommendations and recommended control station information requirements. Details of the methods appear in Appendix E.

3. FUTURE WORK

The work presented in this document represents early stages in the development of recommendations for minimum control station regulations. Minimum function allocation strategies and information requirements were developed using inputs including literature, exemplar control stations, and SME review. The recommendations were evaluated with cognitive walkthroughs conducted electronically (i.e., via editable document exchange and email communication).

Future work should involve evaluation of the methods used to develop the minimum function allocation recommendations, including recruitment of SMEs with a larger range of skills and experience, and additional storyboarding and cognitive walkthroughs.

Similarly, future work should be conducted to evaluate the methods used to identify minimum information requirements for UAS control stations. Regarding the sources used to identify the information elements, a more thorough review of operational and experimental control stations could be performed. This evaluation would also benefit from review by SMEs with a larger range of skills and experience, additional storyboarding and cognitive walkthroughs, and mock-ups of control station interfaces.

Future work should include walkthroughs via face-to-face meeting or via phone with structured interviews and probes. As the scope is expanded beyond that defined by A10 to include more complex and congested airport and airspace operations, the value of cognitive walkthroughs becomes increasingly important. The use of concrete examples (represented as storyboards) in cognitive walkthroughs serves to provide a context to help ensure that both domain experts and human factors experts fully consider important interactions of the operators with the technologies (including richer human-automation interactions), with the full range of varied environments, and with each other.

Beyond cognitive walkthrough, further validation and verification of the recommendations should be conducted via human-in-the-loop experimentation. Part-task and full flight simulations should be designed to test the function allocation strategy and information recommendations.

The methods developed to identify minimum human-automation function allocation recommendations and associated information requirements can be applied to other topic areas relevant to UAS operation for which the system design process is in its infancy. Project A10 addresses recommendations for taxi, takeoff, landing, navigation, communication, contingency, and handover of control. Future work should apply the Project A10 methodology to the following phases of flight not covered by the Project A10 work:

- ground-based and/or airborne detect and avoid systems,
- pre-flight planning, and
- abnormal and emergency situations in addition to the four contingency situations addressed in the Project A10 work, such as aircraft component failure or malfunction.

Operating a UAS under real-world conditions may impose varying workload demands on the RPIC. Future work should address how varying workload demands influence minimum requirements.

The focus of the Project A10 work was on operation of a fixed-wing UA larger than 55 lb that can fly standard airport patterns and comply with ATC clearances. Recommendations for minimum function allocation strategies and information requirements should also be investigated for different types of aircraft (such as rotorcraft and vertical takeoff and landing UA), as well as UA with capabilities that differ from our assumptions, including:

- takeoff that does not require a runway (e.g., takeoff via catapult or launcher),
- landing that does not require a runway (e.g., landing via net capture or sky hook), and
- UA incapable of complying with ATC clearances.

The recommendations were developed to be applicable to all potential UAS platforms, so platform-specific items were not addressed, including health and status information, automated control modes, and specific control devices. Function allocation and information requirements should be developed for more platform-specific contexts, including:

- status of the various systems required to operate the UA (e.g., powerplant, fuel system, electrical system, hydraulic system, and oil system),
- differing control modes, and
- various UAS control devices.

The recommendations assumed that the UAS was operated by a single RPIC that did not have direct sight lines of the airport, requiring assistance from a VO for taxi, takeoff, and landing. Future work should address minimum function allocation strategies and information requirements for alternate control station and crew configurations, such as:

- RPIC with direct visual line of sight of the airport;
- takeoff and/or landing without a VO; and
- operation requiring interaction with other crewmembers, such as a co-pilot, payload operator, mission commander, or collocated VO.

The recommended function allocation strategies and information requirements covered operation at non-towered airports (for both takeoff and landing), with low volume airport traffic, transition from VFR to IFR after takeoff, and transition from IFR to VFR prior to landing. The methodology developed as part of A10 should be applied to alternate environmental contexts, including:

- takeoff and landing at towered airports,
- operation of a UA in high density airspace, and
- instrument departure and arrival procedures.

The current work addresses requirements assuming the RPIC communicates with a VO and ATC via voice radio communication. Function allocation strategies and information requirements may differ for other communication mediums, such as direct voice contact or data communications.

4. KEY POINTS

The following list of key points summarizes the work. The key points are organized by CS task. Note: there were no key points for storyboard development.

4.1 KEY POINTS FROM CS-1

The tables below summarize the function allocation recommendations for taxi, takeoff, and landing tasks by indicating the recommended agent or agents (RPIC, visual observer, alerting automation, and/or control automation) to complete the sub-tasks. The left column of each table contains the task, and to the right of the task is an "X" in the column reflecting the agent to which the task is allocated in the recommendations. Note that no tasks are allocated to alerting automation or control automation, as SME feedback suggested that the tasks could be performed safely by the RPIC and/or VO without assistance from automation. Also note that where appropriate, communication between RPIC and VO has been added, although communication tasks are covered in CS-2. These tables are reproduced from the *Summary of the Recommendations* section in Appendix A.

4.1.1 Taxi Out

Table 1. Overview of CS-1 function allocation recommendations for taxi out tasks.

Task	RPIC	VO	Alerting Automation	Control Automation
Obtain taxi route, including destination	X			
Ensure instruments, avionics, and navigation equipment are functioning properly and are ready for flight	X			
Perform brake check	X			
Control UA speed along taxi route	X			
Control UA track along taxi route	X			
Monitor UA trajectory for obstacles		X		
Configure UA for takeoff	X			
Check for proper flight control surface movement		X		
Turn on required lights	X			
Communication between VO and RPIC	X	X		

4.1.2 Takeoff

Table 2. Overview of CS-1 function allocation recommendations for takeoff tasks.

Task	RPIC	VO	Alerting Automation	Control Automation
Position aircraft for takeoff in the appropriate configuration	X			
Smoothly advance power to takeoff (full) thrust	X			
Observe UA indicators operating normally and not exceeding any limits	X			
Maintain runway centerline	X			
Monitor UA airspeed in relation to scheduled takeoff speeds	X			
Lift off/rotate	X			
Check for positive rate of climb	X			
Configure aircraft for climb out	X			
Communication between VO and RPIC	X	X		

4.1.3 Landing

Table 3. Overview of CS-1 function allocation recommendations for landing tasks.

Task	RPIC	VO	Alerting Automation	Control Automation
Configure UA for landing	X			
Landing decision	X			
Reduce power to thrust required for landing	X			
Ensure UA is in safe location for landing	X			
Perform landing/touchdown	X			
Maintain runway centerline	X			
Slow UA to taxi speed	X			
Determine runway turn-off	X			
Turn UA off runway	X			
Communication between VO and RPIC	X	X		

4.1.4 Taxi In

Table 4. Overview of CS-1 function allocation recommendations for taxi in tasks.

Task	RPIC	VO	Alerting Automation	Control Automation
Obtain taxi route, including destination	X			
Configure UA for taxi	X			
Control UA speed along taxi route	X			
Control UA track along taxi route	X			
Monitor UA trajectory for obstacles		X		
Communication between VO and RPIC	X	X		

4.2 KEY POINTS FROM CS-2

The tables below summarize the function allocation recommendations for navigation, communication, contingency, and handover tasks by indicating the recommended agent to complete the sub-tasks. The left column of each table contains the task, and to the right of the task is an "X" in the column reflecting the agent to which the task is allocated in the recommendations. Note that few tasks are allocated to alerting automation or control automation, as SME feedback suggested that most of the tasks could be performed safely by the RPIC and/or VO without assistance from automation. These tables are reproduced from the *Summary of the Recommendations* section in Appendix B.

4.2.1 Takeoff

Table 5. Overview of CS-2 function allocation recommendations for takeoff tasks.

Task	RPIC	VO	Alerting Automation	Control Automation
Communicate with VO to ensure runway is clear for takeoff	X	X		
Announce takeoff via CTAF	X			

4.2.2 Climb Out

Table 6. Overview of CS-2 function allocation recommendations for climb out tasks.

Task	RPIC	VO	Alerting Automation	Control Automation
Verify top of climb	X			
Communicate with VO and ATC to coordinate handover of separation responsibility from VO to ATC	X	X		

4.2.3 Descent

Table 7. Overview of CS-2 function allocation recommendations for descent tasks.

Task	RPIC	VO	Alerting Automation	Control Automation
Obtain airport data	X			
Communicate with ATC to obtain descent clearance	X			
Determine descent profile	X			
Determine top of descent	X			
Announce landing on runway via CTAF	X			
Communicate with VO and ATC to coordinate handover of separation responsibility from ATC to VO	X	X		

4.2.4 Approach

Table 8. Overview of CS-2 function allocation recommendations for approach tasks.

Task	RPIC	VO	Alerting Automation	Control Automation
Determine approach profile	X			
Identify touchdown target on first third of the runway	X			
Communication between VO and RPIC	X	X		

4.2.5 Communicate

Table 9. Overview of CS-2 function allocation recommendations for communicate tasks.

Task	RPIC	VO	Alerting Automation	Control Automation
Communicate with external agents, as necessary	X			
Tune communication networks/frequency, as necessary	X			

4.2.6 Navigate

Table 10. Overview of CS-2 function allocation recommendations for navigate tasks.

Task	RPIC	VO	Alerting Automation	Control Automation
Tune applicable navigation avionics, as appropriate	X			
Obtain ATC clearance for route, as needed	X			
Monitor UA position along route	X			
Monitor UA heading along route	X			
Monitor UA altitude along route	X			
Determine necessary route/trajectory changes	X			
Implement route/trajectory changes	X			

4.2.7 Manage System Health and Status

Table 11. Overview of CS-2 function allocation recommendations for manage system health and status tasks.

Task	RPIC	VO	Alerting Automation	Control Automation
Pre-flight systems management and checks	X			
Monitor system health and status			X	
Perform system health and status intervention	X			
Inform ATC and/or VO, if necessary	X	X		

4.2.8 Lost Command and/or Control Link Contingency

Table 12. Overview of CS-2 function allocation recommendations for lost link contingency tasks.

Task	RPIC	VO	Alerting Automation	Control Automation
Plan lost link contingency and upload to the UA	X			
Update contingency plan during flight, as necessary	X			
Monitor link status	X			
Detect lost link situation			X	
Identify action(s) that the UA will take, based on the current contingency plan	X			
Communicate UA status and contingency plan with external agents	X	X		

4.2.9 Degraded Ground Position Information Reporting Contingency

Table 13. Overview of CS-2 function allocation recommendations for degraded ground position reporting contingency tasks.

Task	RPIC	VO	Alerting Automation	Control Automation
Plan contingencies for ground operations with degraded position information	X			
Monitor navigation system and UA position/navigation information	X			
Detect degraded UA position/navigation reporting			X	
Identify action(s) required	X			
Communicate issue, contingency plan, and UA status with external agents	X	X		
Execute contingency plan	X			

4.2.10 Degraded Airborne Position Reporting Contingency

Table 14. Overview of CS-2 function allocation recommendations for degraded airborne position reporting contingency tasks.

Task	RPIC	VO	Alerting Automation	Control Automation
Plan contingencies for flight operations with degraded position/navigation information	X			
Update contingency plan/procedure during flight, as necessary	X			
Monitor navigation system and UA position/navigation information	X			
Detect degraded UA position/navigation reporting			X	
Identify action(s) required, based on the current contingency plan/procedure	X			
Communicate issue, contingency plan, and UA status with external agents	X	X		
Execute contingency plan				X

4.2.11 Loss of Contingency Flight Planning Automation

Table 15. Overview of CS-2 function allocation recommendations for loss of contingency flight planning automation tasks.

Task	RPIC	VO	Alerting Automation	Control Automation
Generate plan for airborne loss of contingency planning automation	X			
Detect loss of contingency planning capability	X			
Communicate with crew, VO, and/or ATC about loss of contingency planning automation and the plan that will be executed	X	X		
Execute plan/procedure for loss of contingency planning capability	X			
Monitor status of contingency automation capability	X			

4.2.12 Visual Observer Failure Contingency

Table 16. Overview of CS-2 function allocation recommendations for visual observer failure contingency tasks.

Task	RPIC	VO	Alerting Automation	Control Automation
Plan for loss of VO assistance	X			
Communicate with VO to monitor VO status	X	X		
Identify action(s) required, based on the current contingency plan	X			
Communicate issue and contingency plan with external agents	X	X		
Execute contingency plan	X			
Update ATC on status, as necessary	X			

4.2.13 Handover of Control

Table 17. Overview of CS-2 function allocation recommendations for handover tasks.

Task	RPIC	VO	Alerting Automation	Control Automation
Receiving and transferring RPICs establish two-way voice communication	X			
Receiving and transferring RPICs coordinate handover procedure and timing	X			
Receiving RPIC retrieves UA status and settings	X			
Transferring RPIC provides handover briefing to the receiving RPIC	X			
Positive transfer of control from transferring CS to receiving CS	X			
Receiving RPIC confirms full control of the UA	X			
Transferring RPIC stands by as a backup	X			

4.3 KEY POINTS FROM CS-3

The recommendations contained in this section are reproduced from the *Recommendations* section in Appendix C. The control station should have capability to display the following information elements at all times:

Table 18. Information elements that are recommended to be always displayed.

Active communication radio
Aircraft external lights status
Aircraft ID
Altimeter setting

Altitude above ground level (absolute)
Command sent status
Command/control downlink connection status
Command/control downlink signal strength
Command/control link frequency
Command/control link strength safe operating range/location
Command/control uplink connection status
Command/control uplink signal strength
Communication channel (ATC)
Communication frequency (ATC)
Contingency flight planning automation system status
Control device position
Flight mode annunciation
Indicated airspeed
Indicated altitude
Landing gear control position
Landing gear status
Latitude
Lift/drag device position
Lift/drag device position target
Longitude
Magnetic heading
Maximum flaps extended speed (V_{FE})
Maximum landing gear operating speed (V_{LO})
Maximum operating limit speed (V_{MO})
Maximum operating maneuvering speed (V_{O})
Maximum speed for normal operations (V_{NO})
Never-exceed speed (V_{NE})
Pitch attitude
Roll attitude/bank angle
Slip/skid
Stall speed (V_{S})
Stall speed in landing configuration (V_{S0})
Throttle position
Thrust reverser position
Time of day
Transponder code
Transponder status
Trim device position
Vertical speed

4.4 KEY POINTS FROM CS-4

There were no key points from CS-4 since the objective was solely to develop storyboards for use in CS-5 (i.e., no recommendations were developed).

4.5 KEY POINTS FROM CS-5

The recommendations from the cognitive walkthrough process indicated the following:

1. Require CS to include a display showing a top-down view of the airport surface with the UA's current position indicated dynamically on this surface display. Note that this requirement is more stringent than the one proposed in CS-3.
2. Require certification for VOs to ensure clear understanding of communication protocols, roles and responsibilities, and an understanding of scenarios where risks are higher in order to increase vigilance for such scenarios.
3. Require reliable two-way communication between the RPIC and VO. Note that the technological solutions to this are not directly human factors issues.
4. Require procedures and/or technological solutions that ensure that the detection of a loss of the primary communication channel between the RPIC and VO is noted and handled in a timely and appropriate fashion.
5. The VO must be placed so as to have full visibility of the airport surface as well as departure and arrival airspace. Since changes in runway configuration are a routine practice, such placement of the VO must take this into consideration.
6. Since the VO (as a non-FAA function) is not likely to be located in the ATC Tower and since many of the airports involved do not have airline ramp towers, the possibility of another aircraft or vehicle blocking the line of sight must be considered. Procedures need to be defined to guide VO and RPIC responses when this happens.
7. Information regarding planned or current altitude above terrain should be required.
8. While views from cameras might be useful in some situations, within the scope of A10, there was no strong argument to require them as minimum human factors requirements.
9. For an IFR flight landing and departing in Class G and Class D airspace, there will be aircraft that do not have ADS-B (Out) and furthermore do not have a transponder and radio. ADS-B will not provide information regarding the presence of these aircraft. The recommendations for requirements for a VO to support taxi, arrival, and departure operations, along with required interaction with ATC to fly IFR once airborne (as documented in the report for CS-1) provide adequate minimum standards for taxi, departure, and arrival operations without requiring ADSB (In).

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APPENDIX A—TASK CS-1: FUNCTION ALLOCATION RECOMMENDATIONS FOR TAXI, TAKEOFF, AND LANDING TASKS

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ACKNOWLEDGEMENTS

The authors thank Ashley Awwad, Igor Dolgov John Bridewell, Andrew Shepherd, Richard S. Stansbury, and Stephen “Lux” Luxion for their feedback on earlier versions of this document. The authors also thank the A10 subject matter expert pilot reviewers: Joe Cerreta (Embry Riddle Aeronautical University), Paul Snyder (University of North Dakota), Amanda Brandt (University of North Dakota), Joseph Millette (New Mexico State University), Gary Ullrich (University of North Dakota), Reuben Burch (Mississippi State University), and Kurt Carraway (Kansas State University).

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EXECUTIVE SUMMARY

The objective of A10 Task CS-1, *Function Allocation Recommendations for Taxi, Takeoff, and Landing* was to provide minimum human-automation function allocation recommendations for takeoff, taxi and landing for fixed-wing unmanned aircraft (UA) larger than 55 lb, including transition to/from IFR while the UA is within the visual observer's (VO) visual line of sight limit. The purpose of the task was to explore how removing the pilot from the airplane changes the nature of the tasks performed by the pilot.

A task analysis addressing taxi out, takeoff, landing, and taxi in was used to guide the function allocation recommendations. The work leveraged envisioned aircraft procedures developed as part of the larger A10 project as appropriate. For each task, we identified a recommended functional requirement as well as a minimum human-automation function allocation recommendation (the minimum automation recommendation was more technology-specific than the functional recommendation, which is capability-centered). We also provided rationale for the recommendations including potential safety implications. We included potential higher and/or lower levels of automation than the minimum function allocation recommendation when appropriate. We also provided an autonomous mode function allocation recommendation in the event of lost control link.

The work was refined via feedback from nine Subject Matter Experts (SMEs) who had experience in varying roles of unmanned aircraft system (UAS) and manned aircraft operation, including but not limited to remote pilot in command (RPIC), control station designer, manned/unmanned flight instructor, manned/unmanned test pilot, certified pilot, and RPICs with UAS research experience. Thus, the SMEs were able to provide feedback from the perspective of various stakeholders in the UAS community. SMEs considered whether the task necessitates a regulation and whether they agreed with the recommendation. They were asked to consider what automation is necessary to compensate for any human factors implications associated with operating the aircraft remotely. To help provide some context, they were asked to consider typical flying conditions including if wind is a relevant concern for the task. SME feedback was incorporated into the recommendations and non-supporting inputs were noted.

Several overarching themes were prevalent in the SME feedback. Overall, SMEs indicated that taxi, takeoff, and landing tasks can be accomplished with minimum function allocation strategies similar to those for manned operation; i.e., substantial automation assistance is not required compared to manned aircraft operation. This recommendation assumes, however, timely and accurate delivery of information to the UAS control station.

1. INTRODUCTION

This document focuses on human-automation function allocation recommendations for taxi, takeoff, and landing. Section 2 provides the scope of the recommendations, Section 3 provides the methodology, and Section 4 contains a task analysis of the taxi, takeoff, and landing phases of flight. Section 5 contains general function allocation strategies used to guide our function allocation recommendations, and Section 6 provides minimum function allocation recommendations for the safe achievement of the relevant tasks.

2. SCOPE AND ASSUMPTIONS

The recommendations were developed under the following scope:

- The unmanned aircraft (UA) is a fixed-wing aircraft larger than 55 lb.
- The UAS is capable of flying instrument flight rules (IFR) in an integrated National Airspace System (NAS), including standard takeoff and approach procedures.
- The UA flies beyond visual line of sight (BVLOS).
- The remote pilot in command (RPIC) does not have visual sight lines of the airport taxiways and runways.
- A visual observer (VO) is required and is located at the airport to communicate with the RPIC and to monitor the UA as it performs taxi, takeoff, approach, and landing tasks.
- The Unmanned Aircraft System (UAS) Integration into the NAS Concept of Operations (Federal Aviation Administration, 2012) requires all UAS to be equipped with Automatic Dependent Surveillance-Broadcast (ADS-B) Out capability, so the recommendations assume that the UAS, at minimum, uses this technology for navigation.
- The UA is operated in Visual Meteorological Conditions (VMC), so the impact of weather conditions such as cloud coverage, cloud height, icing, precipitation, convective weather, and visibility are not accounted for in the recommendations.
- Automation for ground and air sense-and-avoid tasks was not part of the scope of this work.

The team considered the general requirements and assumptions published in the Federal Aviation Administration (2013) UAS integration roadmap listed below (note that roadmap assumptions are designated by the letter *R* followed by the assumption number).

R1. RPICs comply with existing, adapted, and/or new operating rules or procedures as a prerequisite for NAS integration.

R2. Civil UAS operating in the NAS must obtain an appropriate airworthiness certificate while public users retain their responsibility to determine airworthiness.

R3. All UAS file and fly an IFR flight plan.

R4. All UAS are equipped with ADS-B (Out) and transponder with altitude-encoding capability. This requirement is independent of the FAA's rule-making for ADS-B (Out).

R5. UAS meet performance and equipage requirements for the environment in which they are operating and adhere to the relevant procedures.

R6. Each UAS has a flight crew appropriate to fulfill the operators' responsibilities, and includes a RPIC. Each RPIC controls only one UA.
R7. Fully autonomous operations are not permitted. The RPIC has full control, or override authority to assume control at all times during normal UAS operations.
R8. Communications spectrum is available to support UAS operations.
R9. No new classes or types of airspace are designated or created specifically for UAS operations.
R10. FAA policy, guidelines, and automation support air traffic decision-makers on assigning priority for individual flights (or flight segments) and providing equitable access to airspace and air traffic services.
R11. Air traffic separation minima in controlled airspace apply to UAs.
R12. ATC is responsible for separation services as required by airspace class and type of flight plan for both manned and unmanned aircraft.
R13. The RPIC complies with all ATC instructions and uses standard phraseology per FAA Order 7110.65 and the Aeronautical Information Manual (Federal Aviation Administration, 2014).
R14. ATC has no direct link to the UAS for flight control purposes.

Based on input from the FAA and discussions about the document scope, additional assumptions were considered. These are listed below and are designated by the letter *A* preceding the assumption number.

A1. The RPIC does not simultaneously control any payload onboard the UA (note that activities related to aerial work are outside of the scope).
A2. VFR flight is permitted only when the UA is within visual line of sight (VLOS) of a VO (necessary for takeoff and landing at non-towered airports).
A3. Each UA has a maximum crosswind component capability that limits the conditions under which it can depart or land.
A4. The airport has sufficient infrastructure (e.g., reliable power source, ATC communication, etc.) for operating the UAS.
A5. While there may be UAS which use alternative methods for control, like differential engine output and rudder, this document assumes the use of traditional manned aircraft controls, including flaps.

3. METHODOLOGY

A task analysis was conducted for taxi out, takeoff, landing, and taxi in. Function allocation strategy recommendations were developed based on the task analysis and a set of taxonomies developed in prior work (Pankok, Bass, Smith, Dolgov, & Walker, 2017). All recommendations were reviewed by subject matter experts (SMEs).

3.1 TASK ANALYSIS METHODOLOGY

A task analysis was conducted for taxi out, takeoff, landing, and taxi in with respect to safely and efficiently operating a UAS in the NAS. The task analysis was conducted via the creation of potential operational scenarios and the identification of associated sub-tasks, adaptation of manned aircraft procedures to envisioned UA operations when appropriate, and validation by SMEs.

3.2 FUNCTION ALLOCATION METHODOLOGY

To address a gap with respect to methods for the development of minimum function allocation recommendations, Pankok and Bass (Pankok & Bass, 2016; Pankok et al., 2017) developed a function allocation taxonomy based on four stages of information processing (Parasuraman, Sheridan, & Wickens, 2000) and created rubrics for developing minimum function allocation recommendations. The rubrics were designed to address planning tasks, monitoring and situation assessment tasks, communication, and continuous and discrete control tasks as these were necessary to differentiate the minimum function allocation recommendations.

A four-step procedure was utilized to develop function allocation recommendations. First, the tasks identified in the task analysis were grouped into four categories: (1) planning tasks, (2) monitoring and situation assessment tasks, (3) continuous control tasks, and (4) discrete control tasks. Planning tasks involve making decisions in advance of performing the action(s). Monitoring and situation assessment tasks involve the acquisition of the UA state and the interpretation of that information to decide whether actions are needed. Continuous control tasks require a control-feedback loop consisting of monitoring the UA and adjusting the control surfaces to maintain the UA state (e.g., monitoring and adjusting thrust to maintain a prescribed speed). Finally, discrete control tasks do not require extended monitoring and control, such as operating the landing gear or setting the altimeter.

In the second step of the function allocation process, we generated function allocation rubrics for each task category based on the function allocation taxonomy developed as part of a previous UAS function allocation literature review. These rubrics are reported in Section 5.

In step 3, the rubrics were used to create an initial set of function allocation recommendations for safe UAS operation in the NAS. The recommendations reflected the least amount of automation possible to maintain safe flight in normal operations (i.e., minimum function allocation recommendations). For each task, SMEs were presented with a recommended potential function allocation strategy and were asked to provide an explanation for why the recommendation was or was not the minimum level of automation required to perform the task safely in non-segregated airspace, or whether the task should be performed by another human in the system, such as the VO or ATC. In addition to the function allocation recommendations, we included related functional requirements that are independent of the automation and technology available to the RPIC.

Step 4 consisted of the refinement of the function allocation recommendations based on SME input. Dissenting opinions are explicitly recorded in the recommendations.

3.3 SME FEEDBACK METHODOLOGY

Feedback was solicited from nine SMEs with experience in varying roles of UAS operation, including but not limited to experience as a RPIC, control station designers, manned/unmanned flight instructors, manned/unmanned test pilots, FAA certified pilots, and RPICs with UAS research experience (Table 1). Due to these diverse experiences, the collection of SMEs that reviewed the recommendations was able to provide feedback from the perspective of various stakeholders in the UAS community.

Table 1. Subject matter expert professional experience.

ID	Professional Experience
1	Held various positions of authority for multiple manned and unmanned test programs. 50+ aircraft types flown. Chief Engineer/Test Pilot for Aurora Flight Science Centaur OPA/UAS (4,000+lbs). Pilot of world UAS endurance flight record: Aurora Flight Science Orion UAS (80+ hours). Civilian and military instructor and evaluation pilot. Naval Test Pilot School graduate.
2	20 years of experience in the UAS industry, including as the UAS industry program manager at Embry Riddle Aeronautical University. Performed Shadow 200 user assessment. Qualified instructor for RQ-5 (Hunter) and RQ-7 (Shadow).
3	Boeing Insitu–Manufacturer certified ScanEagle UAS pilot. Flight instructor. FAA Designated Pilot Examiner (pilot and instructor). Certified commercial pilot.
4	Commander, 348th Reconnaissance Squadron – Global Hawk. RQ-4 UAS Evaluator and Instructor Pilot.
5	1200 hours of UAS pilot experience on a diverse set of airframes including Aerostar, Viking 300, Tigershark, Hornet Maxi Helicopter, Scout Multi-Copter, Rave A sUAS, Leptron Avenger sUAS, SenseFly eBee Six years as Lead Safety Analyst/Risk Management for New Mexico State University's FAA UAS Test Site. Commercial pilot with instrument and multi-engine ratings.
6	UAS simulator trainer for SAIC and Simlat. UAS course instructor. Commercial Pilot Instrument Multi Engine Rating for Boeing 707 and Boeing 720.
7	UAS patent formation and design for pilot/cockpit technology deployment.
8	Led creation of the Global Hawk training program. Flight instructor and evaluator with vast international experience. Flight Operations Manager and Executive Director of UAS Program at Kansas State University. Professor of flight operations courses at Kansas State University. Contributed to the revision of the UAS degree curriculum at Kansas State University.
9	UAS pilot for University of Alaska Fairbanks and the Pan Pacific UAS test site. Trained on small- and medium-sized UAS. Experience operating Predator B, Tiger Shark, Shadow, ScanEagle, Puma, and Seahunter.

A preliminary version of this Function Allocation document, in editable Microsoft Word format, was sent to the SMEs for their feedback. They were asked to provide feedback on the document, particularly answering the following questions:

- Do you feel strongly that this task necessitates a regulation requiring allocation to automation?
- Does the function allocation recommendation for this task represent the minimum level of automation required for safe UAS operation in an integrated NAS?
- Regarding tasks for which wind is a relevant concern, what should be the minimum automation requirement to compensate for the loss of sensory information (e.g., aircraft movement resulting from a wind gust) associated with dealing with wind gusts while operating the aircraft remotely?

SMEs were asked to provide feedback on the initial recommendations and justification for their responses. The responses recorded for each SME were used to augment the original recommendations. To help provide some context, they were asked to consider typical flying conditions including if wind is a relevant concern for the task. Beyond the ubiquitous nature of wind for flight, providing context to SMEs promotes cognitive engagement in the task (Chi & Bjork, 1991; Klein & Hoffman, 1993). When necessary, SMEs were contacted post-hoc for clarification on their responses. Tasks for which there were dissenting opinions among one or more of the SMEs are explicitly identified in Section 6.

4. TASK ANALYSIS

The taxi, takeoff, and landing tasks in the task analysis are presented below in black and bold text. To help place these tasks in context, other related tasks, such as communication tasks, are presented and colored in gray. In the parenthesis accompanying these other related tasks is the categorization of the task.

4.1 TAXI OUT

1. **Obtain taxi route, including destination (i.e., takeoff runway)**
2. Obtain taxi-out clearance to taxi to destination (Communicate)
3. **Ensure instruments, avionics, and navigation equipment are functioning properly and are ready for flight**
4. **Perform brake check**
5. **Control UA speed along taxi route**
6. **Control UA track along taxi route**
7. **Monitor UA trajectory for obstacles**
8. **Configure UA for takeoff**
9. **Check for proper flight control surface movement**
10. **Turn on required lights (e.g., landing, navigation, and anti-collision lights)**
11. Communicate with VO (or tower controllers at a towered airport), when necessary (Communicate)

4.2 TAKEOFF

1. **Position aircraft for takeoff in the appropriate configuration**
2. Communicate with VO to ensure runway is clear for takeoff (Communicate)
3. Announce takeoff from runway XX on CTAF, specifying that the vehicle is a UA (Communicate)
4. **Takeoff roll**
    a. **Smoothly advance power to takeoff (full) thrust**
    b. **Observe UA indicators operating normally and not exceeding any limits**
    c. **Maintain runway centerline**
5. **Monitor UA airspeed in relation to scheduled takeoff speeds (e.g., V_1, V_2, and V_R)**
6. **Lift off/rotate (e.g., pitch adjustment via elevator manipulation)**
7. **Initial climb**
    a. Maintain assigned/runway heading (Aviate)
    b. Maintain airspeed for best rate of climb (V_Y) (Aviate)
    c. Maintain vertical speed (Aviate)
    d. **Check for positive rate of climb**
    e. **Configure UA for climb out, including monitoring airspeed in comparison to configuration-based airspeed limits (e.g., retracting landing gear or high-lift devices)**

4.3 LANDING

1. **Configure UA for landing (e.g., gear, flaps, and lights)**
2. **Landing decision (at decision height)**
3. **Reduce power to thrust required for landing**
4. **Ensure UA is in a safe location for landing (i.e., over the runway)**
5. **Perform landing/touchdown**
6. **Maintain runway centerline**
7. **Slow UA to taxi speed**
8. **Determine runway turn-off**
9. **Turn UA off runway**

4.4 TAXI IN

1. **Obtain taxi route, including destination (e.g., gate or parking area)**
2. **Configure UA for taxi (e.g., retract flaps and configure lighting)**
3. **Control UA speed along taxi route**
4. **Control UA track along taxi route**
5. **Monitor UA trajectory for obstacles**
6. Communicate with VO (and/or tower controllers), as necessary (Communicate)

5. FUNCTION ALLOCATION RUBRICS

For each of the general task categories, a rubric was created for identifying potential function allocation strategy recommendations. The following subsections present the categories, descriptions, and the potential allocations for each category.

5.1 PLANNING TASKS

Planning involves the acquisition of information, projecting potential future states, and making one or more decisions on when, where, and/or how the UAS will be operated. The implementation of actions to satisfy the plans occurs in the continuous and discrete control tasks. It should be noted that flying the UAS is an adaptive planning task. The RPIC needs to continually plan for potential flight events in order to stay ahead of the aircraft. Potential human-automation function allocations include:

(a) *Manual Planning*: RPIC obtains relevant information, generates one or more potential actions, and selects an action.
(b) *Automated Planning Information Acquisition and Presentation*: Automation provides information to RPIC; RPIC generates one or more potential actions, and selects an action. This type of capability requires information acquisition automation and information analysis automation.
(c) *Automated Planning Option Generation*: Automation obtains relevant information and generates one or more potential actions; RPIC selects an action. This type of capability requires information acquisition automation, information analysis automation, and decision and action selection automation.
(d) *Automated Planning*: Automation obtains relevant information, generates one or more potential actions, selects an action, and informs the RPIC. This requires all four types of automation.

5.2 MONITORING AND SITUATION ASSESSMENT TASKS

Monitoring tasks represent both periodic monitoring (e.g., regular scanning of UAS instruments) as well as monitoring in response to an action or alert (e.g., monitoring airspeed after increasing thrust). Monitoring tasks encompass only the information acquisition and information analysis stages of information processing. No decisions are generated or made in these stages; the information gained from monitoring is used to make decisions for the control tasks in the decision and action selection and action implementation stages (reported in Sections 5.3 and 5.4). Since the UA is flying BVLOS, the RPIC does not have the ability to perceive UA state data directly, so UAS automation provides the current UA state in all potential human-automation function allocations listed below. A label in italic text, accompanied by a description of the function allocation strategy, is provided below:

(a) *State*: Automation provides current UA state via the control station; RPIC compares UA state to target state, expected state, and/or threshold for safe operation.

(b) *Filtered State*: Automation provides current UA state via the control station, subject to constraint(s) (e.g., filter settings) set by the RPIC; RPIC compares UA state to target state, expected state, and/or threshold for safe operation.
(c) *State and Comparison State*: Automation provides UA state as well as target state, expected state, and/or threshold for safe operation via the control station; RPIC compares UA state to threshold for safe operation. This type of capability requires information acquisition automation and information analysis automation.
(d) *Filtered State and Comparison State*: Automation provides UA state, subject to constraint(s) (e.g., filter settings) set by the RPIC, as well as target state, expected state, and/or threshold for safe operation via the control station; RPIC compares UA state to target state, expected state, and/or threshold for safe operation. This type of capability requires information acquisition automation and information analysis automation.
(e) *Automated Comparison*: Automation compares UA state to target state, expected state, and/or threshold for safe operation, and this information is reported to the RPIC via the control station. This type of capability requires information acquisition automation and information analysis automation.
(f) *Filtered Automated Comparison*: Automation compares UA state, subject to constraint(s) (e.g., filter settings) set by the RPIC, to target state, expected state, and/or threshold for safe operation, and this information is reported to the RPIC via the control station. This type of capability requires information acquisition automation and information analysis automation.
(g) *Automated Comparison and Alert*: Automation compares UA state to target state, expected state, and/or threshold for safe operation and alerts the RPIC if the UA state approaches any threshold related to achieving the target state, expected state, and/or threshold for safe operation via the control station. This type of capability requires information acquisition automation and information analysis automation.
(h) *Filtered Automated Comparison and Alert*: Automation compares UA state, subject to constraint(s) (e.g., filter settings) set by the RPIC, to target state, expected state, and/or threshold for safe operation, and alerts the RPIC if the UA state approaches any threshold related to achieving the target state, expected state, and/or threshold for safe operation via the control station. This type of capability requires information acquisition automation and information analysis automation.

Examples of current UA states and corresponding planned states and/or thresholds for safe operation are presented in Table 2.

Table 2. Examples of current UA state, target/expected state, and threshold for safe operation referenced in the potential function allocation strategies for monitoring tasks.

Current UA State	Target/Expected State	Threshold for Safe Operation
Airspeed	Target airspeed	Maximum structural cruising speed (V_{NO}), never exceed speed (V_{NE}), stall speed (V_S), etc.
Vertical speed	Target vertical speed	N/A
Altitude/flight level	Cleared altitude/flight level	Maximum operational altitude or altitude exceeding ±200 ft. from altitude clearance
Heading	Heading to next waypoint	N/A
Position	Planned route	N/A

5.3 CONTINUOUS CONTROL TASKS

Continuous control tasks require extended use of resources over time from a system agent to control the UA; these tasks are part of a continuous feedback loop with monitoring tasks, where the monitoring tasks represent the information acquisition and information analysis stages of information processing, and the control tasks represent the decision and action selection and action implementation stages of information processing. The agent that controls the UAS is continuously being informed by the agent performing the monitoring and/or planning tasks (note that the same human and/or automated agent could be performing all the functions). The potential allocations span from manual control of UA thrust and attitude to automated control of UA thrust and attitude to meet heading, speed, and altitude targets or to fly to waypoints uploaded to the UAS. Potential human-automation function allocations include:

(a) RPIC controls an input (thrust, roll, yaw and/or pitch) to maintain target parameter (e.g., heading, vertical speed, airspeed). RPICs refer to this level of automation as *manual control*.
(b) RPIC controls an input based on guidance provided by the automation. Guidance requires information analysis automation and decision and action selection automation. This type of automation is *flight guidance*.
(c) RPIC uploads target parameter (e.g., heading, airspeed, altitude, vertical speed); automation controls UA (surfaces and thrust) to maintain target. Operators refer to this level of automation as *basic autoflight*. This type of capability requires information analysis automation, decision and action selection automation, and action implementation automation.
(d) RPIC uploads flight trajectory targets (e.g., waypoints, runway); automation develops a plan and controls UA (surfaces as well as thrust) to fly to flight trajectory targets. Operators refer to this level of automation as *advanced autoflight*. This type of capability requires information analysis automation, decision and action selection automation, and action implementation automation.

5.4 DISCRETE CONTROL TASKS

Discrete control tasks occur at a specific time during the flight, and while they do require a degree of monitoring as part of a control-monitoring feedback loop, it is not continuous like it is for the control-monitoring feedback loop for continuous control tasks. Monitoring generally occurs in two ways: (1) the RPIC (or automation) monitors the UAS until the UA parameter achieves a state, and then the RPIC (or automation) makes a discrete control input (e.g., extend flaps after the UA slows to V_{FE}); or (2) the RPIC (or automation) makes a discrete change and monitors a continuous process until a particular parameter is met.

Discrete control tasks occur in the decision and action selection and action implementation stages of information processing; the monitoring that occurs prior to and/or following the discrete control action is covered in the monitoring section (Section 5.2). There are five roles that can be allocated to the human RPIC or an automated agent for discrete control tasks, including:

1. *Generate one or more action options:* This role represents the generation of one or more potential options for the discrete control action.
2. *Select an action option:* This role represents the selection of one of the potential actions generated in Step 1, according to some criteria.
3. *Evaluate selection:* This role represents review of the selection from Step 2 to ensure it meets the defined criteria.
4. *Execute selection:* This role represents the delivery of the command to the aircraft to perform the action.
5. *Feedback on implementation:* If a human or automated agent implements an action, this role represents the strategy used to inform the human RPIC that the action has been implemented. The four potential feedback strategies include compulsory feedback, feedback by request, feedback by design, and no feedback. These are defined in the taxonomy of human automation interaction developed as part of the A7 function allocation literature review.

Allocating the RPIC and the automation to these roles, Table 3 reveals the potential function allocations for discrete control tasks. In addition to the function allocation strategies identified in Table 3, each of the eleven strategies can be crossed with each of the four feedback strategies mentioned above, yielding 44 potential strategies. Although we have not explicitly identified the full crossing in Table 3, the feedback strategy has been made explicit in the recommendations.

Table 3. Potential function allocations for UAS discrete control tasks.

Strategy	Generate One Or More Action Options	Select an Action Option	Evaluate Selection	Execute Selection
a	RPIC	RPIC	RPIC	RPIC
b	RPIC	RPIC	Automation	RPIC
c	Automation	RPIC	RPIC	RPIC
d	Automation (constrained by RPIC)	RPIC	RPIC	RPIC
e	Automation	RPIC	Automation	RPIC
f	Automation (constrained by RPIC)	RPIC	Automation	RPIC
g	Automation	Automation	RPIC	RPIC
h	Automation	Automation (constrained by RPIC)	RPIC	RPIC
i	Automation	Automation	Automation	RPIC
j	Automation	Automation (constrained by RPIC)	Automation	RPIC
k	Automation	Automation	Automation	Automation

6. FUNCTION ALLOCATION RECOMMENDATIONS: TAXI, TAKEOFF, AND LANDING

This section contains the minimum function allocation recommendations for each task from the task analysis, organized by phase of flight. Under each task is the following content:

- Functional requirement: Recommended minimum functionality to perform the task.
- Minimum function allocation recommendation: Recommended minimum function allocation strategy for the task, categorized by the rubrics contained in Section 5.
- Rationale: Explanation for the recommendation.
- SME comments: Relevant SME feedback for the task.
- Potential safety implications: Safety implications of performing the task properly.
- Potential higher/lower function allocation(s): Alternative function allocation strategies.
- Autonomous mode recommendation: Our recommendations come with the caveat that all UA larger than 55 lb must have an autonomous mode for lost link situations. This item contains the function allocation strategy associated with the autonomous mode.

6.1 TAXI OUT

6.1.1 Obtain taxi route, including destination (e.g., runway, gate, parking area)

Functional requirement: The control station should have capability for the RPIC to obtain/coordinate the taxi route.

<u>Minimum function allocation recommendation</u>: The RPIC should be able to coordinate the taxi route to the destination at the airport without any assistance from automation (planning function allocation strategy a, *manual planning*).

<u>Rationale</u>: Obtaining taxi route and destination is not substantially different for manned and unmanned aircraft. Therefore, whether the route is coordinated with tower controllers, or the pilot taxis to the runway at a non-towered airport, the RPIC can perform the task with no assistance from automation.

<u>SME comments</u>: All SMEs agreed with the recommendation.

- "The more autonomous the UA is, the more likely it will rely on GPS coordinates in the mission plan to taxi on a route that is already pre-planned. Most mission plans will have several routes for the different runways. I feel this is one where the functional requirement can be left generic and regardless of the level of automation, the requirement remains the same. The ground control/tower has control of everything moving on that airfield and thus the RPIC must obtain/coordinate for permission to move."
- "If we are assuming a towered airport, it is not unusual for either the tower or ground control to prescribe a specific taxi route which the RPIC would need to comply with, or at least articulate if unable to comply and obtain an alternate route clearance for taxi."

<u>Potential safety implication(s)</u>: RPIC, VO, and tower controllers (if applicable) need to be informed of the planned route and destination of the UA in order to guide it safely to its destination.

<u>Potential higher LOA</u>: Automation creates one or more potential taxi route plans and presents them to the RPIC for approval.

<u>Autonomous mode function allocation recommendation</u>: The autonomous mode does not include taxi functionality, so the RPIC should be able to obtain taxi route to the destination at the airport (planning function allocation strategy a, *Manual Planning*).

<u>6.1.2 Ensure instruments, avionics, and navigation equipment are functioning properly and are ready for flight</u>

<u>Functional requirement</u>: The UAS should provide the RPIC with the capability to ensure the instruments, avionics, and navigation equipment are functioning properly and are ready for flight.

<u>Minimum function allocation recommendation</u>: RPIC should be able to compare the instruments, avionics, and navigation equipment with reference conditions/metrics to check that they are reporting what the UA is doing within required deviations (monitoring and situation assessment function allocation strategy a, *state*).

Rationale: The purpose of this task is for the RPIC to ensure that the data presented in the control station is correct (i.e., instruments, avionics, and navigation equipment). Assuming the information delivered to the control station is accurate, there is no substantial difference between performing this task for a UAS and for a manned aircraft. The minimum LOA, therefore, is to compare the information on the instruments, avionics, and navigation equipment with their expected readings based on the actions of the UA (e.g., input from someone with visual contact with the UA, such as the VO).

SME comments: One SME did not think this should be a required task.

- Comments from disagreements:
  - "I don't have anything to add to this because it seems like something that does not even need to be addressed; if your displays are not working then the RPIC should not take off. What is it that we are specifically trying to compare, and is the comparison possible? It would take a bit of time to go through every indication on the screen and see if the VO can confirm it, like confirming if the flaps are at 30 degrees, or if the UA's ground speed is 6 knots. Anything major will be very obvious and of course no one would take off in that situation."
- Regarding a higher level of automation to perform this task: "We used built-in tests to check avionic equipment all the time. We also compared multiple systems to confirm proper operation. It does not need to be done manually. I would recommend needing a validation method for the displays."

Potential safety implication(s): If the instruments, avionics, and navigation equipment are not operating properly, the UA cannot be operated safely.

Potential higher LOA: The control station delivers a video feed of an external camera of the UA so that the RPIC can compare the UA movement to the instruments, avionics, and navigation equipment.

Autonomous mode function allocation recommendation: Ensuring instruments, avionics, and navigation equipment are functioning properly is just as important for the autonomous mode as it is for the manual mode, so the RPIC should be able to ensure they are working properly without assistance from automation, reflecting monitoring and situation assessment function allocation strategy a, *state*.

6.1.3 Perform brake check

Functional requirement: The control station should have the capability to check the UA brakes.

Minimum function allocation recommendation: The RPIC should be able to manually perform the brake check and use feedback presented on the control station displays to ensure that the brakes stopped the UA (discrete control function allocation strategy *a* (Table 3); monitoring and situation assessment function allocation strategy a, *state*).

Rationale: From the RPIC's perspective, there is little difference performing the brake check for a manned or an unmanned aircraft, so the RPIC should be able to manually ensure that the brakes are working properly.

SME comments: All SMEs agreed with the recommendation.

- "We used brake servo feedback as our initial and specific brake check, and then checked the dead man switch once the UA was moving to ensure the controls were working properly."
- "I concur with the need to perform a brake check, but I don't necessarily need a nose camera for this task. A groundspeed or velocity indicator can also tell me the aircraft stopped. A VO can also verbally confirm it stopped. This step is typically conducted immediately upon pulling out of the parking spot. If the brakes do not perform correctly, a higher level of automation we should consider is whether an automated system would shut down the motor to eliminate thrust, or if it has a capability of reverse thrust, applying it to stop movement."
- "I do not believe that there is any reason for autonomous brake checks."
- "Some large UAS that are not taxied manually are designed to have a stop taxi option where the RPIC in the control station would see the speed go to zero and then press a taxi button to initiate taxi again."

Potential safety implication(s): Malfunctioning brakes could lead to a UA incident/accident on the airport surface resulting in damage to the UA, other vehicles on the surface, or airport infrastructure.

Potential higher LOAs: (1) UAS control station alerts the RPIC if it detects that the brakes have been activated in the control station but the UA has not stopped moving. (2) Automation performs the brake check and informs the RPIC whether the brakes work properly.

Autonomous mode function allocation recommendation: The autonomous mode does not include taxi functionality, so the RPIC should be able to manually perform the brake check; discrete control function allocation strategy *a* (Table 3).

6.1.4 Control UA speed along taxi route

Functional requirement: The control station should provide the RPIC a means to control the UA speed along the taxi route as well as an indication of the UA speed.

Minimum function allocation recommendation: Using feedback presented at the control station, the RPIC should be able to manually control aircraft power and brakes to control UA speed while taxiing (continuous control function allocation strategy a, *manual control*; monitoring and situation assessment function allocation strategy a, *state*).

Rationale: Assuming the UA speed information is accurate and there is not substantial lag in the delivery of information and commands between the control station and UA, controlling aircraft speed does not differ substantially between manned and unmanned taxi operation. Thus, the RPIC should be able to manually control the UA speed as it proceeds along its taxi route.

SME comments: All SMEs agreed with the recommendation.

- "I am not sure how much value a nose camera adds here. I need a speed indicator for manual control. Some airports have specific taxi speed limitations; a nose camera does not provide ample feedback to ensure compliance. Another point to consider with nose cameras is that the FAA established a precedent by indicating that such devices do not meet sense and avoid criteria. While a nose camera enhances situation awareness, I'm not sure of the value associated with making it a minimum piece of equipment."
- "Is it a requirement if you have a nose camera to need a VO? I think the intent is correct but should be written more generally. The RPIC should make the decision on how to ensure they comply: maybe a camera with VO, maybe a VO with a GPS guided mission plan, or maybe with just a camera. It should not matter as long as the RPIC is able to guarantee proper taxi speed and braking distance."
- "As a potential higher level of automation, I would also recommend possibility of using a 360-degree virtual reality camera for a higher level of situation awareness. This would promote a higher level of safety."

Potential safety implication(s): Taxiing at an excessive speed could lead to collisions with airport infrastructure or other vehicles on the airport surface. It can also lead to loss of control of the UA on the ground, particularly when making sharp turns, or operating on slippery surfaces.

Potential higher LOA: Control station automation alerts the RPIC if the UA is traveling at a potentially unsafe taxi speed (unsafe either because the braking distance is high in the event of ground traffic or unsafe due to UA operation).

Autonomous mode function allocation recommendation: The autonomous mode does not include taxi functionality, so the RPIC should be able to manually control UA speed along taxi route (continuous control function allocation strategy a)

6.1.5 Control UA track along taxi route

(Note: The recommendation for this task is similar to the taxi out task *control UA speed along taxi route*, Section 6.1.4.)

Functional requirement: The control station should provide the RPIC a means to control the UA track along the taxi route as well as indications of the UA track and position relative to the taxi route.

Minimum function allocation recommendation: Using feedback presented at the control station (e.g., camera video or other method for providing the required position awareness and view of the environment ahead of the UA), the RPIC should be able to manually control UA track while taxiing (continuous control function allocation strategy a, *manual control*; monitoring and situation assessment function allocation strategy a, *state*).

Rationale: Assuming the control station delivers information on the UA position in relation to the taxiway and taxi route (e.g., via video feed of a forward-looking camera video or other method for providing the required position awareness and view of the environment ahead of the UA) and an indication of UA speed, and there is not substantial latency in the transfer of information between the UA and the control station, the RPIC should be able to manually control the UA track along its taxi route similar to taxi operation in manned operation. If a method for providing the required position awareness and view of the environment ahead of the UA is used, the field of view of the camera video or other position awareness sensor has to be sufficient to support the view of the ground and area ahead of the UA so that the pilot can see information referenced by external agents and avoid obstacles.

SME comments: One SME disagreed with the recommendation.

- "The nose camera video should be a requirement for taxi operations. I would also recommend possibility of using a 360-degree virtual reality camera for a higher level of situation awareness. This would add a higher level of safety."

Potential safety implication(s): Inability to steer the UA could lead to collisions with airport infrastructure or other vehicles on the airport surface.

Potential higher LOA: Control station automation alerts the RPIC if it detects that the UA is not within a safe margin on the taxi route.

Autonomous mode function allocation recommendation: The autonomous mode does not include taxi functionality, so the RPIC should be able to manually control UA direction of travel along taxi route (continuous control function allocation strategy a, *manual control*).

6.1.6 Monitor UA trajectory for obstacles

Functional requirement: The control station should have the capability to monitor the UA trajectory for obstacles.

Minimum function allocation recommendation: Data regarding potential obstacles should be available at the control station with sufficient time and fidelity to allow the RPIC to avoid conflicts (monitoring and situation assessment function allocation strategy a, *state*).

Rationale: Since the RPIC may not have visual line of sight with the airport surface and/or UA, data on obstacles along the UA trajectory could be delivered via two-way communication with the VO or via camera video or other method for providing the required position awareness and view of the environment ahead of the UA. The use of camera or other position awareness sensor is dependent on the video quality, environmental conditions, and the potential for latency in the signal.

SME comments: All SMEs agreed with the recommendation.

- "I strongly concur with the use of a VO for providing clearance from both stationary and fixed obstacles during ground movement."
- "The real challenge is to avoid any obstacle, whether built in (structures), aircraft traffic, ground equipment, or even animals. With the proper equipment and training, the UA can taxi with visibility as low as 600 ft., although 1200 to 600 exceptions are more common. In these conditions, the tower (and potentially the VO) cannot see the aircraft and the pilot can only (poorly) see 600 ft. ahead. At 10 kt. taxi, this would give approximately 18 sec. to stop based on visual perception alone. Other situation awareness sensors can be used to increase this time and provide a greater degree of SA during taxi."

Potential safety implication(s): Undetected obstacles along the UA taxi route, including vehicles on the aircraft surface, foreign object debris, or airport infrastructure, could result in a collision between the UA and the obstacle.

Potential higher LOAs: (1) UAS automation detects objects in the path of the UA and alerts the RPIC when the UA is in danger of striking any obstacles. (2) UAS automation detects objects in the path of the UA, applies the UA brakes, and informs the RPIC.

Autonomous mode function allocation recommendation: The autonomous mode does not include taxi functionality, so the VO should be able to manually monitor the UA trajectory for obstacles.

6.1.7 Configure UA for takeoff

Functional requirement: The UAS should provide the RPIC with the capability to configure the UA for takeoff as well as indication of the status of the UA surfaces and systems required for takeoff.

Minimum function allocation recommendation: The RPIC should be able to configure the UA for takeoff without any assistance from automation; the control station should display the status of any UA surfaces and systems (discrete control function allocation strategy *a* (Table 3); monitoring and situation assessment function allocation strategy a, *state*).

Rationale: Continuous feedback of the UA configuration should be provided so that the RPIC can ensure that the UA produces enough lift for successful takeoff for the current wind conditions. Since this task is not substantially different for RPICs compared to manned aircraft pilots, a low level of control automation is required for a RPIC to configure the aircraft for takeoff.

SME comments: All SMEs agreed with the minimum recommendation.

- Regarding the autonomous mode recommendation:
  - "This is a function that an automated system should be able to do completely. Trim settings are a function of aircraft center of gravity, gross weight, and other factors that the aircraft should have as internally available information. In that case, all I care about is ensuring that the trim is properly configured. If I can be confident in the reliability of this system, give me an indication if it is out of limits. For that matter, if it is out of limits, the aircraft could refuse a takeoff command."
  - "I think this is going to be more and more the case- that UAS automation will solve the problem on where to put the control surfaces for best rate of climb/descent, best cruise speed, etc. The large UASs I am exposed to have a computer that doesn't just set the flaps at 30 or 45 degrees, it will set the flaps at 31.22222345 degrees to find the most accurate setting for the conditions provided."

Potential safety implication(s): Incorrect takeoff configuration (or incorrect reporting of the UA configuration to the RPIC) could lead to difficulty taking off the UA, potentially causing the UA to depart the runway past the departure end of the runway before reaching V_{rot}.

Potential higher LOAs: (1) UAS control station alerts the RPIC if the current configuration will not provide enough lift for successful takeoff. (2) UAS control station provides recommended takeoff configuration. (3) Automation configures the UA for takeoff without any input from the RPIC.

Autonomous mode function allocation recommendation: Automation configures the UA for takeoff and provides the RPIC with feedback on its status. This reflects discrete control function allocation strategy *d* (Table 3).

6.1.8 Check for proper flight control surface movement

(Note: The recommendation for this task is similar to the taxi out task *ensure instruments, avionics, and navigation equipment are functioning properly and are ready for flight*, Section 6.1.2.)

Functional requirement: The control station should provide functionality to check movement of UA surfaces required for flight.

Minimum function allocation recommendation: RPIC should be able to manually move the aircraft surfaces from the control station and, based on feedback delivered to the control station (either by communication from the VO, camera feed, or other indication), ensure they are working properly (discrete control function allocation strategy *a* (Table 3); monitoring and situation assessment function allocation strategy a, *state*).

Rationale: Since the RPIC may not have direct visual contact with the UA, information about the status/position of the control surfaces must be delivered to the RPIC. Assuming this information is correct, the act of checking for proper UA flight control surface movement does not differ substantially from manned operation. Therefore, the RPIC should be able to perform this task without assistance from high levels of automation.

SME comments: All SMEs agreed with the recommendation.

- "I concur with the philosophy. Since the RPIC will not be able to visually confirm control surface movement, it may be good to do this with either the crew chief or VO prior to taxi. This is common with larger manned aircraft."
- "I really would stay away from using specific methods/technologies. Cameras are probably how most will do this but if we put it here it will become the only way it can be done. There are also several aircraft on which you cannot see the control surfaces being moved during the check. The only reference for the pilot is the feel/feedback through the control column or a control through display in the flight station."
- "There are large UAS designs that do not let the pilot exercise movement of controls; they use a method prior to taxi to have all the controls show deflection."
- Regarding potential higher levels of automation: "Why can't there be sensors that indicate a problem with the control surfaces? I have flown a UA with this capability. This seems more reliable than a video camera. This is a good example of an area where the traditional manned method may not be as good as the potential afforded by automation."

Potential safety implication(s): If the UA surfaces are not functioning properly, it cannot be operated safely due to increased risk of an incident or accident.

Potential higher LOA: Automation checks for proper flight control surface movement and alerts the RPIC of any surfaces that are operating incorrectly.

Autonomous mode function allocation recommendation: Ensuring the UA control surfaces are functioning properly is just as important for the autonomous mode as it is for the manual mode, so the RPIC should be able to ensure they are working properly without assistance from automation, reflecting discrete control function allocation strategy *a* (Table 3).

6.1.9 Turn on required lights

Functional requirement: The control station should provide the RPIC functionality to control lights on the UA as well as feedback on whether lights are on or off.

Minimum function allocation recommendation: RPIC should be able to control UA external lighting without assistance from automation; the control station should have indication of whether the lights are on or off (discrete control function allocation strategy *a* (Table 3); monitoring and situation assessment function allocation strategy a, *state*).

Rationale: Controlling external lighting (including navigation, anti-collision, landing, icing, and taxi lights) is not substantially affected by operating the UA remotely compared to being onboard the aircraft. Therefore, the RPIC should be able to perform this task without any assistance from automation.

SME comments: All SMEs agreed with the recommendation.

Potential safety implication(s): Improperly working external lights could make it difficult for operators of surrounding aircraft to see the UA.

Potential higher LOAs: (1) Automation informs the RPIC if external lights should be on when they are not on. (2) Automation controls the external lights to turn them on and off when appropriate.

Autonomous mode function allocation recommendation: Autonomous mode refers to UA control, so the RPIC should be able to manually control external lighting, even when the UAS is in autonomous mode. This reflects discrete control function allocation strategy *a* (Table 3).

6.2 TAKEOFF

6.2.1 Position aircraft for takeoff in the appropriate configuration

Functional requirement: The control station provides functionality to allow the RPIC to position the aircraft for takeoff in the appropriate configuration, including providing feedback on the position of the aircraft relative to the takeoff runway.

Minimum function allocation recommendation: RPIC should be able to manually control the UA to position it for takeoff in the appropriate configuration; feedback at the control station should allow the RPIC to ensure the UA is properly aligned for takeoff (discrete control function allocation strategy *a* (Table 3); monitoring and situation assessment function allocation strategy a, *state*).

Rationale: Assuming the information delivered to the control station is timely and accurate, there is little difference performing this task for a UAS compared to manned operation. Therefore, the RPIC should be able to, at minimum, control the UA to takeoff position in the appropriate configuration.

SME comments: All SMEs agreed with the recommendation.

- "Requiring engagement of the brakes on the runway assumes the UA must center and stop on the runway prior to applying takeoff power. Although a common practice, I do not think applying the brakes for this task should be a requirement. For example, a RPIC may position the UA from the hold short line, obtain the runway centerline and apply takeoff power without braking or stopping on the active runway."

- "Performing this task does not always require visual cues. I have performed takeoffs using only instruments with only the next runway light visible. While an extreme, there are takeoffs where it is based more on instruments for heading, and visual cues for the location laterally (relative to runway centerline) on the runway."
- Regarding the autonomous mode recommendation:
    - "In a highly-automated system, the UA would have the airfield data available, including runway headings. Typically, there will be waypoints on the runway to show centerline deviation."
    - "If the mission plan is already loaded is based on the take-off runway, the RPIC does not upload the runway heading to the UAS. The aircraft is using GPS coordinates to taxi out to the centerline and align with runway heading. Even if the UAS is being taxied manually, the RPIC would not upload a runway heading to the UAS."

Potential safety implication(s): A UA that is not properly aligned with the runway could drift off of the side of the runway during takeoff, resulting in a collision with airport infrastructure or other vehicles on the airport surface.

Potential higher LOAs: (1) UAS control station provides the difference between the UA heading and runway heading. (2) UAS alerts the RPIC if the difference between the UA heading and runway heading exceeds a threshold representing safe operation.

Autonomous mode function allocation recommendation: The RPIC uploads the runway heading to the UAS, and automation controls the UA thrust, nose wheel, and/or brakes to align the UA with the runway heading. The RPIC receives continuous feedback of the position and heading of the UA in relation to the runway heading; discrete control function allocation strategy *k* (Table 3).

6.2.2 Takeoff roll

6.2.2.1 Smoothly advance power to takeoff (full) thrust

Functional requirement: The control station should provide the capability to smoothly advance power to takeoff thrust (and release brakes, if necessary), as well as provide feedback on the throttle and brake status to the control station.

Minimum function allocation recommendation: RPIC should be able to advance the power to takeoff (full) thrust (and release the brakes, if necessary) without assistance from automation and feedback on thrust should be continually displayed in the control station (discrete control function allocation strategy *a* (Table 3); monitoring and situation assessment function allocation strategy a, *state*).

Rationale: The RPIC should be able to manually control the thrust and brakes, assuming the control station provides continual feedback of the thrust level, since this task is not substantially different from manned aircraft operation.

SME comments: All SMEs agreed with the recommendation.

- "Keep in mind that with takeoff thrust set, there could be movement of the aircraft even with brakes engaged; again, I question the value of the nose camera here."
- "This is also an issue if only one brake releases since you would either not move or start to turn depending on the UA design and brake effectiveness."

Potential safety implication(s): Inability to control the thrust and/or brakes on takeoff, or insufficient feedback on the thrust and brake status, could lead to inability to take off.

Potential higher LOA: Automation releases UA brakes (if necessary) and smoothly advances thrust to takeoff thrust.

Autonomous mode function allocation recommendation: Automation advances the throttle to full thrust (after the RPIC indicates that the UA is clear to takeoff), reflecting discrete control function allocation strategy *k* (Table 3).

6.2.2.2 Observe UA instruments, avionics, and navigation equipment operating normally and not exceeding any limits

(Note: The recommendation for this task is similar to the taxi out task *ensure instruments, avionics, and navigation equipment are functioning properly and are ready for flight*, Section 6.1.2.)

Functional requirement: The control station should provide the status of instruments, avionics, and navigation equipment, allowing the RPIC to monitor UA status.

Minimum function allocation recommendation: RPIC should be able to monitor the control station instruments, avionics, and navigation equipment to ensure the power plant and performance indications are operating as expected and not exceeding any limits (monitoring and situation assessment function allocation strategy a, *state*).

Rationale: Being remote from the UA has little implication on the act of observing the instruments, avionics, and navigation equipment during takeoff roll. Therefore, the RPIC should be able to monitor the UAS indications to ensure they are operating within safe limits.

SME comments: All SMEs agreed with the recommendation.

- Regarding the autonomous mode recommendation, "an automated system could actually command the aircraft to abort the takeoff if parameters are not met. This reduces the possibility of a delayed response by the RPIC to cause an accident or incident."

Potential safety implication(s): If the indicators are not operating properly, the UA cannot be operated safely.

Potential higher LOAs: (a) The control station provides the engine and performance indicator readings as well as the ranges/limits for normal operation. (b) The control station alerts the RPIC if it observes a discrepancy between the control input(s) and the engine and performance indicators.

Autonomous mode function allocation recommendation: Ensuring instruments, avionics, and navigation equipment are functioning properly is just as important for the autonomous mode as it is for the manual mode, so the RPIC should be able to ensure they are working properly without assistance from automation, reflecting monitoring and situation assessment function allocation strategy a, *state*.

6.2.2.3 Maintain runway centerline

Functional requirement: The control station should have functionality to maintain runway centerline and provide feedback to the RPIC about the UA position relative to centerline.

Minimum function allocation recommendation: RPIC should be able to control the UA track manually and have sufficient feedback (e.g., communication with VO, camera feed, or representation of UA on airport map) at the control station to maintain runway centerline (continuous control function allocation strategy a, *manual control*; monitoring and situation assessment function allocation strategy a, *state*).

Rationale: Assuming that sufficient information is presented to the RPIC in the control station and there is no significant latency in the data being transmitted to and from the UA, the RPIC should be able to manually maintain runway centerline, since this task does not differ substantially from manned operation.

SME comments: All SMEs agreed with the recommendation.

- Regarding the autonomous mode recommendation, "the UAS could also perform a fully autonomous take-off and the RPIC can monitor the gauges as a check and balance."

Potential safety implication(s): The UA could drift off the side of the runway if the cross-track error becomes excessively large, potentially resulting in an accident.

Potential higher LOAs: (1) The control station explicitly provides the cross-track error to the RPIC. (2) The control station alerts the RPIC if the UA cross track error exceeds a threshold representing safe operation.

Autonomous mode function allocation recommendation: Automation controls the UA surfaces to maintain runway centerline, reflecting continuous control function allocation strategy d, *advanced autoflight*.

6.2.3 Monitor UA airspeed in relation to scheduled takeoff speeds

Functional requirement: The control station should provide UA speed information to the RPIC.

Minimum function allocation recommendation: The control station should provide UA airspeed, allowing the RPIC to compare the UA airspeed to velocity reference speeds (e.g., V_1, V_2, V_R) during takeoff roll (monitoring and situation assessment function allocation strategy a, *state*).

Rationale: The RPIC being remote from the aircraft has little implication on monitoring aircraft speed relative to scheduled takeoff speeds, so the RPIC should be able to perform this task without assistance from automation, as is standard for manned aircraft pilots. Observation of current-day operations suggests that takeoff tasks, including the takeoff decision, can be performed manually.

SME comments: All SMEs agreed with the recommendation.

- "Not all aircraft use V_1 terminology for this. V_1 is the proper term as defined by the FAA but small aircraft don't really use it and it more commonly used with multi-engine aircraft. Small single engine planes typically use V_R. This is really a minutia detail as the V_1 descriptor is really correct but there a lot of pilot flying small aircraft that have only seen V_R."
- "What is also critical is reaching V_R in the right distance. Too long of a roll can be an indication of power issues. Some flight systems also check distance compared to speed"
- Regarding the autonomous mode recommendation: "In the worst-case scenario, the takeoff decision can be prone to pilot error, exacerbated by potential latent information in the control station. UA have the capability to autonomously reject a takeoff (or abort) based on anomalies occurring at various V speeds"

Potential safety implication(s): If an issue develops or is discovered after the UA achieves V_1, the UA could overrun the runway or collide with infrastructure, terrain, or other traffic.

Potential higher LOAs: (1) The control station provides the RPIC with the difference between UA airspeed and the maximum abort takeoff speed (V_1). (2) The control station alerts the RPIC when the UA approaches the maximum abort takeoff speed (V_1).

Autonomous mode function allocation recommendation: Automation continually monitors the aircraft speed in comparison to scheduled takeoff speeds and informs the RPIC when takeoff can no longer be aborted. This reflects monitoring function allocation strategy e, *automated comparison*.

6.2.4 Lift off/rotate

Functional requirement: The control station should provide the means to control the UA to successfully lift off the UA during takeoff sequence.

Minimum function allocation recommendation: RPIC should be able to control the UA surfaces and/or thrust manually to lift off; discrete control function allocation strategy *a* (Table 3).

Rationale: Assuming there is not a substantial latency in transmitting data between the control station and the UA, lift off/rotate is not substantially different than manned operation. Therefore, the RPIC can lift off/rotate the UA without assistance from automation.

SME comments: All SMEs agreed with the recommendation.

- "The recommendation can be interpreted to imply that the VO should announce when the UA is airborne. During this critical phase of flight, I would do this only by exception; the RPIC should have indications of the aircraft being airborne, such as a positive indication on the VSI and an increase in altitude—both common to manned pilot IFR departure procedures."
- "Rotating a UA could be as simple as the RPIC rotating to a known pitch setting based on the weight and configuration for that aircraft."
- "The autonomous mode takes into account temperature, air density, weight and selects the perfect rotate speed to climb away at. Some aircraft start in a "hiked" position and don't require a rotation as it lifts off based on the angle of attack it is at during the takeoff roll."

Potential safety implication(s): Improper lift off could lead to a runway overrun and/or an accident.

Potential higher LOAs: (1) Control station automation informs the RPIC when the UA becomes airborne. (2) The control station provides guidance on properly lifting off or rotating the UA (e.g., similar to VNAV guidance in a commercial manned aircraft).

Autonomous mode function allocation recommendation: Automation controls the UA thrust and pitch to lift off or rotate, reflecting discrete control function allocation strategy *k* (Table 3).

6.2.5 Initial climb

6.2.5.1 Check for positive rate of climb

Functional requirement: The UAS control station should provide an indication (either directly or indirectly) that lets the RPIC know that the UA has achieved a positive rate of climb.

<u>Minimum function allocation recommendation</u>: The UAS control station should provide an indication of the UA altitude, allowing the RPIC to determine whether the UA has achieved a positive rate of climb via UA altitude change and/or UA vertical speed (monitoring and situation assessment function allocation strategy a, *state*).

<u>Rationale</u>: Checking positive rate of climb is a critical task in takeoff. Since the RPIC is remote from the aircraft, (s)he is deprived the direct out-window visual cues that the manned aircraft pilot has that indicate that the UAS is climbing. Therefore, at minimum, the control station should provide the RPIC with UA altitude and/or vertical speed information that indicates whether the UA has achieved a positive rate of climb. While it is feasible that the VO could indicate to the RPIC that the UA has achieved a positive rate of climb, the Project A7 Recommendations for Control Station Information Requirements recommends that altitude and vertical speed be presented to the RPIC in the control station at all times, so this task can be performed using information that will already be available to the RPIC.

<u>SME comments</u>: All SMEs agreed with the recommendation.

- "This does not need to be performed with a Vertical Speed Indicator (VSI); it can just be the altimeter reading starts to increase."
- "Typically for a positive rate of climb, we look at two things: the altimeter (which is the primary instrument) and the vertical speed indicator, which is the secondary instrument. Also, the VSI, even on a manned aircraft, lags."
- "The nose camera can give an indication of an increased attitude during rotation, but if the entire field of view is the sky above the horizon, it may not be an indication of a climb…just attitude."
- "Larger than small UASs should have a form of attitude indicator display the pilot can see to determine climb, descent, level flight, etc. Once the UA is off the ground there a various ways different software display airborne and it might not be a visual/aural alert. The attitude indicator is really all you need to be in the CS software for confirmation of a climb."

<u>Potential safety implication(s)</u>: Inability to achieve a positive rate of climb could lead to an incident or accident with terrain, other aircraft, ground vehicles, or infrastructure.

<u>Potential lower and higher LOAs</u>: (1) VO informs the RPIC when the UA achieves a positive rate of climb (lower LOA). (2) The UAS control station produces a visual/aural alert when the UA achieves a positive rate of climb (higher LOA).

<u>Autonomous mode function allocation recommendation</u>: UAS control station informs the RPIC when the UA achieves a positive rate of climb (monitoring and situation assessment function allocation strategy e, a*utomated comparison*).

6.2.5.2 Configure UA for climb out

Functional requirement: The UAS control station should provide the RPIC with the UA speed (to compare to configuration-based airspeed limits) and functionality to configure the aircraft for climb out.

Minimum function allocation recommendation: RPIC should be able to monitor UA airspeed in relation to configuration-based airspeed limits (e.g., maximum landing gear extended airspeed (V_{LE}) and maximum landing gear operating airspeed (V_{LO})) and manually configure the UA for climb out (discrete control function allocation strategy *a* (Table 3); monitoring and situation assessment function allocation strategy a, *state*).

Rationale: Manned aircraft RPICs are able to manually configure the aircraft for climb out, and there is little implication for conducting this task remotely compared to being in the aircraft cockpit (except for the potential for latency). Therefore, as in manned aircraft, the RPIC should be able to configure the aircraft for its planned climb to cruise altitude.

SME comments: All SMEs agreed with the recommendation.

- Regarding the autonomous mode recommendation, "the autonomy will lift landing gear usually based on positive indication of weight on wheels no longer and when climbing past an altitude (300 AGL for RQ-4)."

Potential safety implication(s): Incorrect configuration could lead the UA to gradually drift to off course from the planned climb route, potentially losing separation with other aircraft or terrain. Furthermore, latencies in delivering information to the control station and/or in delivering commands to the UA may limit RPIC ability to change the climb profile in a timely manner.

Potential higher LOAs: (1) UAS alerts the RPIC if the UA is approaching a configuration-based airspeed limit with the surface in an unsafe configuration (e.g., alert the RPIC when airspeed is approaching V_{LE} and the landing gear is still deployed). (2) Automation provides one or more recommendations for climb configuration settings to achieve the objective of efficiently climbing to the cruise altitude.

Autonomous mode function allocation recommendation: Automation configures the aircraft to meet the climb profile and informs the RPIC, reflecting discrete control function allocation strategy *k* (Table 3).

6.3 LANDING

6.3.1 Configure UA for landing

(Note: The recommendation for this task is similar to the takeoff task *configure UA for climb out*, Section 6.2.5.2.)

<u>Functional requirement</u>: The UAS control station should provide the RPIC with the UA speed (to compare to configuration-based airspeed limits) and functionality to configure the aircraft for landing.

<u>Minimum function allocation recommendation</u>: RPIC should be able to monitor UA airspeed in relation to configuration-based airspeed limits (e.g., maximum landing gear extended airspeed (V_{LE}) and maximum landing gear operating airspeed (V_{LO})) and manually configure the UA for landing (discrete control function allocation strategy *a* (Table 3); monitoring and situation assessment function allocation strategy a, *state*).

<u>Rationale</u>: Manned aircraft operators are able to manually configure the aircraft for landing, and there is little implication for conducting this task remotely compared to being in the aircraft cockpit (except for the potential for latency). Therefore, as in manned aircraft, the RPIC should be able to configure the aircraft for landing.

<u>SME comments</u>: All SMEs agreed with the recommendation.

- "Different from takeoff, this isn't usually based on altitude but rather triggered by passing the instrument approach procedure on the mission plan."

<u>Potential safety implication(s)</u>: Inability to configure the UA for landing will result in a situation in which the UA either cannot land, or must perform an emergency landing without the use of landing gear (e.g., ditching).

<u>Potential higher LOAs</u>: (1) UAS alerts the RPIC if the UA is approaching a configuration-based airspeed limit with the surface in an unsafe configuration (e.g., alert the RPIC when airspeed is approaching V_{LE} and the landing gear is not deployed). (2) Automation provides one or more recommendations for landing configuration settings to support safe and efficient landing.

<u>Autonomous mode function allocation recommendation</u>: Automation configures the aircraft for landing and informs the RPIC, reflecting discrete control function allocation strategy *k* (Table 3).

6.3.2 Landing decision

<u>Functional requirement</u>: The UAS control station should provide sufficient information to the RPIC to make an informed landing decision.

<u>Minimum function allocation recommendation</u>: RPIC should be able to make a landing decision, without assistance from automation, assuming that accurate and timely information pertinent to landing is presented in the control station (planning function allocation strategy a, *manual planning*; monitoring and situation assessment function allocation strategy a, *state*).

<u>Rationale</u>: The landing phase of flight is the most difficult and demanding on the RPIC due to the much smaller margin of error compared with other phases of flight; descending to a runway target requires more precision than climbing to a cruise altitude. Operating the UA remotely may

result in loss of position awareness, stemming from the diminished depth perception from substituting the nose-mounted camera for a manned aircraft pilot's out-window view. This is particularly the case in high wind conditions. A manned aircraft pilot has the ability to turn his/her head to ensure the aircraft is in line with the runway. Furthermore, since the margin of error of landing so small compared to other phases of flight, any potential latencies in the system are magnified since small control manipulations could result in an aborted landing. All of these considerations may make it difficult for the RPIC to make an accurate landing decision. Therefore, it is critical that accurate and timely information relevant to making a landing decision is presented to the RPIC to support making the correct landing decision.

Note: Our original function allocation recommendation was for a higher LOA, that the automation should provide a landing decision recommendation based on the information and data available. Therefore, the SME comments below are referencing this comment. The recommendation was subsequently changed to account for the SME feedback.

SME comments: All SMEs agreed with the recommendation.

- "I concur with the assertion that the landing phase of flight is the most difficult. I believe there is research that confirms the majority of UAS accidents involving pilot error occur during landing. While manual landings should be feasible, this is probably the most critical phase of flight where automation can enhance safe operations."
- "I would recommend that the minimum should be manual flight with telemetry data and video feed so that the pilot can make the decision on go/no go for landing (just like a manned aircraft)."
- "If flown with automation it would either initiate its own go-around or just land, I haven't seen technology that gives a recommendation on whether to continue or go-around."
- "The autonomy I am familiar with will initiate a go-around prior to 300 ft. if any of several parameters are not met. It is the RPIC's responsibility to override the automated go-around. However, there is no warning or recommendation prior to it going missed approach."
- "Dealing with wind is not really any different from manned flight, except there could be a time delay in the detection and reaction (transport delay). This is not a simple solution to this problem. But its very nature wind solutions on aircraft are fairly noisy, so they are filtered/smoothed. This builds in both a time delay and an averaging effect. If the solution is not filtered, the data are very noisy and difficult to interpret. Even manned aircraft pilots are less concerned with the wind data itself and more concerned with the resultant track and glidepath. Pilots can anticipate wind based on some observed signs (e.g., trees, dust, or previous aircraft) or based on previous landings (e.g., always sink at this runway on final)."

Potential safety implication(s): One of the main safety concerns is the wind. Problems arise from sudden changes in wind speed and direction. Making an incorrect landing decision could (a) result in an accident when landing should have been aborted but was not, or (b) result in an aborted landing when a safe landing could have been conducted.

Potential higher LOAs: (1) The UAS makes a landing decision recommendation, and the RPIC chooses to follow the recommendation or override it. (2) UAS makes a landing decision and uploads it to the UA, allowing the RPIC to override it if necessary.

Autonomous mode function allocation recommendation: UAS automation makes the landing decision and informs the RPIC of the decision (planning function allocation strategy d, *automated planning*).

6.3.3 Reduce power to thrust required for landing

Functional requirement: The UAS control station should provide the RPIC the ability to reduce thrust as well as feedback on the thrust status/level.

Minimum function allocation recommendation: RPIC should be able to manually reduce power to idle thrust (discrete control function allocation strategy *a* (Table 3); monitoring and situation assessment function allocation strategy a, *state*).

Rationale: Continual feedback of the power should be provided so that the RPIC can effectively manage UA energy as it is descending to the runway. Since this task is not substantially different for RPICs compared to manned aircraft pilots, a low level of control automation is required for a RPIC to reduce power to idle thrust during landing.

SME comments: All SMEs agreed with the recommendation.

Potential safety implication(s): Inability to control the thrust on landing, or insufficient feedback on the thrust level, could lead to a situation in which the UA is traveling too fast to attempt a landing.

Potential higher LOA: UAS automation continually informs the RPIC whether the UA is traveling too fast to perform a safe landing.

Autonomous mode function allocation recommendation: Automation reduces the throttle to idle thrust, reflecting discrete control function allocation strategy *k* (Table 3).

6.3.4 Ensure UA is in a safe location for landing

Functional requirement: The UAS control station should provide sufficient information for the RPIC to determine the UA location relative to the runway.

Minimum function allocation recommendation: The RPIC should be able to use the information presented in the control station (or via communication with the VO) to determine whether the UA is in a safe location for landing, i.e., over the runway threshold (monitoring and situation assessment function allocation strategy c, *state and comparison state*).

Rationale: Since the RPIC does not have direct, out-window visual cues of the runway, it may be difficult to judge whether the UA is over the runway threshold. A forward-looking camera or other method for gaining a forward view of the environment ahead of the UA may be sufficient for providing sufficient information about the UA position relative to the runway threshold in order to safely land the UA.

SME comments: All SMEs agreed with the recommendation.

- "For consideration: A VO can assist here."
- "A 360-degree virtual reality camera could be used to promote a higher level of situation awareness. This would add a higher level of safety to allow the pilot added information regarding runway threshold."
- "Use of a fixed nose camera can be difficult in situations where the aircraft has a nose-up attitude, which is typically the case throughout the final approach."
- "This is where a VO usually comes in and confirms the aircraft is lined up for the correct runway, gear is confirmed down, and the VO gives the touchdown call to the pilot."

Potential safety implication(s): Inability to determine UA position relative to runway threshold could result in inability to touch down on the runway or missing the runway completely, resulting in an incident or accident.

Potential higher LOA: UAS automation alerts the RPIC if the UA is too close to the ground and is not over the runway threshold.

Autonomous mode function allocation recommendation: UAS automation determines whether the UA is over the runway threshold, reflecting monitoring and situation assessment function allocation strategy e, *automated comparison*.

6.3.5 Perform landing/touchdown

Functional requirement: The UAS should provide the RPIC the ability to touch down smoothly, both in terms of controlling the UA as well as displaying sufficient information in the control station.

Minimum function allocation recommendation: The RPIC should be able to manually control UA thrust and attitude to perform a landing/touchdown within the limits of the UA design. The CS should provide adequate data and feedback to enable the RPIC to conduct this maneuver and determine a safe touchdown location (discrete control function allocation strategy *a* (Table 3); monitoring and situation assessment function allocation strategy a, *state*).

Rationale: The landing phase of flight is the most difficult and demanding on the RPIC due to the much smaller margin of error compared to other phases of flight; descending to a runway target is more difficult than climbing to a cruise altitude. Operating the UA remotely may result in loss of situation awareness compared to manned aircraft operation, where the pilot can simply look out-window to gather the information necessary to land the aircraft. This is particularly the case in high wind conditions, in which a crabbed UA may result in the runway being completely out of view of a fixed nose camera, or inability of a VO to sufficiently describe the UA position and orientation relative to the runway. A manned aircraft pilot has the ability to turn his/her head to ensure the aircraft is in line with the runway. Furthermore, since the margin of error of landing is so much smaller, any potential latencies in the system are magnified since small control manipulations could result in an accident. All of these considerations may make it difficult for the RPIC to safely touch down on the runway. Therefore, the control station should provide the essential information for safely touching down, including continual lateral distance, longitudinal distance, vertical distance, and heading of the UA relative to the runway location, altitude, and heading. Presentation of wind information is also critical, as a wind gust could result in the UA missing the runway.

SME comments: All SMEs agreed with the recommendation.

- "Wind gusts are an issue, but not one that I have found to be insurmountable, whether manned or unmanned."

Potential safety implication(s): One of the main safety concerns is the wind. Problems come from sudden changes in wind speed and direction. Inability to safely touch down could lead to an incident/accident.

Potential higher LOAs: (1) UAS automation alerts the RPIC in the case of excessive lateral, longitudinal, and/or vertical error. (2) UAS automation presents RPIC with guidance on control of the UA, similar to LNAV or VNAV guidance in commercial aircraft.

Autonomous mode function allocation recommendation: Automation controls UA thrust and control surfaces to perform touch down, reflecting discrete control function allocation strategy *k* (Table 3).

6.3.6 Maintain runway centerline

(Note: The recommendation for this task is similar to the takeoff task *maintain runway centerline*, Section 6.2.2.3.)

Functional requirement: The control station should have functionality to maintain runway centerline and provide feedback to the RPIC about the UA position relative to centerline.

Minimum function allocation recommendation: RPIC should be able to control the UA track manually and have sufficient feedback (e.g., communication with VO, camera feed, or representation of UA on airport map) at the control station to maintain runway centerline (continuous control function allocation strategy a, *manual control*; monitoring and situation assessment function allocation strategy a, *state*).

Rationale: Assuming that sufficient information is presented to the RPIC in the control station and there is no significant latency in the data being transmitted to and from the UA, the RPIC should be able to manually maintain runway centerline, since this task does not differ substantially from manned operation.

SME comments: All SMEs agreed with the recommendation.

Potential safety implication(s): The UA could drift off the side of the runway if the cross track error becomes excessively large, potentially resulting in an accident.

Potential higher LOAs: (1) The control station explicitly provides the cross track error to the RPIC. (2) The control station alerts the RPIC if the UA cross track error exceeds a threshold representing safe operation.

Autonomous mode function allocation recommendation: Automation controls the UA surfaces to maintain runway centerline, reflecting continuous control function allocation strategy d, *advanced autoflight*.

6.3.7 Slow UA to taxi speed

Functional requirement: The control station should provide the RPIC the ability to slow the aircraft to taxi speed, including continual feedback on UA speed in the control station.

Minimum function allocation recommendation: RPIC should be able to manually control UA to slow the UA to taxi speed while maintaining safe positioning on the runway. The control station should provide the RPIC with required data and feedback to determine adequate deceleration, track, and safe positioning on the runway (continuous control function allocation strategy a, *manual control*; monitoring and situation assessment function allocation strategy a, *state*).

Rationale: Once the aircraft is on the runway, there are no substantial differences in slowing down the aircraft between being onboard the aircraft versus operating it remotely. Therefore, the RPIC should be able to manually control UA functionality (e.g., brakes, thrust reversers) to slow the UA to taxi speed. This LOA requires that the UA groundspeed be provided to the RPIC, so that it can be continually monitored until the UA slows sufficiently.

SME comments: All SMEs agreed with the recommendation.

Potential safety implication(s): Inability to slow the UA to taxi speed, or provide the position of the UA relative to the runway centerline and runway distance remaining, could lead to an accident involving the UA, another vehicle, and/or infrastructure.

Potential higher LOAs: (1) UAS control station continually informs the RPIC of the difference between UA groundspeed and speed required for safe taxi. (2) UAS control station alerts the RPIC if the UA is traveling too fast to exit the runway onto a taxiway.

Autonomous mode function allocation recommendation: Automation controls the UA surfaces to slow the UA to safe taxi speed, reflecting continuous control function allocation strategy c, *basic autoflight*.

6.3.8 Determine runway turn-off

(Note: The recommendation for this task is similar to the taxi out task *obtain taxi route, including destination*, Section 6.1.1.)

Functional requirement: The control station should provide the RPIC the ability to coordinate with ATC and/or VO, as necessary, to taxi clear of runway.

Minimum function allocation recommendation: The RPIC should be provided the required data and feedback at the CS to determine runway remaining and runway exit path (planning function allocation strategy a, *manual planning*; monitoring and situation assessment function allocation strategy a, *state*).

Rationale: Obtaining runway turn-off is not substantially different for manned and unmanned aircraft. Therefore, whether the turn-off is coordinated with tower controllers, or the RPIC determines the proper turn-off, the RPIC can perform the task with no assistance from automation.

SME comments: All SMEs agreed with the recommendation.

- "A 360-degree virtual reality camera could be used to promote a higher level of situation awareness. This would add a higher level of safety to allow the pilot added information regarding runway turnoff."
- "If the autonomous mode is relying on GPS coordinates from mission plan, the UA is limited to the exits the aircraft can take, and if the UA misses the exits in landing roll, it often will need to be towed off the runway."

Potential safety implication(s): RPIC, VO, and tower controllers (if applicable) need to be informed of the planned turn-off in order to guide it safely to its destination.

Potential higher LOA: Automation recommends one or more potential turn-offs and presents them to the RPIC for approval.

Autonomous mode function allocation recommendation: The RPIC should be able to determine runway turn-off without assistance from automation (planning function allocation strategy a, *manual planning*).

6.3.9 Turn UA off runway

(Note: The recommendation for this task is similar to the taxi out task *control UA track along taxi route*, Section 6.1.5.)

Functional requirement: The control station should provide the RPIC a means to turn the UA off runway as well as indications of the UA track and position relative to the taxi route.

Minimum function allocation recommendation: Using feedback presented at the control station (e.g., camera video or other method for gaining a forward view of the environment ahead of the UA), the RPIC should be able to manually turn the UA off the runway (continuous control function allocation strategy a, *manual control*; monitoring and situation assessment function allocation strategy a, *state*).

Rationale: Assuming the control station contains accurate and timely indication of UA speed and position relative to runway turn-off, the RPIC should be able to manually control the UA as it proceeds along its taxi route. Furthermore, the VO is monitoring the UA along its path, and can communicate with the RPIC about potential obstacles and traffic on the airport surface. If a nose camera is being used, the field of view must be sufficient to support the view of the ground and area ahead of the UA so that the pilot can safely avoid obstacles when necessary.

SME comments: All SMEs agreed with the recommendation.

- "A 360-degree virtual reality camera could be used to promote a higher level of situation awareness. This would add a higher level of safety to allow the pilot added information regarding runway turnoff."
- "If the autonomous mode is relying on GPS coordinates from mission plan, the UA is limited to the exits the aircraft can take, and if the UA misses the exits in landing roll, it often will need to be towed off the runway."

Potential safety implication(s): Inability to control the UA could lead to collisions with airport infrastructure or other vehicles on the airport surface.

Potential higher LOA: Control station automation alerts the RPIC if it detects that the UA is not within a safe margin on the taxi route.

Autonomous mode function allocation recommendation: The autonomous mode does not include taxi functionality, so the RPIC should be able to manually control UA to safely turn it off of the runway (continuous control function allocation strategy a, *manual control*).

6.4 TAXI IN

(Note: The recommendations for this task are repeated from the similar to the taxi out tasks in Section 6.1.)

6.4.1 Obtain taxi route, including destination (e.g., gate or parking area)

Functional requirement: The control station should have capability for the RPIC to obtain/coordinate the taxi route.

Minimum function allocation recommendation: The RPIC should be able to coordinate the taxi route to the destination at the airport without any assistance from automation (planning function allocation strategy a, *manual planning*).

Rationale: Obtaining taxi route and destination is not substantially different for manned and unmanned aircraft. Therefore, whether the route is coordinated with tower controllers, or the pilot taxis to the runway at a non-towered airport, the RPIC can perform the task with no assistance from automation.

SME comments: All SMEs agreed with the recommendation.

- "The more autonomous the UA is, the more likely it will rely on GPS coordinates in the mission plan to taxi on a route that is already pre-planned. Most mission plans will have several routes for the different runways. I feel this is one where the functional requirement can be left generic and regardless of the level of automation, the requirement remains the same. The ground control/tower has control of everything moving on that airfield and thus the RPIC must obtain/coordinate for permission to move."
- "If we are assuming a towered airport, it is not unusual for either the tower or ground control to prescribe a specific taxi route which the RPIC would need to comply with, or at least articulate if unable to comply and obtain an alternate route clearance for taxi."

Potential safety implication(s): RPIC, VO, and tower controllers (if applicable) need to be informed of the planned route and destination of the UA in order to guide it safely to its destination.

Potential higher LOA: Automation creates one or more potential taxi route plans and presents them to the RPIC for approval.

Autonomous mode function allocation recommendation: The autonomous mode does not include taxi functionality, so the RPIC should be able to obtain taxi route to the destination at the airport (planning function allocation strategy a, *manual planning*).

6.4.2 Configure UA for taxi

Functional requirement: The control station should provide the RPIC with the capability to configure the UA for taxi as well as indication of the status of the UA surfaces and systems required for taxi.

Minimum function allocation recommendation: The RPIC should be able to configure the UA for taxi without any assistance from automation; the control station should display the

status of any UA surfaces and systems (discrete control function allocation strategy *a* (Table 3); monitoring and situation assessment function allocation strategy a, *state*).

Rationale: Continuous feedback of the UA configuration should be provided so that the RPIC can ensure that the UA is configured for taxi, in terms of control surfaces, lighting, etc. Since this task is not substantially different for RPICs compared to manned aircraft pilots, a low level of control automation is required for a RPIC to configure the UA for taxi.

SME comments: All SMEs agreed with the minimum recommendation.

Potential safety implication(s): Incorrect taxi configuration (or incorrect reporting of the UA configuration to the RPIC) could lead to difficulty taxiing the UA, potentially causing a collision with traffic or airport infrastructure.

Potential higher LOAs: (1) UAS control station alerts the RPIC if the UA is not in proper configuration for taxi. (2) Automation configures the UA for taxi without any input from the RPIC.

Autonomous mode function allocation recommendation: Automation configures the UA for taxi and provides the RPIC with feedback on its status. This reflects discrete control function allocation strategy *d* (Table 3).

6.4.3 Control UA speed along taxi route

Functional requirement: The control station should provide the RPIC a means to control the UA speed along the taxi route as well as an indication of the UA speed.

Minimum function allocation recommendation: Using feedback presented at the control station, the RPIC should be able to manually control aircraft power and brakes to address UA speed while taxiing (continuous control function allocation strategy a, *manual control*; monitoring and situation assessment function allocation strategy a, *state*).

Rationale: Assuming the UA speed information is accurate and there is not substantial lag in the delivery of information and commands between the control station and UA, controlling aircraft speed does not differ substantially between manned and unmanned taxi operation. Thus, the RPIC should be able to manually control the UA speed as it proceeds along its taxi route.

SME comments: All SMEs agreed with the recommendation.

- "I am not sure how much value a nose camera adds here. I need a speed indicator for manual control. Some airports have specific taxi speed limitations; a nose camera does not provide ample feedback to ensure compliance. Another point to consider with nose cameras is that the FAA established a precedent by indicating that such devices do not meet sense and avoid criteria. While a nose camera enhances situation awareness, I'm not sure of the value associated with making it a minimum piece of equipment."

- "Is it a requirement if you have a nose camera to need a VO? I think the intent is correct but should be written more generally. The RPIC should make the decision on how to ensure they comply: maybe a camera with VO, maybe a VO with a GPS guided mission plan, or maybe with just a camera. It should not matter as long as the RPIC is able to guarantee proper taxi speed and braking distance."
- "As a potential higher level of automation, I would also recommend possibility of using a 360-degree virtual reality camera for a higher level of situation awareness. This would promote a higher level of safety."

Potential safety implication(s): Taxiing at an excessive speed could lead to collisions with airport infrastructure or other vehicles on the airport surface. It can also lead to loss of control of the UA on the ground, particularly when making sharp turns, or operating on slippery surfaces.

Potential higher LOA: Control station automation alerts the RPIC if the UA is traveling at a potentially unsafe taxi speed (unsafe either because the braking distance is high in the event of ground traffic or unsafe due to UA operation).

Autonomous mode function allocation recommendation: The autonomous mode does not include taxi functionality, so the RPIC should be able to manually control UA speed along taxi route (continuous control function allocation strategy a, *manual control*).

6.4.4 Control UA track along taxi route

Functional requirement: The control station should provide the RPIC a means to control the UA track along the taxi route as well as indications of the UA track and position relative to the taxi route.

Minimum function allocation recommendation: Using feedback presented at the control station (e.g., camera video or other method for gaining a forward view of the environment ahead of the UA), the RPIC should be able to manually control UA track while taxiing (continuous control function allocation strategy a, *manual control*; monitoring and situation assessment function allocation strategy a, *state*).

Rationale: Assuming the control station delivers information on the UA position in relation to the taxiway and taxi route (e.g., via video feed of a forward-looking camera video or other position awareness sensor feed) and an indication of UA speed, and there is not substantial latency in the transfer of information between the UA and the control station, the RPIC should be able to manually control the UA track along its taxi route similar to taxi operation in manned operation. If a position awareness sensor is used, the field of view of the camera video or other position awareness sensor has to be sufficient to support the view of the ground and area ahead of the UA so that the pilot can see information referenced by the VO.

SME comments: One SME disagreed with the recommendation.

- "The nose camera video should be a requirement for taxi operations. I would also recommend possibility of using a 360-degree virtual reality camera for a higher level of situation awareness. This would add a higher level of safety."

Potential safety implication(s): Inability to steer the UA could lead to collisions with airport infrastructure or other vehicles on the airport surface.

Potential higher LOA: Control station automation alerts the RPIC if it detects that the UA is not within a safe margin on the taxi route.

Autonomous mode function allocation recommendation: The autonomous mode does not include taxi functionality, so the RPIC should be able to manually control UA direction of travel along taxi route (continuous control function allocation strategy a, *manual control*).

6.4.5 Monitor UA trajectory for obstacles

Functional requirement: The control station should have the capability to monitor the UA trajectory for obstacles.

Minimum function allocation recommendation: Data regarding potential obstacles should be available at the control station with sufficient time and fidelity to allow the RPIC to avoid conflicts (monitoring and situation assessment function allocation strategy a, *state*).

Rationale: Since the RPIC may not have visual line of sight with the airport surface and/or UA, data on obstacles along the UA trajectory could be delivered via two-way communication with the VO or via camera video or other method for gaining a forward view of the environment ahead of the UA. The use of camera or other position awareness sensor is dependent on the video quality, environmental conditions, and the potential for latency in the signal.

SME comments: All SMEs agreed with the recommendation.

- "I strongly concur with the use of a VO for providing clearance from both stationary and fixed obstacles during ground movement."
- "The real challenge is to avoid any obstacle, whether built in (structures), aircraft traffic, ground equipment, or even animals. With the proper equipment and training, the UA can taxi with visibility as low as 600 ft., although 1200 to 600 exceptions are more common. In these conditions, the tower (and potentially the VO) cannot see the aircraft and the pilot can only (poorly) see 600 ft. ahead. At 10 kt. taxi, this would give approximately 18 sec. to stop based on visual perception alone. Other situation awareness sensors can be used to increase this time and provide a greater degree of SA during taxi."

Potential safety implication(s): Undetected obstacles along the UA taxi route, including vehicles on the aircraft surface, foreign object debris, or airport infrastructure, could result in a collision between the UA and the obstacle.

Potential higher LOAs: (1) UAS automation detects objects in the path of the UA and alerts the RPIC when the UA is in danger of striking any obstacles. (2) UAS automation detects objects in the path of the UA, applies the UA brakes, and informs the RPIC.

Autonomous mode function allocation recommendation: The autonomous mode does not include taxi functionality, so the VO should be able to manually monitor the UA trajectory for obstacles.

7. SUMMARY OF THE RECOMMENDATIONS

The subsections that follow contain tables with an overview of the function allocation recommendation for each task, organized by phase of flight. The left column of each table contains the task, and to the right of the task is an "X" in the column reflecting the agent to which the task is allocated in the recommendations. Note that no tasks are allocated to alerting automation or control automation, as SME feedback suggested that the tasks could be performed safely by the RPIC and/or VO without assistance from automation.

7.1 TAXI OUT

Task	RPIC	VO	Alerting Automation	Control Automation
Obtain taxi route, including destination	X			
Ensure instruments, avionics, and navigation equipment are functioning properly and are ready for flight	X			
Perform brake check	X			
Control UA speed along taxi route	X			
Control UA track along taxi route	X			
Monitor UA trajectory for obstacles		X		
Configure UA for takeoff	X			
Check for proper flight control surface movement		X		
Turn on required lights	X			

7.2 TAKEOFF

Task	RPIC	VO	Alerting Automation	Control Automation
Position aircraft for takeoff in the appropriate configuration	X			
Smoothly advance power to takeoff (full) thrust	X			
Observe UA indicators operating normally and not exceeding any limits	X			
Maintain runway centerline	X			
Monitor UA airspeed in relation to scheduled takeoff speeds	X			
Lift off/rotate	X			
Check for positive rate of climb	X			
Configure aircraft for climb out	X			

7.3 LANDING

Task	RPIC	VO	Alerting Automation	Control Automation
Configure UA for landing	X			
Landing decision	X			
Reduce power to thrust required for landing	X			
Ensure UA is in safe location for landing	X			
Perform landing/touchdown	X			
Maintain runway centerline	X			
Slow UA to taxi speed	X			
Determine runway turn-off	X			
Turn UA off runway	X			

7.4 TAXI IN

Task	RPIC	VO	Alerting Automation	Control Automation
Obtain taxi route, including destination	X			
Configure UA for taxi	X			
Control UA speed along taxi route	X			
Control UA track along taxi route	X			
Monitor UA trajectory for obstacles		X		

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9. APPENDIX A1: OVERVIEW OF SME COMMENTS

A majority of SME comments addressed the following:

- The use of specific technologies in the function allocation recommendations. To address this, we added a functional requirement to accompany our function allocation recommendations.
- Many SMEs had repeated comments about the assumption of a forward-facing nose camera. We addressed these comments by removing any reference to the assumption. Generally, the SME comments indicated that UAS operations can be performed without the fixed nose camera.
    - "I disagree with the assumption about the nose camera. I have operated UAS that don't need this to be able to fly safely. The FAA has not allowed cameras as a safe separation method either. I could use VO or millimeter wavelength radar to do something similar. I would recommend that we remove the assumption."
- The terminology referring to the person flying the UA. "Since the release of the FAA UAS integration roadmap, the FAA released 14CFR Part 107. In this new regulation, the FAA refers to the RPIC as the Remote Pilot in Command, or RPIC. I recommend adopting this term to refer to the pilot in command; if there are other pilots, perhaps using the term RP for remote pilot as a more generic position is worthy of consideration. However, my understanding is that the scope of this effort is based on a single pilot for the crew composition flying a single engine fixed-wing UA. If that's accurate, RPIC throughout the document should suffice." In accordance with this comment, we replaced *UAS operator* with *RPIC* throughout the document.

We also received the following emails on the recommendations, which give brief overviews of the SME comments:

After reading through the document while reading all of the other comments as well, I don't have much to add. Most of my experience is with ground-based autonomy so this was more educational opportunity for me. But there were a number of common themes throughout reviews by the SMEs that were similar to some of the same issues we've encountered when designing ground-based vehicles. The comments about the nose camera versus a virtual camera 360 view or some sort of sensor feedback are similar to what we've learned the hard way. While a camera in front is great in some situations, it often times leaves out too much context. The 360 camera suggestion is one we've seen and experimented with in ground vehicles where a series of cameras and sensors were used to provide a virtual top-down perspective. An argument could be made for both in order to provide more complete situational awareness but this is a minimums recommendation.

Also, the comments about the size of the airport, the VO, and whether or not the RPIC is the only person in the control room were impactful. Most of our autonomy work (while GSE based) was at large airports and the only assumption that could be made was that you could not see everything from the control tower (especially once you factor in extensive vehicle movement). So Joe's comment about not assuming the VO will always be able to see the state of the UA

really makes sense. I also agree with the comments about adding deicing considerations into the process. Again, I'm not saying anything someone hasn't already said in a much more eloquent way but the feedback so far certainly makes sense to a non-pilot.
My biggest comment is that I feel we need to keep the recommendations general to the function and not specify to a method or technology. The example that I saw the most was the use of video. While I agree that this is a method that is commonly used, it is not the only way to fulfill these functions. I understand that people like video and feel it is easy to install but there are other issues with requiring specific technological solutions. If I want to use a different method I can't because the minimum requirement stipulates video. If I want to operate and I can't get a link that has enough bandwidth to provide video I can't fly. This might not be an issue for a local operation but UAS do fly remotely. I have done operations where we didn't have video and were still able to complete the task safely. Video is nice and I would want it if possible but I don't think we should make it or other specific solutions requirements. I tried to write my recommendations in terms of what function was required or what tools/data the pilot might need to complete the function in a more basic way.
Some comments are directed toward using standardized terms. I'd also encourage using RPIC now since it's an FAA term in 14CFR Part 107. I personally feel there is a bit too much emphasis placed on the nose camera. Don't get me wrong, it's a great tool for SA, but I think in some cases it's over emphasized.
I agree with the minimums presented in the documentation. The situational awareness sections, with today's technologies regarding VR and 360 cameras, there is no reason that this functionality cannot be added to >55 lb UAS. This can allow the pilot/operator to have more visibility of the environment the UAS is operating in (such as an airport). In addition, more UAS are gaining the ability of auto takeoff and landing (ATOL). This can allow the UAS to complete these phases of flight (Take-off and landing) safer and more consistently. The pilot/operator is there to monitor and take over in any emergency situations. With that said, a complete manual piloted UAS or RPA, should fall under similar FARs as manned aircraft. (in my opinion).

APPENDIX B—TASK CS-2: FUNCTION ALLOCATION RECOMMENDATIONS FOR NAVIGATION, COMMUNICATION, CONTINGENCY, AND HANDOVER TASKS

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ACKNOWLEDGEMENTS

The authors thank Ashley Awwad, Igor Dolgov, Richard S. Stansbury, and Stephen "Lux" Luxion for their feedback on earlier versions of this document. The authors also thank the A10 subject matter expert pilot reviewers: Joe Cerreta (Embry Riddle Aeronautical University), Paul Snyder (University of North Dakota), Amanda Brandt (University of North Dakota), Joseph Millette (New Mexico State University), Gary Ullrich (University of North Dakota), Reuben Burch (Mississippi State University), and Kurt Carraway (Kansas State University).

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EXECUTIVE SUMMARY

The objective of A10 Task CS-2, *Function Allocation Recommendations for Navigation, Communication, Contingency, and Handover Tasks*, was to provide minimum human-automation function allocation recommendations for navigation, communication, contingencies, and handover of control for fixed-wing unmanned aircraft (UA) larger than 55 lb. Enroute flight operations are assumed to be conducted under IFR. Terminal operations are assumed at both non-towered and limited traffic towered (Class D) fields under both IFR and VFR. In addition, operations with Visual Observers (VO) are discussed in case they are operationally required.

A task analysis addressing navigation, communication, contingencies, and handover of control was used to guide the function allocation recommendations. The work leveraged envisioned aircraft procedures developed as part of the larger A10 project as appropriate. For each task, we identified a recommended functional requirement as well as a minimum human-automation function allocation recommendation (the minimum automation recommendation was more technology-specific than the functional recommendation, which is capability-centered). We also provided rationale for the recommendations including potential safety implications. We included potential higher and/or lower levels of automation than the minimum function allocation recommendation when appropriate. We also provided an autonomous mode function allocation recommendation in the event of lost control link.

The work was refined via feedback from nine Subject Matter Experts (SMEs) who had experience in varying roles of UAS and manned aircraft operation, including but not limited to remote pilot in command (RPIC), control station designer, manned/unmanned flight instructor, manned/unmanned test pilot, certified pilot, and RPICs with UAS research experience. Thus the SMEs were able to provide feedback from the perspective of various stakeholders in the UAS community. SMEs considered whether the task necessitates a regulation and whether they agreed with the recommendation. They were asked to consider what automation is necessary to compensate for any human factors implications associated with operating the aircraft remotely. To help provide some context, they were asked to consider typical flying conditions including if wind is a relevant concern for the task. SME feedback was incorporated into the recommendations and non-supporting inputs were noted.

Except for lost link, SMEs indicated that navigation, communication, and contingency tasks can be accomplished with regulations similar to those for manned operation; i.e., substantial automation assistance is not required as compared to manned aircraft operation. This input assumes timely and accurate delivery of information to the UAS control station. Similarly, the SME comments for handover of control suggest it is primarily a communication task, requiring little automated assistance. Lost link and its associated contingency requirements were identified as being unique to UA. These lost-link requirements represent unique failure modes that will need to be captured in UA platform and Control Station (CS) certification as well as the procedural recommendations.

1. INTRODUCTION

This document focuses on human-automation function allocation recommendations for navigation, communication, contingency, and handover of control for larger than 55 lb. unmanned aircraft system (UAS) operation in the National Airspace System (NAS). Section 2 provides the scope of the recommendations and Section 3 describes the methodology for developing the recommendations. Section 4 provides a task analysis of the navigation, communication, contingency, and handover tasks organized by phase of flight (or identified as phase-agnostic). Section 5 describes the general function allocation rubric. Section 6 provides minimum automation recommendations for the relevant tasks.

2. SCOPE AND ASSUMPTIONS

The recommendations were developed under the following scope:

- The unmanned aircraft (UA) is a fixed-wing aircraft larger than 55 lb.
- The UAS is capable of flying instrument flight rules (IFR) in an integrated NAS, including standard takeoff and approach procedures.
- The UA flies beyond visual line of sight (BVLOS).
- The remote pilot in command (RPIC) does not have visual sight lines of the airport taxiways and runways.
- A visual observer (VO) is required and is located at the airport to communicate with the RPIC and to monitor the UA as it performs taxi, takeoff, approach, and landing tasks.
- The Unmanned Aircraft System (UAS) Integration into the NAS Concept of Operations (Federal Aviation Administration, 2012) requires all UAS to be equipped with Automatic Dependent Surveillance-Broadcast (ADS-B) Out capability, so the recommendations assume that the UAS, at minimum, uses this technology for navigation.
- The UA is operated in Visual Meteorological Conditions (VMC), so weather conditions such as cloud coverage, cloud height, icing, precipitation, convective weather, and visibility are not accounted for in the recommendations.
- Automation for ground and air sense-and-avoid tasks was not part of the scope of this work.

The team considered the general requirements and assumptions published in the Federal Aviation Administration (2013) UAS integration roadmap listed below (note that roadmap assumptions are designated by the letter *R* followed by the assumption number).

R1. RPICs comply with existing, adapted, and/or new operating rules or procedures as a prerequisite for NAS integration

R2. Civil UAS operating in the NAS must obtain an appropriate airworthiness certificate while public users retain their responsibility to determine airworthiness.

R3. All UAS file and fly an Instrument Flight Rules (IFR) flight plan.

R4. All UAS are equipped with ADS-B (Out) and transponder with altitude-encoding capability. This requirement is independent of the FAA's rule-making for ADS-B (Out).

R5. UAS meet performance and equipage requirements for the environment in which they are operating and adhere to the relevant procedures.
R6. Each UAS has a flight crew appropriate to fulfill the operators' responsibilities, and includes a RPIC. Each RPIC controls only one UA.
R7. Fully autonomous operations are not permitted. The RPIC has full control, or override authority to assume control at all times during normal UAS operations.
R8. Communications spectrum is available to support UAS operations.
R9. No new classes or types of airspace are designated or created specifically for UAS operations.
R10. Federal Aviation Administration (FAA) policy, guidelines, and automation support air traffic decision-makers on assigning priority for individual flights (or flight segments) and providing equitable access to airspace and air traffic services.
R11. Air traffic separation minima in controlled airspace apply to UA.
R12. Air Traffic Control (ATC) is responsible for separation services as required by airspace class and type of flight plan for both manned and unmanned aircraft.
R13. The RPIC complies with all ATC instructions and uses standard phraseology per FAA Order 7110.65 and the Aeronautical Information Manual (Federal Aviation Administration, 2014).
R14. ATC has no direct link to the UAS for flight control purposes.

Based on input from the FAA and discussions about the document scope, additional assumptions were considered. The assumptions below support providing the scope for our recommendations and are designated by the letter *A* preceding the assumption number.

A1. The RPIC does not simultaneously control any payload onboard the UA (note that activities related to aerial work are outside of the scope).
A2. VFR flight is permitted only when the UA is within visual line of sight (VLOS) of a VO (necessary for takeoff and landing at non-towered airports).
A3. Each UA has a maximum crosswind component capability that limits the conditions under which it can depart or land.
A4. The airport has sufficient infrastructure (e.g., reliable power source, ATC communication, etc.) for operating the UAS.
A5. While there may be UAS which use alternative methods for control, like differential engine output and rudder, this document assumes the use of traditional manned aircraft controls, including flaps.

Additional assumptions are related to communication tasks. These assumptions are designated by the letter *C* preceding the assumption number.

C1. Communication with VO always occurs via voice communication.
C2. We do not specify a communication medium between the RPIC and ATC (i.e., datalink vs. radio frequency). Selecting a recipient and communicating with the recipient (either with datalink or radio frequency) is considered the lowest level of communication automation.

C3. VOs are not required to have direct transmit capability with ATC but may have receiving capabilities.

Additional assumptions are related to handover tasks: transfer of control from one remote pilot at a control station (i.e., transferring CS) to a second remote pilot located at a second control station (i.e., receiving CS). The recommendations related to handover (designated by the letter *H* preceding the assumption number) are subject to the following assumptions with respect to the roles and communication:

H1. Voice communication is used to coordinate the handover.
H2. Synchronous communication occurs between the transferring and receiving control stations.
H3. Only the RPICs are actively involved in the handover. If the crew contains any sensor/mission operators, their workstations do not contain any critical functionality that would be required during a handover.
H4. At no point during the handover is there a loss of voice communication between the control stations.
H5. The CS contains, at minimum, three independent communication systems: one for communication with ATC, one for communication with VO, and one for communication with other CSs

The recommendations related to handover also assume that transfers will only occur under the following flight and airspace conditions:

H6. The UA is on straight and level flight; handover must be completed before the UA initiates any turns or changes in altitude.
H7. There should be a minimum altitude only above which transfer of control is permitted (except in the case of an emergency).
H8. There are no ATC instructions or compliance issues that need to be resolved.
H9. Handovers do not occur in congested airspace.
H10. Handovers do not occur during emergency or critical situations (unless the handover itself is part of the emergency or critical checklist sequence).

The recommendations assume limited UAS capability:

H11. The UA contains only one uplink and downlink connection and thus the handover of control and the transfer of relevant UA state information must be performed predominately via two-way communication between the RPICs located at the transferring and receiving CSs.
   a. If there are multiple control stations, manufacturers will likely include two links. If there are two links, then the UAS has a primary and secondary link, and the links would need to be tracked as such.
   b. The UA does not contain automation that checks the accuracy of the settings on the receiving CS. Procedures are required to ensure safety.

H12. The receiving UA does not have transfer of control override authority.

3. METHODOLOGY

A task analysis was conducted for navigation, communication, contingency, and handover. Function allocation strategy recommendations were developed based on the task analysis and a set of taxonomies developed in prior work (Pankok, Bass, Smith, Dolgov, & Walker, 2017). All recommendations were reviewed by subject matter experts (SMEs).

3.1 TASK ANALYSIS METHODOLOGY

A task analysis was conducted for navigation, communication, contingency, and handover with respect to safely and efficiently operating a UAS in the NAS. The task analysis was conducted via the creation of potential operational scenarios and the identification of associated sub-tasks, adaptation of manned aircraft procedures to envisioned UA operations when appropriate, and validation by SMEs. It also benefited from the Project A10 PC-2 document entitled *Standard Operating Procedures Framework: Pilot Procedures and Operational Requirements* (Bruner, Carraway, & Meyer, 2017). The tasks were also refined via pilot SME input.

Situations requiring contingency planning unique to UAS operation include:

- Lost command and/or control link
- Degraded vertical and/or lateral navigation position information during ground operations (e.g., Global Positioning System (GPS) denial/loss)
- Degraded vertical and/or lateral navigation position information during air operations (e.g., GPS denial/loss)
- Loss of contingency flight plan automation (generation and/or evaluation)
- VO failure. This includes VO availability and the RPIC ability to communicate/coordinate with the VO.

3.2 FUNCTION ALLOCATION METHODOLOGY

To address a gap with respect to methods for the development of minimum function allocation recommendations, Pankok and Bass (Pankok & Bass, 2016; Pankok et al., 2017) developed a function allocation taxonomy based on four stages of information processing (Parasuraman, Sheridan, & Wickens, 2000) and created rubrics for developing minimum function allocation recommendations. The rubrics were designed to address planning tasks, monitoring and situation assessment tasks, communication, and continuous and discrete control tasks as these were necessary to differentiate the minimum function allocation recommendations.

A four-step procedure was utilized to develop function allocation recommendations. First, the tasks identified in the task analysis were grouped into four categories: (1) planning tasks, (2) monitoring and situation assessment tasks, (3) continuous control tasks, and (4) discrete control tasks. Planning tasks involve making decisions in advance of performing the action(s). Monitoring and situation assessment tasks involve the acquisition of the UA state and the interpretation of that information to decide whether actions are needed. Continuous control tasks require a control-feedback loop consisting of monitoring the UA and adjusting the control surfaces to maintain the UA state (e.g., executing a contingency plan under degraded position reporting conditions). Finally, discrete control tasks do not require extended monitoring and control, such as setting a communication frequency. Communication tasks involve communicating with a party external to the UAS, such as a VO or ATC.

In the second step of the function allocation process, we generated function allocation rubrics for each task category (Section 5) based on the function allocation taxonomy developed as part of A7 Task 3 "Function allocation literature review".

In step 3, the rubrics were used to create an initial set of function allocation recommendations for safe UAS operation in the NAS. The recommendations reflected the least amount of automation possible to maintain safe flight. For each task, SMEs were presented with a recommended potential function allocation strategy and were asked to provide an explanation for why the recommendation was or was not the minimum level of automation required to perform the task safely in non-segregated airspace, or whether the task should be performed by another human in the system, such as the VO or ATC. In addition to the function allocation recommendations, we included related functional requirements that are independent of the automation and technology available to the RPIC.

Step 4 consisted of the refinement of the function allocation recommendations based on SME input. Dissenting opinions are explicitly recorded in the recommendations.

Additionally, previous inputs from Project A7 and the Project A10 CS-1 task were incorporated.

3.3 SME FEEDBACK METHODOLOGY

Feedback was solicited from nine SMEs with experience in varying roles of UAS operation, including but not limited to experience as a RPIC, control station designers, manned/unmanned flight instructors, manned/unmanned test pilots, FAA certified pilots, and RPICs with UAS research experience (Table 1). Due to these diverse experiences, the collection of SMEs that reviewed the recommendations was able to provide feedback from the perspective of various stakeholders in the UAS community.

A preliminary version of this Function Allocation document, in editable Microsoft Word format, was sent to the SMEs for their feedback. They were asked to provide feedback on the document, particularly answering the following questions:

- Do you feel strongly that this task necessitates a regulation requiring allocation to automation?
- Does the function allocation recommendation for this task represent the minimum level of automation required for safe UAS operation in an integrated NAS?
- Regarding tasks for which wind is a relevant concern, what should be the minimum automation requirement to compensate for the loss of sensory information (e.g., aircraft movement resulting from a wind gust) associated with dealing with wind gusts while operating the aircraft remotely?

SMEs were asked to provide feedback on the initial recommendations and justification for their responses. The responses recorded for each SME were used to augment the original recommendations. To help provide some context, they were asked to consider typical flying conditions including if wind is a relevant concern for the task. Beyond the ubiquitous nature of wind for flight, providing context to SMEs promotes cognitive engagement in the task (Chi & Bjork, 1991; Klein & Hoffman, 1993). When necessary, SMEs were contacted post-hoc for clarification on their responses. Tasks for which there were dissenting opinions among one or more of the SMEs are explicitly identified.

Table 1. Subject matter expert professional experience.

ID	Professional Experience
1	Held various positions of authority for multiple manned and unmanned test programs. 50+ aircraft types flown. Chief Engineer/Test Pilot for Aurora Flight Science Centaur OPA/UAS (4,000+lbs). Pilot of world UAS endurance flight record: Aurora Flight Science Orion UAS (80+ hours). Civilian and military instructor and evaluation pilot. Naval Test Pilot School graduate.
2	20 years of experience in the UAS industry, including as the UAS industry program manager at Embry Riddle Aeronautical University. Performed Shadow 200 user assessment. Qualified instructor for RQ-5 (Hunter) and RQ-7 (Shadow).
3	Boeing Insitu–Manufacturer certified ScanEagle UAS pilot. Flight instructor. FAA Designated Pilot Examiner (pilot and instructor). Certified commercial pilot.
4	Commander, 348th Reconnaissance Squadron – Global Hawk. RQ-4 UAS Evaluator and Instructor Pilot.
5	1200 hours of UAS pilot experience on a diverse set of airframes including Aerostar, Viking 300, Tigershark, Hornet Maxi Helicopter, Scout Multi-Copter, Rave A sUAS, Leptron Avenger sUAS, SenseFly eBee Six years as Lead Safety Analyst/Risk Management for New Mexico State University's FAA UAS Test Site. Commercial pilot with instrument and multi-engine ratings.
6	UAS simulator trainer for SAIC and Simlat. UAS course instructor. Commercial Pilot Instrument Multi Engine Rating for Boeing 707 and Boeing 720.
7	UAS patent formation and design for pilot/cockpit technology deployment.
8	Led creation of the Global Hawk training program. Flight instructor and evaluator with vast international experience. Flight Operations Manager and Executive Director of UAS Program at Kansas State University. Professor of flight operations courses at Kansas State University. Contributed to the revision of the UAS degree curriculum at Kansas State University.
9	UAS pilot for University of Alaska Fairbanks and the Pan Pacific UAS test site. Trained on small- and medium-sized UAS. Experience operating Predator B, Tiger Shark, Shadow, ScanEagle, Puma, and Seahunter.

4. TASK ANALYSIS

The navigation, communication, and contingency tasks in the outline form task analysis are presented below in black and bold text. To help place these tasks in context, other related tasks, such as aviate tasks, are presented and colored in gray. In the parenthesis accompanying these other related tasks is the categorization of the task.

4.1 TAKEOFF

1. Align aircraft with runway heading with brakes engaged (Takeoff)
2. Configure UA for takeoff (e.g., deploy high-lift devices (e.g., flaps, slats)) (Takeoff)
3. **Communicate with VO (and/or tower controllers at a towered airport) to ensure runway is clear for takeoff**
4. **Announce takeoff from runway XX on Common Traffic Advisory Frequency (CTAF), specifying that the vehicle is a UA**
5. Takeoff roll (Takeoff)
6. Check velocity in relation to V_R (Takeoff)
7. Rotate (e.g., pitch adjustment via elevator manipulation) (Takeoff)
8. Initial climb (Takeoff)

4.2 CLIMB OUT

1. **Verify top of climb (TOC)**
2. **Facilitate handover of separation responsibility from VO to ATC (before UA is Beyond Visual Line of Sight (BVLOS))**

4.3 DESCENT

1. **Obtain airport data (e.g., determine runway and weather/wind conditions)**
2. **Communicate with ATC to obtain descent clearance**
3. **Plan descent**
   a. **Determine descent profile**
   b. **Determine top of descent (TOD)**
4. **Announce landing on the runway via CTAF (or obtain approach clearance from ATC if landing at a controlled airport)**
5. **If required, perform missed approach profile and procedure**
6. **Facilitate handover of separation responsibility from ATC to VO (or contact tower controllers if landing at a towered airport)**

4.4 APPROACH

1. **Plan approach**
   a. **Determine approach profile (e.g., descent rate, thrust, angle of descent, etc.)**
   b. **Identify touchdown target on first third of the runway**
2. Execute approach given approach profile (Aviate)

4.5 PHASE AGNOSTIC FUNCTIONS

4.5.1 Communicate

1. **Communicate with external agents, as necessary**
2. **Tune communication networks/frequency, as necessary**

4.5.2 Navigate

1. **Tune applicable navigation avionics, as appropriate**
2. **Obtain ATC clearance for route (as needed)**
3. **Monitor UA position along route**
4. **Monitor UA heading along route**
5. **Monitor UA altitude along route**
6. **Route/trajectory change(s)**
    a. **Determine necessary route/trajectory change(s)**
    b. **Implement route/trajectory change(s)**

4.5.3 Manage System Health and Status (e.g., remaining battery life/fuel reserves)

1. **Pre-flight systems management and checks (e.g., check engines, instruments, and primary and backup communication links)**
2. **Monitor system health and status**
3. **Perform system health and status intervention**
4. **Inform ATC and/or VO, if necessary**

4.5.4 Contingency Management

4.5.4.1 Lost Command and/or Control Link

Pre-taxi:

1. **Plan lost link contingency and upload to UA**

During normal operation, prior to lost link:

2. **Update contingency plan during flight, as necessary**
3. **Monitor link status**

During lost link:

4. **Detect lost link situation**
5. **Identify action(s) that UA will take, based on the current contingency plan**
6. **Communicate UA status and contingency plan with ATC**

4.5.4.2 Degraded Vertical and/or Lateral Navigation Position Information during Ground Operations (e.g., GPS Denial/Loss)

Pre-taxi:

1. **Plan contingencies for ground operation degraded position information**

During normal operation, prior to degraded UA position reporting:

2. **Monitor GPS navigation system and UA position information**

During degraded UA position reporting:

3. **Detect degraded UA position reporting**
4. **Identify action(s) required, based on the current contingency plan**
5. **Communicate issue, contingency plan, and UA status with VO and/or ATC**
6. **Execute contingency plan**

4.5.4.3 Degraded Vertical and/or Lateral Navigation Position Information during Air Operations (e.g., GPS Denial/Loss)

Pre-taxi:

1. **Plan contingencies for air operation degraded position information**

During normal operation, prior to degraded UA position reporting:

2. **Update contingency plan along flight, as necessary**
3. **Monitor GPS navigation system and UA position information**

During degraded UA position reporting:

4. **Detect degraded UA position reporting**
5. **Identify action(s) required, based on the current contingency plan**
6. **Communicate issue, contingency plan, and status with VO and/or ATC**
7. **Execute contingency plan**

4.5.4.4 Loss of Contingency Flight Plan Automation (Generation and/or Evaluation)

1. **Generate plan for loss of contingency planning automation**
2. **Detect loss of contingency planning automation**
3. **Communicate with crew, VO, and/or ATC about loss of contingency planning automation and the plan that will be executed**
4. **Execute plan for loss of contingency planning automation**
5. **Monitor status of contingency planning automation**

4.5.4.5 Visual Observer Failure (e.g., VO Unavailable or Loss of Communication)

Pre-taxi:

1. **Plan contingency for loss of VO assistance**

During normal operation, prior to loss of VO:

2. **Communicate with VO to monitor VO status**

During loss of VO:

3. **Identify action(s) required, based on the current contingency plan**
4. **Communicate issue and contingency plan with ATC**
5. **If required, execute contingency plan**
6. **Update ATC on status, as necessary**

4.5.5 Handover of Control

As compared to piloting a manned aircraft, the handover of control from one control station to another is unique to unmanned operation. In manned operation handover of control from one pilot to another occurs on the same flight deck. In this situation, pilots are able to leverage verbal communication and non-verbal cues such as gestures to communicate. There is no uncertainty about whether the settings on one pilot's workstation differ from the settings on the other pilot's workstation as both pilots can view the information before, during and after the handover. With transfer of control between two remote UAS CSs, remote pilots are unable to leverage non-verbal cues, and there is a degree of uncertainty about the settings on the two CSs.

The following definitions reflect the parties involved in performing a handover of control of an unmanned aircraft (UA):

- Transferring CS: CS that has control authority that it is transferring to a receiving CS. The transferring CS is controlled by the transferring remote pilot in command (RPIC).
- Receiving CS: CS that is receiving control authority from the transferring CS. The receiving CS is controlled by the receiving RPIC.

Through a military UAS accident analysis, Williams (2006) identified that mishaps occur due to the lack of awareness of system settings on the part of the receiving crew. However, there is little work assessing the automation or minimum information requirements necessary to ensure reliable transfer of control for civil UAS. In one human-in-the-loop experiment, Fern and Shively (2011) assessed the effect of four display designs on the receiving RPIC's ability to effectively take over control of a UA. Participants were given control of a UA already in flight, and as quickly as possible were required to use the information display to obtain knowledge about the planned route and cleared waypoints. The four display formats included a *baseline* display (unformatted chat history with UA state information), a *text* display (formatted textual information with UA state information), a *graphics* display (map with UA state information), and a *map with overlay* display (tactical situation display with moving map and route/waypoint information plus UA state information overlay). Empirical results revealed that time to determine airspace status was significantly shorter with the *text* and *graphics* displays than with the *baseline* chat history display (since the *map with overlay* configuration was integrated with the tactical information display, which was displayed at all times, time to determine airspace status was not measured for the *map with overlay* condition). There were no significant differences among the display types with respect to time spent on each mission. The *baseline* display yielded significantly lower subjective ratings of situation awareness, usefulness, and ease of use as compared to the three remaining displays; there was no statistical differences among the other three. Subjective ratings of workload were higher for the *baseline* display than the remaining displays. The *map with overlay* display was ranked as the most preferred display, followed by the *graphics* display, the *text* display, and the *baseline* display.

The following represents the sequence of tasks to handover UA control from the transferring CS to the receiving CS:

1. **Receiving and transferring RPICs establish two-way voice communication.**
2. **Receiving and transferring RPICs coordinate handover procedure and timing.**
3. **Receiving RPIC retrieves UA status and settings.**
4. **Transferring RPIC provides handover briefing to the receiving RPIC.**
5. **Positive transfer of control from transferring CS to receiving CS occurs.**
6. **Receiving RPIC confirms full control of the UA.**
7. **Transferring RPIC stands by as a backup.**

5. FUNCTION ALLOCATION RUBRICS

The following subsections present the categories, descriptions, and the potential function allocation strategies applied in this work.

5.1 PLANNING TASKS

Planning involves the acquisition of information, projecting potential future states, and making one or more decisions about when, where, and/or how the UA will be operated. The implementation of actions to satisfy the plan occurs in the continuous and discrete control tasks. Flying the UAS is an adaptive planning task. The RPIC needs to be able to continually plan for potential flight events to stay ahead of the aircraft. Potential human-automation function allocations are listed below, including a label for each function allocation description in italic text:

(a) *Manual Planning*: RPIC obtains relevant information, generates one or more potential actions, and selects an action.

(b) *Automated Planning Information Acquisition and Presentation*: Automation provides information to RPIC; RPIC generates one or more potential actions, and selects an action. This type of capability requires information acquisition automation and information analysis automation.

(c) *Automated Plan Evaluation*: RPIC generates one or more potential plans, and automation evaluates the plan to ensure it is feasible. This requires decision and action selection automation.

(d) *Automated Planning Option Generation*: Automation obtains relevant information and generates one or more potential actions; RPIC selects an action. This type of capability requires information acquisition automation, information analysis automation, and decision and action selection automation.

(e) *Automated Planning*: Automation obtains relevant information, generates one or more potential actions, selects an action, and informs the RPIC. This requires all four types of automation.

5.2 MONITORING AND SITUATION ASSESSMENT TASKS

Monitoring tasks represent both periodic monitoring (e.g., regular scanning of the strength of the communication link) as well as monitoring in response to an action or alert (e.g., monitoring heading after a planned turn). Monitoring tasks encompass only the information acquisition and information analysis stages of information processing. No decisions are generated or made in these stages; the information gained from monitoring is used to make decisions for the control tasks in the decision and action selection and action implementation stages (reported in Sections 5.3 and 5.4). Since the UA is flying BVLOS, the RPIC does not have the ability to perceive UA state data directly, so UAS automation provides the current UA state in all potential human-automation function allocations listed below. A label in italic text, accompanied by a description of the function allocation strategy, is provided below:

(a) *State*: Automation provides current UA state via the control station; RPIC compares UA state to target state, expected state, and/or threshold for safe operation.

(b) *Filtered State*: Automation provides current UA state via the control station subject to constraint(s) (e.g., filter settings) set by the RPIC; RPIC compares UA state to target state, expected state, and/or threshold for safe operation.

(c) *State and Comparison State*: Automation provides UA state as well as target state, expected state, and/or threshold for safe operation via the control station; RPIC compares UA state to threshold for safe operation. This type of capability requires information acquisition automation and information analysis automation.

(d) *Filtered State and Comparison State*: Automation provides UA state, subject to constraint(s) (e.g., filter settings) set by the RPIC, as well as target state, expected state, and/or threshold for safe operation via the control station; RPIC compares UA state to target state, expected state, and/or threshold for safe operation. This type of capability requires information acquisition automation and information analysis automation.

(e) *Automated Comparison*: Automation compares UA state to target state, expected state, and/or threshold for safe operation, and this information is reported to the RPIC via the control station. This type of capability requires information acquisition automation and information analysis automation.

(f) *Filtered Automated Comparison*: Automation compares UA state, subject to constraint(s) (e.g., filter settings) set by the RPIC, to target state, expected state, and/or threshold for safe operation, and this information is reported to the RPIC via the control station. This type of capability requires information acquisition automation and information analysis automation.

(g) *Automated Comparison and Alert*: Automation compares UA state to target state, expected state, and/or threshold for safe operation and alerts the RPIC if the UA state approaches any threshold related to achieving the target state, expected state, and/or threshold for safe operation via the control station. This type of capability requires information acquisition automation and information analysis automation.

(h) *Filtered Automated Comparison and Alert*: Automation compares UA state, subject to constraint(s) (e.g., filter settings) set by the RPIC, to target state, expected state, and/or threshold for safe operation and alerts the RPIC if the UA state approaches any threshold related to achieving the target state, expected state, and/or threshold for safe operation via the control station. This type of capability requires information acquisition automation and information analysis automation.

Examples of current UA states and corresponding planned states and/or thresholds for safe operation are presented in Table 2.

Table 2. Examples of current UA state, target/expected state, and threshold for safe operation referenced in the potential function allocation strategies for monitoring tasks.

Current UA State	**Target/Expected State**	**Threshold for Safe Operation**
Altitude/flight level	Cleared altitude/flight level	Maximum operational altitude or altitude exceeding ±200 ft. from altitude clearance
Position	Planned route (or contingency route)	N/A

5.3 CONTINUOUS CONTROL TASKS

Continuous control tasks require extended use of resources over time from a system agent to control the UA; these tasks are part of a continuous feedback loop with monitoring tasks, where the monitoring tasks represent the information acquisition and information analysis stages of information processing, and the control tasks represent the decision and action selection and action implementation stages of information processing. The agent that controls the UAS is continuously informed by the agent performing the monitoring and/or planning tasks (note that the same human and/or automated agent could be performing all functions). The potential allocations span from manual control of UA thrust and attitude to automated control of UA thrust and attitude to meet heading, speed, and altitude targets or to fly to waypoints uploaded to the UAS. Potential human-automation function allocations include:

(a) RPIC controls an input (thrust, roll, and/or pitch) to maintain target parameter (e.g., heading). RPICs refer to this level of automation as *manual control*.

(b) RPIC controls an input based on guidance provided by the automation. Guidance requires information analysis automation and decision and action selection automation. This type of automation is *flight guidance*.

(c) RPIC uploads target parameter (e.g., heading, vertical speed); automation controls UA (surfaces and thrust) to maintain target. Operators refer to this level of automation as *basic autoflight*. This type of capability requires information analysis automation, decision and action selection automation, and action implementation automation.

(d) RPIC uploads flight trajectory targets (e.g., waypoints, runway); automation develops a plan and controls UA (surfaces as well as thrust) to fly to flight trajectory targets. Operators refer to this level of automation as *advanced autoflight*. This type of capability requires information analysis automation, decision and action selection automation, and action implementation automation.

5.4 DISCRETE CONTROL TASKS

Discrete control tasks occur at a specific time during the flight, and while they do require a degree of monitoring as part of a control-monitoring feedback loop, it is not continuous like it is for the control-monitoring feedback loop for continuous control tasks. Monitoring generally occurs in two ways: (1) the RPIC (or automation) monitors the UAS until the UA parameter achieves a state, and then the RPIC (or automation) makes a discrete control input (e.g., set the communication frequency); or (2) the RPIC (or automation) makes a discrete change and monitors a continuous process until a parameter is met.

Discrete control tasks occur in the decision and action selection and action implementation stages of information processing; the monitoring that occurs prior to and/or following the discrete control action is covered in the monitoring section (Section 5.2). There are five roles that can be allocated to the human operator or an automated agent for discrete control tasks, including:

1. *Generate one or more action options:* This role represents the generation of one or more potential options for the discrete control action.
2. *Select an action option*: This role represents the selection of one of the potential actions generated in Step 1, according to some criteria.
3. *Evaluate selection*: This role represents review of the selection from Step 2 to ensure it meets the defined criteria.
4. *Execute selection*: This role represents the delivery of the command to the aircraft to perform the action.
5. *Feedback on implementation*: If a human or automated agent implements an action, this role represents the strategy used to inform the human operator that the action has been implemented. The four potential feedback strategies include compulsory feedback, feedback by request, feedback by design, and no feedback. These are defined in the taxonomy of human automation interaction developed as part of the A7 function allocation literature review.

Allocating the human RPIC and the automation to these roles, Table 3 reveals the potential function allocations for discrete control tasks. In addition to the function allocation strategies identified in Table 3, each of the eleven strategies can be crossed with each of the four feedback strategies mentioned above, yielding 44 potential strategies. Although we have not explicitly identified the full crossing in Table 3, the feedback strategy has been made explicit in the recommendations.

Table 3. Potential function allocations for UAS discrete control tasks.

Strategy	Generate One Or More Action Options	Select an Action Option	Evaluate Selection	Execute Selection
a	RPIC	RPIC	RPIC	RPIC
b	RPIC	RPIC	Automation	RPIC
c	Automation	RPIC	RPIC	RPIC
d	Automation (constrained by RPIC)	RPIC	RPIC	RPIC
e	Automation	RPIC	Automation	RPIC
f	Automation (constrained by RPIC)	RPIC	Automation	RPIC
g	Automation	Automation	RPIC	RPIC
h	Automation	Automation (constrained by RPIC)	RPIC	RPIC
i	Automation	Automation	Automation	RPIC
j	Automation	Automation (constrained by RPIC)	Automation	RPIC
k	Automation	Automation	Automation	Automation

5.5 COMMUNICATION TASKS

Communication tasks are those for which the RPIC communicates with other human system agents, such as ATC or VO. Typical communication tasks include announcements (e.g., RPIC announces takeoff), requests for information (e.g., RPIC requests wind speed and direction at the airport), instructions (e.g., ATC gives an altitude clearance), and off-nominal communications (e.g., requesting a re-route due to an emergency). These tasks are comprised of determining an appropriate time to communicate, the technology/medium used to communicate, the message itself, and monitoring for a response. In the potential function allocation strategies below, we do not specify the communication medium (e.g., face-to-face, radio communication, or data link communications). There may often be cases in which multiple communication channels are required. For example, during takeoff, the RPIC could be required to communicate with ATC, the VO, and other aircraft (via CTAF) within a short time frame.

Potential human-automation function allocation strategies are listed in Table 4. The determination of the communication time is based on an understanding of the context which could be supported by information analysis automation. Generating the message could be supported by decision and action selection automation. Delivering the message could be supported by action implementation automation. Monitoring for the response could be supported by both information acquisition automation for the data itself and information analysis automation to support interpretation.

Table 4. Function allocation recommendations strategies for communication

Label	**Determine appropriate context to communicate** (Information Analysis Automation**)**	**Generate message content** (Decision and Action Selection Automation)	**Deliver message** (Action Implementation Automation)	**Monitor communication medium for response** (Information Acquisition Automation & Information Analysis Automation)
a	RPIC	RPIC	RPIC	RPIC
b	Automation	RPIC	RPIC	RPIC
c	RPIC	Automation	RPIC	RPIC
d	RPIC	Automation	Automation, then informs RPIC	RPIC
e	Automation	Automation	RPIC	RPIC
f	Automation	Automation	Automation, then informs RPIC	RPIC
g	Automation	Automation	Automation	Automation

6. FUNCTION ALLOCATION RECOMMENDATIONS: NAVIGATION, COMMUNICATION, CONTINGENCY, AND HANDOVER

This section contains the minimum function allocation recommendations for each task from the task analysis, organized by phase of flight. Under each task is the following content:

- Minimum function allocation recommendation: Recommended minimum function allocation strategy for the task, categorized by the rubrics contained in Section 5.
- Rationale: Explanation for the recommendation.
- SME comments: Relevant SME feedback for the task.
- Potential safety implications: Safety implications of performing the task properly.
- Potential higher/lower function allocation(s): Alternative function allocation strategies.
- Autonomous mode recommendation: Our recommendations come with the caveat that all UA larger than 55 lb must have an autonomous mode for lost link situations. This item contains the function allocation strategy associated with the autonomous mode.

6.1 TAKEOFF

6.1.1 Communicate with external agents (including VO and other pilots via CTAF)

Please see our recommendation for *Communicate with external agents* in Section 6.5.1.

6.2 CLIMB OUT

6.2.1 Verify top of climb (TOC)

Minimum function allocation recommendation: The CS should provide the required information for the RPIC to determine the TOC (planning function allocation recommendation a, *manual planning*).

Rationale: The RPIC planned the original TOC pre-flight, and needs to verify the TOC to make any necessary changes. The RPIC being remote from the aircraft has little implication on the verification of TOC, so the RPIC should be able to perform this task similarly to a manned aircraft pilot.

SME comments: All SMEs agreed with the recommendation.

Potential safety implication(s): Inaccurate identification of TOC could result in a loss of separation or mid-air collision with another aircraft, since the UA could be arriving to TOC later than planned or at a different location than planned. Furthermore, arrival at TOC before or after schedule has implications for the power plant (e.g., fuel consumption or battery life), potentially necessitating a route change.

Potential higher LOA: Automation identifies TOC for the UA based on the planned cruise altitude, climb rate, and environmental conditions.

Autonomous mode function allocation recommendation: The autonomous mode does not apply to planning tasks; the RPIC and/or other crew members manually identify the TOC, reflecting planning function allocation strategy a, *manual planning*.

6.2.2 Facilitate handover of separation responsibility from VO to ATC

Please see our recommendation for *Communicate with external agents* in Section 6.5.1.

6.3 DESCENT

6.3.1 Obtain airport data (e.g., determine runway and weather/wind conditions)

Minimum function allocation recommendation: The CS should provide the RPIC the means to determine the terminal area and field conditions prior to arrival, such as via ATIS or ASOS (planning function allocation strategy a, *manual planning*).

Rationale: The destination airport and runway are planned pre-flight, so the RPIC needs to obtain updated relevant airport information (e.g., wind conditions and open/closed runways) to ensure landing can be performed as planned. A common method to accomplish this is by obtaining the airport's ATIS or ASOS information. Alternatively, the RPIC could contact the VO at the arrival airport and request that the VO obtain relevant airport data and report it to the RPIC.

SME comments: All SMEs agreed with the recommendation.

Potential safety implication(s): The RPIC needs to be aware of open/closed runways, approach reference conditions, and relevant weather information to plan a safe descent, approach, and landing. Being uninformed could lead to an attempted landing on a closed runway, potentially leading to an accident involving the UA, other vehicles on the airport surface, and/or airport infrastructure.

Potential higher LOA: (1) Automation acquires airport data and presents it to the RPIC in the control station. (2) Automation acquires airport information and provides one or more recommendations for planned descent and approach routes.

Autonomous mode function allocation recommendation: The autonomous mode applies to UA control, so the RPIC should be able to obtain airport data (planning function allocation strategy a, *manual planning*).

6.3.2 Communicate with ATC to obtain descent clearance

Please see our recommendation for *Communicate with external agents* in Section 6.5.1.

6.3.3 Plan descent

6.3.3.1 Determine descent profile

Minimum function allocation recommendation: The CS should provide the RPIC with the information to determine the descent profile without assistance from automation (planning function allocation strategy a, *manual planning*).

Rationale: The descent was planned pre-flight, but may be updated to account for weather or other environmental conditions. As a minimum requirement, the RPIC should be able to determine the UA descent profile to meet the descent objective (e.g., fuel efficiency or time efficiency), UA performance characteristics (e.g., optimal descent rate), and any ATC clearance(s) without any assistance from automation. The RPIC being remote from the aircraft has little implication for this task, so there is no additional support required beyond what is required for manned aircraft.

SME comments: All SMEs agreed with the recommendation.

Potential safety implication(s): Planning a descent profile that does not satisfy ATC clearance(s) and/or is not possible for the UA to fly (due to its performance characteristics) could lead to the

UA drifting off its cleared descent route, resulting in a potential incident or accident with other aircraft or terrain, or missing the runway altogether.

Potential higher LOAs: (1) Automation acquires relevant information and/or constraints for determining the descent profile and presents it to the RPIC in the UAS control station. (2) Automation makes one or more recommendations for a descent profile meeting all constraints, and the RPIC has the ability to accept or reject the recommendation(s).

Autonomous mode function allocation recommendation: The autonomous mode applies to UA control, so the RPIC should be able to determine the descent profile (planning function allocation strategy a, *manual planning*).

6.3.3.2 Determine TOD

Minimum function allocation recommendation: The CS should provide the RPIC with the information needed to determine the top of descent point based on the planned descent profile and approach route (planning function allocation strategy a, *manual planning*).

Rationale: TOD was planned pre-flight, but may need to be updated due to changing weather or updated clearance. Manned aircraft operators perform this task manually (particularly general aviation pilots), and the remote status of the RPIC has little implication on this task, so the RPIC should be able to determine the TOD, accounting for the planned descent profile, planned runway approach route, and any ATC clearances.

SME comments: All SMEs agreed with the recommendation.

Potential safety implication(s): Determining a TOD that is too close to the airport could result in a situation in which the UA cannot descend quickly enough, while also sufficiently slowing UA speed, leading to landing at an unsafe speed or inability to land at all. Landing at an unsafe speed could lead to overrunning the runway or an incident/accident with vehicles on the airport surface or airport infrastructure.

Potential higher LOAs: (1) Automation acquires relevant information for determining TOD and presents it to the RPIC in the UAS control station. (2) Automation makes one or more recommendations for a TOD point, and the RPIC has the ability to accept or reject the recommendation(s).

Autonomous mode function allocation recommendation: The autonomous mode applies to UA control, so the RPIC should be able to determine TOD point (planning function allocation strategy a, *manual planning*).

6.3.4 Announce landing on the runway via CTAF

Please see our recommendation for *Communicate with external agents* in Section 6.5.1.

6.3.5 Facilitate handover of separation responsibility from ATC to VO

Please see our recommendation for *Communicate with external agents* in Section 6.5.1.

6.4 APPROACH

Execution requirements for the approach phase are covered in the Communications and Navigation sections (Sections 6.5 and 6.6, respectively).

6.4.1 Plan approach

6.4.1.1 Determine approach profile

Minimum function allocation recommendation: The CS should provide the RPIC with the information to determine the approach profile (planning function allocation strategy a, *manual planning*).

Rationale: This criterion is being evaluated for approach profiles that do not require visual references. While there are approaches with visual descent points (VDP) and/or visual reference navigation points, it is assumed that methods with equivalent levels of safety would be utilized to navigate these types of approaches or they would not be authorized. The approach profile is planned pre-flight, but changing weather and clearances could necessitate changes to the plan. As a minimum requirement, the RPIC should be able to plan the UA approach profile, taking into consideration the approach route/procedure, UA performance characteristics, and any ATC clearance(s) without any assistance from automation. The PIC being remote from the aircraft has little implication for this task, so there is no additional support required beyond what is required for manned aircraft.

SME comments: All SMEs agreed with the recommendation.

Potential safety implication(s): Planning an approach profile that does not satisfy ATC clearance(s) and/or is not possible for the UA to fly (due to its performance characteristics) could lead to the UA drifting off the approach route, resulting in a potential incident or accident with other aircraft or terrain, or missing the runway altogether.

Potential higher LOAs: (1) Automation acquires relevant information and/or constraints for determining the approach profile and presents it to the RPIC in the UAS control station. (2) Automation makes one or more recommendations for an approach profile meeting all constraints, and the RPIC has the ability to accept or reject the recommendation(s).

Autonomous mode function allocation recommendation: The autonomous mode applies to UA control, so the RPIC should be able to determine the approach profile without assistance (planning function allocation strategy a, *manual planning*).

6.4.1.2 Identify touchdown target on first third of the runway

Minimum function allocation recommendation: The CS should provide the RPIC with the information needed to determine the UA touchdown point in the landing environment within safe limits (planning function allocation strategy a, *manual planning*).

Rationale: SME comments indicate that the UA can be manually controlled to landing. Therefore, the RPIC should have the capability to identify a touchdown target, current touchdown point, and that they are within acceptable deviations. This also assumes that sufficient information is being delivered to the control station in a timely manner.

SME comments: All SMEs agreed with the recommendation.

Potential safety implication(s): Inability to touch down within acceptable deviation within the landing environment could lead to an attempted landing in which the UA misses the acceptable touchdown area and results in a mishap.

Potential higher LOA: Automation recommends a touch down target and/or the current touchdown point based on UA state and environmental conditions.

Autonomous mode function allocation recommendation: Automation should identify the touch down target and touchdown point on the runway (planning function allocation strategy e, *automated planning*).

6.5 COMMUNICATE

6.5.1 Communicate with external agents

Minimum function allocation recommendation: The CS should provide the RPIC the means to communicate to external agents via common aviation communications circuits (voice and datalink radios) (communication function allocation strategy *a*).

Rationale: The capability for two-way communications is a requirement of typical flight operations, especially IFR flight. There are no differences between manned and unmanned operations that substantially affect pilot ability to obtain clearance from ATC or communicate with other external agents. Takeoff, departure, terminal sequencing, and cruise flight all require the ability to communicate with multiple external agents throughout. Therefore, the RPIC should be able to communicate with required external agents without assistance from high levels of automation.

SME comments: All SMEs agreed with the recommendation.

Potential safety implication(s): Inability to communicate could lead to an accident with other vehicles.

Potential higher LOAs: (1) UAS control station automation generates one or more messages, and the RPIC relays the message. (2) UAS control station automation generates one or more messages and automatically sends them to the proper external agent.

Autonomous mode function allocation recommendation: The autonomous mode does not apply to communication tasks, so the RPIC should be able to communicate with external agents without assistance from automation, reflecting communication function allocation strategy *a*.

6.5.2 Tune communication networks/frequency, as necessary

Minimum function allocation recommendation: CS should provide the RPIC with the ability to monitor, identify, and tune communication networks/frequencies as necessary (discrete control function allocation strategy *a*).

Rationale: Assuming the UAS presents accurate and timely UA position information to the RPIC, (s)he should be able to tune the communicate network/frequency, as the task in the UAS environment is not substantially different from the task in the manned aviation environment.

SME comments: All SMEs agreed with the recommendation.

Potential safety implication(s): Inability to tune the communication frequency has similar implications to lost communication link; the RPIC is unable to generate requests or receive commands from external agents, potentially leading to loss of separation or mid-air collision with another aircraft.

Potential higher LOAs: (1) Automation alerts the RPIC whenever the communication network/frequency needs to be updated. (2) Automation continually informs the RPIC of the required network/frequency in the current area (ARTCC/sector, arrival/departure control, Tower, etc.), and the RPIC manually updates the frequency in the control station. (3) Automation updates the communication network/frequency and informs the RPIC of the changes whenever necessary.

Autonomous mode function allocation recommendation: Autonomous mode applies to UAS control, so the RPIC should be able to update communication network/frequencies as necessary, reflecting discrete control function allocation strategy *a*.

6.6 NAVIGATE

6.6.1 Tune applicable navigation avionics, as necessary

Minimum function allocation recommendation: CS should provide the RPIC with the ability to monitor, identify, and tune navigational networks/frequencies as necessary (discrete control function allocation strategy *a*).

Rationale: Based on UA position information the RPIC should be able to manually tune applicable navigation avionics, as the task in the UAS environment is not substantially different from the task in the manned aviation environment.

SME comments: All SMEs agreed with the recommendation.

Potential safety implication(s): Inability to tune navigation avionics could make it difficult to determine where the UA is flying relative to its planned route, potentially leading to loss of separation or mid-air collision with another aircraft.

Potential higher LOA: Automation tunes the navigation instruments and informs the RPIC of the change whenever necessary.

Autonomous mode function allocation recommendation: Autonomous mode applies to UAS control, so the RPIC should still be able to manually tune the navigation instruments as necessary, reflecting discrete control function allocation strategy ***a***.

6.6.2 Obtain ATC clearance for route (as needed)

Please see our recommendation for *Communicate with external agents* in Section 6.5.1.

6.6.3 Monitor UA position along route

Minimum function allocation recommendation: The CS should provide the RPIC with information to determine UA position and track relative to the cleared route for both maintaining and intercepting cleared routes (monitoring and situation assessment function allocation strategy a, *state*).

Rationale: The control station should provide the aircraft position and track in a manner that allows the RPIC to compare them to the cleared route. This information needs to be provided in a manner that allows for acceptable off course deviations to be detected. These deviation levels will vary based on the navigational source and phase of flight (enroute, terminal, approach). Additionally, the provided information needs to allow the RPIC to be able to both maintain and intercept clearance routes (track over ground) within acceptable deviations and with reasonable workload/skill levels.

SME comments: All SMEs agreed with the recommendation.

Potential safety implication(s): Without providing position and track information relative to the cleared route, the UA could be flying a route for which it was not cleared to fly, potentially resulting in loss of separation with other aircraft, controlled flight into terrain, or collision with other aircraft.

Potential lower and higher LOAs: (1) UAS control station automation provides the UA position and track as well as information about the cleared route (higher LOA). (2) UAS control station automation compares the UA position to the cleared route and displays the difference between the two (higher LOA). (3) UAS control station automation compares the UA position to the cleared route and alerts the RPIC if the error exceeds a threshold representing safe operation (higher LOA).

Autonomous mode function allocation recommendation: The autonomous mode applies to UA control, so the RPIC should be able to monitor the UA position and track relative to the cleared route (monitoring and situation assessment function allocation strategy c, *state and comparison state*).

6.6.4 Monitor UA heading along route

Minimum function allocation recommendation: The CS should provide the RPIC with the information and control means to intercept and maintain a cleared magnetic heading (discrete control function allocation strategy *a*).

Rationale: The control station should provide the aircraft heading in a manner that allows the RPIC to compare it to the cleared heading. This information needs to be provided in a manner that allows for acceptable off course deviations to be detected. These deviation levels will vary based on the phase of flight (enroute, terminal, approach). Additionally, the provided information needs to allow the RPIC to be able to both maintain and intercept cleared headings within acceptable deviations and with reasonable workload/skill levels.

SME comments: All SMEs agreed with the recommendation.

Potential safety implication(s): Without providing a means to fly an assigned heading, the UA could be flying a route for which it was not cleared to fly, potentially resulting in loss of separation with other aircraft, controlled flight into terrain, or collision with other aircraft.

Potential lower and higher LOAs: (1) CS automation provides the UA heading as well as information about the cleared heading (higher LOA). (2) UAS control station automation compares the UA heading to the cleared heading and displays the difference between the two (higher LOA). (3) UAS control station automation compares the UA heading to the cleared heading and alerts the RPIC if the error exceeds a threshold representing safe operation (higher LOA).

Autonomous mode function allocation recommendation: The autonomous mode applies to UA control, so the RPIC should be able to monitor the UA heading relative to the cleared heading (monitoring and situation assessment function allocation strategy c, *state and comparison state*).

6.6.5 Monitor UA altitude along route

Minimum function allocation recommendation: The CS should provide the RPIC with information to determine UA altitude relative to the cleared altitude for both maintaining and intercepting cleared altitudes and vertical profiles (monitoring and situation assessment function allocation strategy a, *state*).

Rationale: Manned aircraft are required to contain altimeters to provide the pilot with aircraft altitude (14 CFR 23.1303(b), 14 CFR 91.205(b)(2), 14 CFR 121.305(b), 14 CFR 121.323(f), 14 CFR 121.325(b), 14 CFR 125.205(j)). Therefore, this information should also be provided to the RPIC, who has no other way of estimating UA altitude due to being remote from the aircraft. This information needs to be provided in a manner that allows for acceptable “off altitude” and “off vertical profile” deviations to be detected. These deviation levels will vary based on the phase of flight (enroute, terminal, approach). Additionally, the provided information needs to allow the RPIC to be able to both maintain and intercept cleared altitudes and vertical profiles (i.e. Glidepaths) within acceptable deviations and with reasonable workload/skill levels.

SME comments: All SMEs agreed with the recommendation.

Potential safety implication(s): Without providing altitude information, the UA could fly at an incorrect altitude, potentially resulting in loss of separation with other aircraft, controlled flight into terrain, or collision with other aircraft.

Potential higher LOAs: (1) CS automation provides the UA altitude and the cleared altitude. (2) CS automation compares the UA altitude to the cleared altitude and displays the difference between the two. (3) CS automation compares the UA altitude to the cleared altitude and alerts the RPIC if the error exceeds a threshold representing safe operation.

Autonomous mode function allocation recommendation: The autonomous mode applies to UA control, so the RPIC should be able to monitor the UA altitude relative to the cleared altitude (monitoring and situation assessment function allocation strategy a, *state*).

6.6.6 Route/trajectory change(s)

6.6.6.1 Determine necessary route/trajectory change(s)

Minimum function allocation recommendation: The CS provides the RPIC with information needed to generate and select potential re-routes (planning function allocation strategy a, *manual planning*).

Rationale: Operating the aircraft remotely does not substantially change the task of determining necessary route/trajectory change(s) compared to being onboard the aircraft. Therefore, a high level of automation is not required for determining necessary route/trajectory changes, apart from presenting the RPIC with relevant information.

SME comments: All SMEs agreed with the recommendation.

Potential safety implication(s): Insufficient information presented to the RPIC that impedes determination of route/trajectory changes could lead to loss of separation with other aircraft or inability to avoid terrain, potentially leading to an incident or accident.

Potential higher LOAs: (1) Automation generates one or more potential route/trajectory changes and presents them to the RPIC, who can choose one of the automation-generated route/trajectory change or generate his/her own route/trajectory change. (2) Automation generates one or more potential route/trajectory changes utilizing weather information (i.e. winds) and selects one, informing the RPIC of the selection.

Autonomous mode function allocation recommendation: The autonomous mode applies to UA control, so the RPIC should be able to determine route/trajectory changes based on information provided to the RPIC in the control station (planning function allocation strategy b, *automated information acquisition and presentation*).

6.6.6.2 Implement route/trajectory change(s)

Minimum function allocation recommendation: The CS should provide the RPIC with the ability to implement route/trajectory change(s) (discrete control function allocation strategy *a*).

Rationale: Envisioned UAS integration into the NAS will require the RPIC to be the final decision-maker during flight. Furthermore, our recommendations for the minimum level of control automation were for low levels of automation (Pankok et al., 2017). Therefore, the RPIC should be able to manually implement the route/trajectory changes.

SME comments: All SMEs agreed with the recommendation.

Potential safety implication(s): Inability to implement route/trajectory changes, particularly when a route/trajectory change is required to avoid another aircraft or terrain, could lead to an incident or accident.

Potential higher LOA: Automation implements the route/trajectory change and informs the RPIC that it has been implemented.

Autonomous mode function allocation recommendation: Automation implements the route/trajectory change and informs the RPIC that it has been implemented, reflecting discrete control function allocation strategy *k*.

6.7 MANAGE SYSTEM HEALTH AND STATUS

6.7.1 Pre-flight systems management and checks (e.g., check engines, instruments, and primary and backup communication links)

Minimum function allocation recommendation: RPIC (or crew members collocated with the UA) should be able to perform UA systems management task(s) to ensure the UA is operating properly (discrete control function allocation strategy *a*).

Rationale: Assuming this task is performed prior to taxi, automation is not required to check the systems via system readings and visual inspection of the aircraft surfaces. The RPIC should be able to use system readings to check the operability of systems, and any crewmembers that are physically located with the UA should be able to visually inspect that the surfaces are operating as designed.

SME comments: All SMEs agreed with the recommendation.

Potential safety implication(s): Inability to properly diagnose malfunctioning UAS systems could result in an incident or accident with the UA itself, with the UA and other vehicles, or the UA and terrain.

Potential higher LOA: Automation alerts the RPIC if, during the systems checks, any value does not fall into a normal range.

Autonomous mode function allocation recommendation: The autonomous mode applies to UA control, so the crew should perform systems checks tasks manually, reflecting discrete control function allocation strategy *a*.

6.7.2 Monitor system health and status

Minimum function allocation recommendation: The CS should provide system health and status indications, and alert the RPIC if the status of any systems could result in unsafe operations (monitoring and situation assessment function allocation strategy g, *automated comparison and alert*).

Rationale: Regulations for manned aircraft require alerting functionality for some system functions, including fuel pump malfunction (14 CFR 23.991(c)), low fuel pressure (14 CFR 23.1305(c)(3)), low oil pressure (14 CFR 23.1305(c)(6)), generator/alternator failure (14 CFR 23.1351(c)(4)), battery temperature (14 CFR 23.1353(g)(2)), and power failure (14 CFR 125.205(d)). The RPIC will likely prioritize aviating and navigating tasks to monitoring system health and status; since aviating and navigating require large amounts of attentional and information processing resources, automation should alert the RPIC of any system health and status indicative of unsafe operation. These indications should have a logical and functional grouping and display methodology to aid the RPIC in identifying both level of alert and affected system(s). This requirement is also reflected in manned aircraft certification requirements.

Furthermore, the RPIC lacks the ability to retrieve visual, auditory, olfactory, and/or kinesthetic cues indicative of a system health and status issue.

SME comments: All SMEs agreed with the recommendation.

Potential safety implication(s): System malfunctioning could result in a situation with diminished or no ability to control the UA, potentially leading to an accident with other aircraft or terrain.

Potential lower LOAs: (1) UAS control station automation provides the system health and status alone. (2) UAS control station automation provides the system health and status as well as the corresponding threshold(s) for safe operation. (3) UAS control station automation compares the system health and status to the corresponding threshold for safe operation and displays the difference between the two.

Autonomous mode function allocation recommendation: The autonomous mode applies to UA control, so the RPIC should be alerted when the UA, in autonomous mode, is approaching an area in which the C2 link strength (monitoring and situation assessment function allocation strategy g, *automated comparison and alert*).

6.7.3 Perform system health and status intervention

Minimum function allocation recommendation: The CS should provide the RPIC with means to perform an action that alleviates the health and safety issue; the CS should also provide the RPIC with the information needed to monitor the system and assess the effectiveness of the intervention (discrete control function allocation strategy *a*).

Rationale: As mentioned, there are significant differences as to the types of cues available to diagnose and to evaluate the effects of an intervention when a RPIC as compared as being onboard the aircraft. For example, vibrations, sounds, smells and other perceptual information would not be available to the remote pilot. However, the actions themselves may be quite similar as to when onboard. It is also possible that there is an advantage to being remote during an emergency; there may be less stress on the RPIC, enhancing decision making, since the RPIC is not collocated with the vehicle. Therefore, assuming sufficient information is provided, the RPIC should be able to perform the intervention manually. These indications should have a logical and functional grouping and display methodology to aid the RPIC in identifying both level of alert and affected system(s). This requirement is also reflected in manned aircraft certification requirements. The most significant difference is possibly in post-hoc retrieval of information for evaluating the intervention; the pilot onboard the aircraft will receive almost immediate feedback to assess the effectiveness of the intervention, while the remote RPIC may experience some latency in receiving the information necessary to evaluate the intervention.

SME comments: All SMEs agreed with the recommendation.

Potential safety implication(s): Inability to perform a successful intervention could lead to diminished or complete loss of UA control, leading to an accident with other aircraft or terrain.

Potential higher LOAs: (1) RPIC generates and selects an intervention, and automation evaluates the intervention for its potential success. (2) Automation presents one or more potential interventions, allowing the RPIC to choose one or develop his/her own intervention.

Autonomous mode function allocation recommendation: The autonomous mode applies to UA control, so, if required, the RPIC should be able to switch the UAS to manual mode and perform the intervention (discrete control function allocation strategy *g*).

6.7.4 Inform ATC/VO, if necessary

Please see our recommendation for *Communicate with external agents* in Section 6.5.1.

6.8 CONTINGENCY MANAGEMENT

6.8.1 Lost command and/or control link

6.8.1.1 Pre-taxi: Plan lost link contingency and upload to UA

Minimum function allocation recommendation: The CS should provide the RPIC with the means to plan the lost link contingency and upload it to the UA (planning function allocation strategy a, *manual planning*).

Rationale: Although this emergency situation is not applicable for manned aircraft operation (lost command and/or control link), UAS pre-flight planning for potential emergencies does not deviate substantially from manned operation (e.g., manned pilots identifying potential alternate airports or ditching areas along planned route). Furthermore, since this task is performed pre-flight, it is not subject to the human factors implications that are present during flight, such as competition for resources due to multiple concurrent tasks, latency, and loss of sensory information. Therefore, as a minimum requirement, the RPIC should be able to manually plan the lost link contingency plan and upload it to the UA.

SME comments: All SMEs agreed with the recommendation.

Potential safety implication(s): Errors in planning/uploading lost link actions could lead to a situation in which there is uncertainty in what the UA will do in a lost link situation, making it difficult for ATC to make traffic adjustments accordingly.

Potential higher LOAs: (1) Automation provides information relevant for contingency planning (e.g., alternate airports, loitering areas) and the RPIC uses this information to create a contingency plan for lost link. (2) Automation provides suggested contingency plans, and the RPIC selects one or generates another plan. (3) RPIC generates a contingency plan for lost link and automation evaluates the plan for feasibility and/or efficiency.

Autonomous mode function allocation recommendation: The importance of contingency planning is not affected by the UAS operating in an autonomous mode, so the autonomous mode recommendation is the same as the minimum recommendation (planning function allocation strategy a, *manual planning*).

6.8.1.2 Normal operation, prior to lost link: Update contingency plan during flight, as necessary

Minimum function allocation recommendation: The CS should provide a means for the RPIC to change and update the lost link contingency plan during flight, as necessary (planning function allocation strategy a, *manual planning*).

Rationale: Planning for potential emergencies does not deviate substantially from manned operation (e.g., manned pilots update potential alternate airports while operating along the planned route). Link coverage is the one aspect that does present a difference. The CS needs to provide the RPIC with a means to plan for any potential areas of reduced link quality. This is analogous to minimum reception altitudes for ground base navigational aids or verifying GPS coverage levels along one's route which are true for both manned and unmanned flight. Latency and loss of sensory information due to remote operation have little implication for completing this task. Therefore, as a minimum requirement, the RPIC should be able to manually update the lost link contingency plan.

SME comments: All SMEs agreed with the recommendation.

Potential safety implication(s): If the lost link contingency plan is not updated as necessary, it could lead to a situation in which the UA is operating a lost link route that is not appropriate for the UA location or phase of flight, potentially resulting in an incident/accident.

Potential higher LOAs: (1) Automation informs the RPIC when the lost link contingency plan needs to be updated, and the RPIC updates the plan. (2) Automation generates one or more lost link contingency re-plan options, and the RPIC selects one or generates a different re-plan. (3) RPIC generates one or more potential re-plans and automation evaluates the re-plan for feasibility and/or efficiency.

Autonomous mode function allocation recommendation: The autonomous mode applies to UAS control, so the autonomous mode recommendation is the same as the minimum recommendation (planning function allocation strategy a, *manual planning*).

6.8.1.3 Normal operation, prior to lost link: Monitor link status

Minimum function allocation recommendation: UAS control station should provide the C2 link status to the RPIC and monitor link strength compared to the threshold strength required for reliable UAS C2 (monitoring and situation assessment function allocation strategy e, *automated comparison*).

Rationale: Due to the criticality of maintaining a strong C2 link, the RPIC should be able to monitor its status. Furthermore, due to our recommendation for alerting automation when lost link is detected (Section 6.8.1.4), automation should also monitor the control link.

SME comments: All SMEs agreed with the recommendation.

Potential safety implication(s): Inability to monitor the C2 link status could prevent the RPIC from making route changes prior to lost link that could prevent losing the C2 link.

Potential higher LOA: UAS control station automation projects the link status in the future and informs the RPIC if the C2 link is projected to be lost.

Autonomous mode function allocation recommendation: Monitoring the C2 link is just as critical in the autonomous mode as it is in the manual mode, so the recommendation for autonomous mode is the same as for the manual mode (monitoring and situation assessment function allocation strategy e, *automated comparison*).

6.8.1.4 During lost link: Detect lost link situation

Minimum function allocation recommendation: Automation should detect lost link and alert the RPIC of the lost link situation (monitoring and situation assessment function allocation strategy h, *filtered automated comparison and alert*).

Rationale: Maintaining the C2 link with the UA (and knowledge of whether the link is currently active) is extremely critical for safe UAS operation. Current manned regulations require alerting functionality for some system functions, including fuel pump malfunction (14 CFR 23.991(c)), low fuel pressure (14 CFR 23.1305(c)(3)), low oil pressure (14 CFR 23.1305(c)(6)), generator/alternator failure (14 CFR 23.1351(c)(4)), and battery temperature (14 CFR 23.1353(g)(2)), and maintaining an active C2 link is potentially more critical than those systems. Furthermore, a threshold time should be established so that the RPIC is not being alerted continually for small, inconsequential periods of lost link (e.g., the RPIC is alerted when lost link exceeds 15 seconds). This threshold should be set based on phase of operations and the associated time criticality of lost link.

SME comments: All SMEs agreed with the recommendation.

Potential safety implication(s): In flight, the RPIC being unaware that the UA is flying lost link can lead to a loss of separation with another aircraft since the RPIC is unable to deliver commands to the UA and ATC is not able to move air traffic to account for the lost link route. Similarly, during ground operations loss of control link can result in conflicts.

Potential lower LOA: UAS control station reports the link strength, but does not alert the RPIC when the link has been lost.

Autonomous mode function allocation recommendation: Automation should detect lost link and alert the RPIC that (s)he no longer can override the autonomous mode, reflecting monitoring and situation assessment function allocation strategy h, *filtered automated comparison and alert*.

6.8.1.5 During lost link: Identify action(s) that UA will take, based on the current contingency plan

Minimum function allocation recommendation: The RPIC should be able to access/identify the actions that the UA will take based on the current contingency plan (planning function allocation strategy a, *manual planning*).

Rationale: When the UAS C2 link is lost, the RPIC needs to be able to maintain awareness of the UA along its contingency plan so that it can be communicated to ATC. Beyond this requirement, there are no competing demands associated with operating the UAS since the UA is autonomously performing its lost link actions. For these reasons, as a minimum requirement, the RPIC should be able to manually access/identify the actions the UA will perform in accordance with its current contingency plan.

SME comments: All SMEs agreed with the recommendation.

Potential safety implication(s): Inability to access/identify the contingency plan prevents the RPIC from communicating the planned route accurately to ATC, making it difficult for ATC to adjust traffic patterns to account for the lost link contingency plan.

Potential higher LOA: Automation presents the lost link plan to the RPIC upon detecting lost link situation.

Autonomous mode function allocation recommendation: The RPIC should be able to access/identify the current contingency plan, reflecting planning function allocation strategy a, *manual planning*.

6.8.1.6 During lost link: Communicate UA status and contingency plan with external agents

Please see our recommendation for *Communicate with external agents* in Section 6.5.1.

6.8.2 Degraded vertical and/or lateral navigation/position information during ground operations

6.8.2.1 Pre-taxi: Plan contingencies for ground operations with degraded position information

Please see our recommendation for *Pre-taxi: Plan lost link contingency and upload to UA* in Section 6.8.1.1.

6.8.2.2 Normal operations: Monitor navigation system and UA position/navigation information

Minimum function allocation recommendation: UAS control station should provide the status of any position/navigation reporting equipment and downlink status, and monitor the status compared to the threshold strength required for reliable position/navigation reporting (monitoring and situation assessment function allocation strategy e, *automated comparison*).

Rationale: Due to the criticality of accurate UA position/navigation information (i.e., the RPIC cannot operate the UA without accurate feedback on its position/navigation), the RPIC should be able to monitor its status. Furthermore, due to our recommendation for alerting automation when degraded position/navigation reporting is detected (Section 0), automation should also monitor the position/navigation reporting equipment including the status of the downlink connection.

SME comments: All SMEs agreed with the recommendation.

Potential safety implication(s): Inability to monitor the C2 link status could prevent the RPIC from making route changes prior to lost link that could prevent losing the C2 link.

Potential higher LOA: UAS control station automation projects the downlink status in the future and informs the RPIC if the UA position/navigation reporting functionality is projected to be degraded or lost.

Autonomous mode function allocation recommendation: Monitoring the UA position/navigation reporting functionality is just as critical in the autonomous mode as it is in the manual mode, so the recommendation for autonomous mode is the same as for the manual mode (monitoring and situation assessment function allocation strategy e, *automated comparison*).

6.8.2.3 During degraded UA position/navigation reporting: Detect degraded UA position/navigation reporting

Please see our recommendation for *During lost link: Detect lost link situation* in Section 6.8.1.4.

6.8.2.4 During degraded UA position/navigation reporting: Identify action(s) required

Please see our recommendation for *During lost link: Identify action(s) that UA will take, based on the current contingency plan* in Section 6.8.1.5.

6.8.2.5 During degraded UA position/navigation reporting: Communicate issue, contingency plan, and UA status with external agents

Please see our recommendation for *Communicate with external agents* in Section 6.5.1.

6.8.2.6 During degraded UA position/navigation reporting: Execute contingency plan

Minimum function allocation recommendation: RPIC should be able to modify/update the contingency plan to the UA, and UA automation should be able to execute the plan (discrete control function allocation strategy *a*).

Rationale: Since the UA is delivering degraded (or no) feedback about its position/navigation, the RPIC may not be able to provide continuous, manual control to the UA. However, since the UA is on the ground, the RPIC should be able to execute the contingency plan without high levels of automation (which could be as simple as stopping the aircraft and waiting for it to be towed to a safe area).

SME comments: All SMEs agreed with the recommendation.

Potential safety implication(s): Inability to execute the contingency plan/procedure could lead to a collision between the UA and other traffic on the airport surface or airport infrastructure.

Potential higher LOA: UAS automatically executes the contingency plan/procedure upon detecting degraded or lost position/navigation reporting functionality and informs the RPIC.

Autonomous mode function allocation recommendation: Since the UA is on the ground, there is no difference from the minimum recommendation (discrete control function allocation strategy *a*).

6.8.3 Degraded vertical and/or lateral position/navigation information during air operations

6.8.3.1 Pre-taxi: Plan contingencies for flight operations with degraded position/navigation information

Please see our recommendation for *Pre-taxi: Plan lost link contingency and upload to UA* in Section 6.8.1.1.

6.8.3.2 Normal operation, prior to degraded UA position/navigation reporting: Update contingency plan/procedure during flight, as necessary

Please see our recommendation for *Normal operation, prior to lost link: Update contingency plan during flight, as necessary* in Section 6.8.1.2.

6.8.3.3 Normal operation, prior to degraded UA position/navigation reporting: Monitor navigation system and UA position/navigation information

Please see our recommendation for *Normal operation, prior to lost link: Monitor link status* in Section 6.8.1.3.

6.8.3.4 During degraded UA position/navigation reporting: Detect degraded UA position/navigation reporting

Please see our recommendation for *During lost link: Detect lost link situation* in Section 6.8.1.4.

6.8.3.5 During degraded UA position/navigation reporting: Identify action(s) required, based on the current contingency plan/procedure

Please see our recommendation for *During lost link: Identify action(s) that UA will take, based on the current contingency plan* in Section 6.8.1.5.

6.8.3.6 During degraded UA position/navigation reporting: Communicate issue, contingency plan, and UA status with external agents

Please see our recommendation for *Communicate with external agents* in Section 6.5.1.

6.8.3.7 During degraded UA position/navigation reporting: Execute contingency plan

Minimum function allocation recommendation: RPIC should be able to modify/update the contingency plan to the UA, and UA automation should be able to execute the plan (continuous control function allocation strategy c, *basic autoflight*, or d, *advanced autoflight*).

Rationale: Since the UA is delivering degraded (or no) feedback about its position/navigation, the RPIC may not be able to provide continuous, manual control to the UA. Therefore, the RPIC should be able to modify/update the contingency plan/procedure based on the level of system degradation as well as risks associated with platform controllability and flight profile location. Furthermore, due to the inaccurate feedback, the RPIC may need to rely on communication with ATC to ensure the aircraft is following its contingency plan.

SME comments: All SMEs agreed with the recommendation.

Potential safety implication(s): Inability to execute the contingency plan/procedure could lead to a collision between the UA and other traffic.

Potential higher LOA: UAS automatically executes the contingency plan/procedure upon detecting degraded or lost position/navigation reporting functionality and informs the RPIC.

Autonomous mode function allocation recommendation: The UA flies in an autonomous mode under certain degraded position/navigation reporting (continuous control function allocation strategy c, *basic autoflight*, or d, *advanced autoflight*).

6.8.4 Loss of contingency flight plan automation

Two levels of contingency are covered in this section: Lost link contingency and other contingency plan capabilities. While fundamentally similar, in the lost link contingency case the RPIC will not have manual control capability or status information on the UA. This makes the lost link contingency capability of the system unique to unmanned aircraft operations. Link coverage is another aspect that does present a difference for unmanned flight. The CS needs to provide the RPIC with a means to plan for any potential areas of reduced link quality. This is analogous to minimum reception altitudes for ground base navigational aids or verifying GPS coverage levels along one's route which are true for both manned and unmanned flight. Flight profiles could elevate the ability to load and/or change a specific lost link contingency plan capability to a critical failure and require a safety assessment of continuing the mission or flight. Due to this potential criticality, the lost link contingency capability could be an abort criteria. This assessment will be required both at the design certification level by the OEM and the certifying agency as well as during inflight failures by the RPIC.

6.8.4.1 Generate plan for airborne loss of contingency planning automation

(Note: The recommendation for this task is similar to the lost command and/or control link task *pre-taxi: plan lost link contingency and upload it to UA*, Section 6.8.1.1.)

Minimum function allocation recommendation: The CS should provide the RPIC the means to plan for cases in which there is a loss of contingency planning capability preventing the upload of feasible contingency plans to the UA while airborne (planning function allocation strategy a, *manual planning*).

Rationale: UAS pre-flight planning for potential airborne emergencies does not deviate substantially from manned operation (e.g., manned pilots identifying potential alternate airports or ditching areas along planned route). Furthermore, since this task is performed pre-flight, it is not subject to the human factors implications that are present during flight, such as competition for resources due to multiple concurrent tasks, latency, and loss of sensory information. Therefore, as a minimum requirement, the RPIC should be able to manually plan for cases in which the contingency planning automation is operating incorrectly while the UA is airborne.

SME comments: All SMEs agreed with the recommendation.

Potential safety implication(s): Inability to generate/upload contingency plans could lead to a situation in which there is no plan when an emergency arises, potentially resulting in an incident/accident.

Potential higher LOA: Automation explicitly provides the status of the contingency planning automation.

Autonomous mode function allocation recommendation: The importance of contingency planning is not affected by the UAS operating in an autonomous mode, so the autonomous mode recommendation is the same as the minimum recommendation (planning function allocation strategy a, *manual planning*).

6.8.4.2 Detect loss of contingency planning capability

Minimum function allocation recommendation: The control station should provide feedback about the upload status of the contingency plan, allowing the RPIC to detect the loss of contingency planning automation (monitoring and situation assessment function allocation strategy a, *state*).

Rationale: The RPIC requires feedback on the status of the contingency plan when it is uploaded to the UAS, because there is no alternative method to ensure that the UA did, in fact, receive the contingency plan or that the plan is feasible. For example, it is not feasible for the RPIC to execute the contingency plan for the sole purpose of ensuring that it was successfully uploaded to the UA. Feedback should be provided whenever the RPIC uploads a contingency plan and they should be able to determine whether there was an error uploading the plan.

SME comments: All SMEs agreed with the recommendation.

Potential safety implication(s): Inability to detect loss of contingency planning automation could result in the lack of awareness that a contingency plan has not been uploaded to the UA, causing uncertainty in the RPIC's knowledge of the route upon encountering an emergency.

Potential higher LOAs: (1) UAS control station continually provides status of the contingency planning automation. (2) UAS control station automation alerts the RPIC when there is a loss of contingency planning automation.

Autonomous mode function allocation recommendation: Autonomous mode has no effect on detecting loss of contingency planning automation, so the RPIC should be able to manually detect the loss of contingency planning automation, reflecting monitoring and situation assessment function allocation strategy a, *state*.

6.8.4.3 Communicate with crew, VO, and/or ATC about loss of contingency planning automation and the plan that will be executed

Please see our recommendation for *Communicate with external agents* in Section 6.5.1.

6.8.4.4 Execute plan/procedure for loss of contingency planning capability

Minimum function allocation recommendation: The CS should provide the RPIC with the means to execute the plan/procedure for loss of contingency planning capability (discrete control function allocation strategy *a*).

Rationale: The human factors issues associated with operating the aircraft remotely (e.g., latency or loss of sensory information) have little implication for executing the plan for loss of contingency planning automation, so the RPIC should be able to perform the task manually. The plan/procedure for addressing loss of contingency flight planning automation could include informing ATC, handing over control to another control station, or manually flying the UA to a safe landing area. If the contingency plan involves operating the UA (e.g., terminating the flight or ditching the UA), please refer to our recommendations for aviating tasks, as part of the A7 function allocation recommendations (Pankok et al., 2017).

SME comments: All SMEs agreed with the recommendation.

Potential safety implication(s): Inability to execute the plan to restore contingency planning automation could lead to a situation in which there is no plan (or an outdated plan) when an emergency arises, potentially resulting in an incident/accident.

Potential higher LOAs: (1) RPIC generates the plan and automation evaluates its potential feasibility/effectiveness. (2) Automation generates one or more plans to restore contingency planning automation and the RPIC chooses one or generates an alternate option. (3) Automation generates and executes a plan to restore contingency planning automation and informs the RPIC.

Autonomous mode function allocation recommendation: Autonomous mode has no effect on executing a plan in response to loss of contingency planning automation, so the RPIC should be able to manually execute the plan, reflecting discrete control function allocation strategy *a*.

6.8.4.5 Monitor status of contingency automation capability

Please see our recommendation for *Monitor system health and status* in Section 6.7.2.

6.8.5 Visual observer failure

The current FAA requirements for UAS under 55 lb stipulate the need for a dedicated VO to satisfy the see and avoid regulations. This is applicable during operations in certain airspace categories and phases of flight. If, in future designs, a detect and avoid (DAA) system is provided with an equivalent level of safety, then the following recommendations may be deprecated or applicable to the DAA system. If a VO is not operationally required, then this section would not be applicable.

6.8.5.1 Plan for loss of VO assistance

Minimum function allocation recommendation: The RPIC should be able to plan for loss of VO without the assistance of high levels of automation (planning function allocation strategy a, *manual planning*).

Rationale: UAS pre-flight planning for potential emergencies does not deviate substantially from manned operation (e.g., manned pilots identifying potential alternate airports or ditching areas along planned route). Furthermore, since this task is performed pre-flight, it is not subject to the human factors implications that are present during flight, such as competition for resources due to multiple concurrent tasks, latency, and loss of sensory information. Therefore, as a minimum requirement, the RPIC should be able to manually plan the lost VO contingency.

SME comments: All SMEs agreed with the recommendation.

Potential safety implication(s): Errors in planning for lack of VO actions could lead to a situation in which there is loss of a level of safety (visual observation of the UA and surrounding environment), potentially leading to a collision with airport traffic or infrastructure.

Potential higher LOAs: (1) Automation provides information relevant for contingency planning and the RPIC uses this information to create a plan for lost VO. (2) Automation provides suggested contingency plans, and the RPIC selects one or generates another plan. (3) RPIC generates a contingency plan for lost VO and automation evaluates the plan for feasibility and/or efficiency.

Autonomous mode function allocation recommendation: The importance of contingency planning is not affected by the UAS operating in an autonomous mode, so the autonomous mode recommendation is the same as the minimum recommendation (planning function allocation strategy a, *manual planning*).

6.8.5.2 During normal operation, prior to loss of VO: Monitor VO status

Minimum function allocation recommendation: RPIC should be able to monitor the status of the VO through the communication medium (communication function allocation strategy *a*).

Rationale: The RPIC will contact the VO before takeoff and landing to ensure the VO is aware of the UA status. Any communication with the VO will be done manually (see Section 6.5.1), and monitoring VO status does not deviate substantially from the task of communicating with the VO. Therefore, assuming the RPIC can communicate with the VO, (s)he should be able to manually monitor the VO status.

SME comments: All SMEs agreed with the recommendation.

Potential safety implication(s): Inability to monitor the status of the VO could result in a situation in which the RPIC must operate the UA without the level of safety provided by the VO, potentially resulting in an incident/accident.

Potential higher LOAs: (1) UAS control station continually provides status of the VO. (2) UAS control station automation alerts the RPIC when the VO is unavailable.

Autonomous mode function allocation recommendation: Autonomous mode has no effect on monitoring the status of the VO, so the RPIC should be able to perform this task without automation assistance, reflecting communication function allocation strategy *a*.

6.8.5.3 During loss of VO: Identify action(s) required, based on the current contingency plan

Minimum function allocation recommendation: The RPIC should be able to access/identify the actions necessary to safely cope with the loss of the VO without high levels of automation (planning function allocation strategy a, *manual planning*).

Rationale: When the VO is unable to observe the UA and its surrounding environment, the RPIC needs to be able to identify the best course of action to compensate for the lack of visual observation of the UA. It is important for the RPIC to know this plan/procedure so that (s)he can operate the UA accordingly.

SME comments: All SMEs agreed with the recommendation.

Potential safety implication(s): Inability to access/identify the best course of action prevents the RPIC from making the adjustments necessary to account for lack of VO guidance, potentially resulting in an incident/accident.

Potential higher LOA: Automation presents the lost VO contingency plan to the RPIC upon detecting unavailable VO.

Autonomous mode function allocation recommendation: The RPIC should be able to manually access/identify the best course of action, reflecting planning function allocation strategy a, *manual planning*.

6.8.5.4 During loss of VO: Communicate issue and contingency plan with external agents

Please see our recommendation for *Communicate with external agents* in Section 6.5.1.

6.8.5.5 During loss of VO: Execute contingency plan

Minimum function allocation recommendation: The CS should provide the RPIC with the means to execute the plan for loss of VO (discrete control function allocation strategy *a*).

Rationale: The human factors issues associated with operating the aircraft remotely (e.g., latency or loss of sensory information) have little implication for executing the plan for loss of VO, so the RPIC should be able to perform the task manually. If the contingency plan involves operating the UA (e.g., landing the UA without VO guidance), please refer to our recommendations for aviating tasks, as part of the A7 function allocation recommendations. This recommendation focuses on restoring VO involvement.

SME comments: All SMEs agreed with the recommendation.

Potential safety implication(s): Inability to execute the plan to restore VO involvement could lead to a situation in which the UA must operate without the level of safety provided by visual observation of the aircraft, potentially resulting in an incident/accident.

Potential higher LOAs: (1) RPIC generates the plan and automation evaluates its potential feasibility/effectiveness. (2) Automation generates one or more plans to restore VO involvement and the RPIC chooses one or generates an alternate option. (3) Automation generates and executes a plan to restore VO involvement and informs the RPIC.

Autonomous mode function allocation recommendation: Autonomous mode has no effect on executing a plan in response to loss of VO, so the RPIC should be able to manually the plan, reflecting discrete control function allocation strategy *a*.

6.8.5.6 Update ATC on status, as necessary

Please see our recommendation for *Communicate with external agents* in Section 6.5.1.

6.9 HANDOVER OF CONTROL

One SME provided an overall comment about the handover recommendations: "We recently completed all of the interviews for Project CS-8, and while all of the RPIC control handovers discussed were during military missions, it was clear that all handovers that occurred during shifts were driven by verbal communication via 30-minute debriefs during which the status of all components of the aircraft is reviewed as the receiving RPIC performed a visual inspection of

UAS status guided by the RPIC leaving the CS. There was minimal to no autonomy or software control involved in the handover process, so I would have to agree that based on SME feedback, the minimum recommendations for control handover were validated through the data we collected. The tasks and recommendations developed for control handover reflected the reality that we heard pilot SMEs discuss."

6.9.1 Receiving and transferring RPICs establish two-way voice communication

Minimum automation recommendation: The receiving RPIC should be able to establish two-way voice communication with the transferring RPIC without assistance from automation. Voice communication should be via approved aviation or direct communication circuits, such as voice and datalink radios (communication function allocation strategy *a*).).

Rationale: Current manned operations do not require high levels of automation for voice communication. RPICs should be able to perform this task without the assistance from high levels of automation.

SME Comments: All SMEs agreed with the recommendation.

6.9.2 Receiving and transferring RPICs coordinate handover procedure and timing

Minimum automation recommendation: The receiving RPIC should be able to coordinate handover procedure and timing with the transferring RPIC without assistance from automation. Coordination of handover procedures and timing should be via approved aviation or direct communication circuits, such as voice and datalink radios (communication function allocation strategy *a*).

Rationale: Current manned operations do not require high levels of automation for voice communication. RPICs should be able to perform this task without the assistance from high levels of automation.

SME Comments: All SMEs agreed with the recommendation.

- "I agree with the recommendation. The PC task for Control Station Handoff operational procedure includes a handoff briefing, which includes: UA overall health, fuel state, altitude, altimeter setting, airspeed, heading, ATC clearances, any abnormal occurrences, contingency/emergency plan(s), safety critical information that the receiving pilot will need to ensure safe flight, and confirmation of command link integrity (strength/reliability). All of these should be performed via approved aviation or direct communication circuits and not require assistance from automation."

6.9.3 Receiving RPIC retrieves UA status and settings

Minimum automation recommendation: The minimum requirement assumes that the UA has only one downlink connection (only one CS can receive information from the aircraft at a given time). The receiving RPIC retrieves UA status and settings via voice communication with the transferring RPIC and manually enters of the settings to the receiving control station (communication function allocation strategy *a*).

Rationale: Current manned operations do not require high levels of automation for voice communication. RPICs should be able to perform this task without the assistance from high levels of automation.

SME Comments: All SMEs agreed with the recommendation.

- "I agree with the assumption that a minimum requirement would be with only one downlink."
- "I agree with the recommendation. The PC task for control station transfer recommended receiving CS preflight inspection and verification of correct function of essential systems. This can be done with minimal automation."
- Regarding the potential higher LOA:
  - "I agree that this represents a higher LOA; however, I would consider this as a minimum requirement for a UA with multiple links instead of a higher LOA."
  - "This should be a separate scenario. Transferring UA control with multiple simultaneous links. This really is not a higher level of automation."

Potential Higher LOA: If the UA has multiple uplink and downlink connections, the receiving CS has the ability to establish a downlink connection with the UA without requiring the transferring CS to disconnect. In this case, the receiving CS is able to monitor the UA prior to positive transfer of control, and to receive UA settings.

6.9.4 Transferring RPIC provides handover briefing to the receiving RPIC

Minimum automation recommendation: The transferring RPIC should be able to provide handover briefing with the receiving RPIC without assistance from automation. The handover briefing should be via approved aviation or direct communication circuits, such as voice and datalink radios (communication function allocation strategy *a*).

Rationale: Current manned operations do not require high levels of automation for voice communication. RPICs should be able to perform this task without the assistance from high levels of automation.

SME Comments: All SMEs agreed with the recommendation.

- "The handover brief should be a pre-approved format (checklist style) that both RPICs are able to follow to minimize miscommunications during handover."

6.9.5 Positive transfer of control from transferring CS to receiving CS occurs

Minimum automation recommendation: Assuming that the UA contains only one uplink connection, the transferring RPIC should be able to manually relinquish control (sending the UA into an autopilot mode). The receiving RPIC should be able to manually establish the uplink connection to the UA (discrete control function allocation strategy *a*).

Rationale: The A10 PC-2 document suggests that positive transfer of control can be conducted without assistance from automation, assuming the two RPICs have communicated and the receiving RPIC has been fully briefed.

SME Comments: All SMEs agreed with the recommendation.

- "One assumption that should be addressed is that a UA should know the difference between an intentional lack of command/control link and the unintentional loss of a command/control link."
- "I agree with the recommendation. However, there may need to be some level of automation when switching datalinks on/off. It is probably just semantics, but some systems require software logic to turn CS datalinks on/off while other systems may require a physical switch."
- Regarding the potential higher LOAs:
  - "As stated earlier, the UA containing multiple links is not really a higher LOA; it is another scenario entirely"
  - "I disagree with the supposition that the receiving CS can initiate positive transfer of control. The transferring RPIC should always initiate procedures until (s)he no longer has control."

Potential Higher LOAs:

- If the UA has automation to check the accuracy of the settings of the receiving CS prior to establishing the link, this capability could prevent the receiving CS from establishing an uplink connection with incorrect UA settings. Control would be transferred if the settings on the receiving CS are accurate. If the receiving CS settings are not accurate, then an indication should be presented to both RPICs.
- If the UA contains multiple uplink connections, the transferring CS initiates positive transfer of control to receiving CS.
- If the UA contains multiple uplink connections and the receiving CS can initiate positive transfer of control from the transferring CS, the receiving CS can initiate positive transfer of control from the transferring CS.

6.9.6 Receiving RPIC confirms full control of the UA

Minimum automation recommendation: The receiving RPIC should be able to confirm full UA control with the transferring RPIC without assistance from automation. Verification of UA control should be via approved aviation or direct communication circuits, such as voice and datalink radios (communication function allocation strategy *a*).

Rationale: Current manned operations do not require high levels of automation for voice communication. RPICs should be able to perform this task without the assistance from high levels of automation.

SME Comments: All SMEs agreed with the recommendation.

Potential Higher LOA: If the UA contains multiple downlink connections, the UA sends an indication to both the transferring CS and receiving CS verifying that the receiving CS has control of the UA.

6.9.7 Transferring RPIC stands by as a backup

Minimum automation recommendation: The transferring RPIC should be able to monitor the appropriate communication channel for any communication indicating that control of the UA may need to be transferred back to the transferring CS (monitoring and situation assessment function allocation strategy a, *state*).

Rationale: Current manned operations do not require high levels of automation for voice communication. RPICs should be able to perform this task without the assistance from high levels of automation.

SME Comments: All SMEs agreed with the recommendation.

- "I agree with this recommendation. This is also an industry best practice for the Hunter, Shadow, and Gray Eagle systems."

Potential Higher LOA: If the UA contains multiple downlink connections, the transferring CS should maintain downlink connection to monitor the UA, and be able to re-establish the uplink connection if necessary.

7. SUMMARY OF THE RECOMMENDATIONS

The subsections that follow contain tables with an overview of the function allocation recommendation for each task, organized by phase of flight. The left column of each table contains the task, and to the right of the task is an "X" in the column reflecting the agent to which the task is allocated in the recommendations. Note that few tasks are allocated to alerting automation or control automation, as SME feedback suggested that most of the tasks could be performed safely by the RPIC and/or VO without assistance from automation.

7.1 TAKEOFF

Task	RPIC	VO	Alerting Automation	Control Automation
Communicate with VO to ensure runway is clear for takeoff	X			
Announce takeoff via CTAF	X			

7.2 CLIMB OUT

Task	RPIC	VO	Alerting Automation	Control Automation
Verify top of climb	X			
Communicate with VO and ATC to coordinate handover of separation responsibility from VO to ATC	X			

7.3 DESCENT

Task	RPIC	VO	Alerting Automation	Control Automation
Obtain airport data	X			
Communicate with ATC to obtain descent clearance	X			
Determine descent profile	X			
Determine top of descent	X			
Announce landing on runway via CTAF	X			
Communicate with VO and ATC to coordinate handover of separation responsibility from ATC to VO	X			

7.4 APPROACH

Task	RPIC	VO	Alerting Automation	Control Automation
Determine approach profile	X			
Identify touchdown target on first third of the runway	X			

7.5 COMMUNICATE

Task	RPIC	VO	Alerting Automation	Control Automation
Communicate with external agents, as necessary	X			
Tune communication networks/frequency, as necessary	X			

7.6 NAVIGATE

Task	RPIC	VO	Alerting Automation	Control Automation
Tune applicable navigation avionics, as appropriate	X			
Obtain ATC clearance for route, as needed	X			
Monitor UA position along route	X			
Monitor UA heading along route	X			
Monitor UA altitude along route	X			
Determine necessary route/trajectory changes	X			
Implement route/trajectory changes	X			

7.7 MANAGE SYSTEM HEALTH AND STATUS

Task	RPIC	VO	Alerting Automation	Control Automation
Pre-flight systems management and checks	X			
Monitor system health can status			X	
Perform system health and status intervention	X			
Inform ATC and/or VO, if necessary	X			

7.8 LOST COMMAND AND/OR CONTROL LINK CONTINGENCY

Task	RPIC	VO	Alerting Automation	Control Automation
Plan lost link contingency and upload to the UA	X			
Update contingency plan during flight, as necessary	X			
Monitor link status	X			
Detect lost link situation			X	
Identify action(s) that the UA will take, based on the current contingency plan	X			
Communicate UA status and contingency plan with external agents	X			

7.9 DEGRADED GROUND POSITION INFORMATION REPORTING CONTINGENCY

Task	RPIC	VO	Alerting Automation	Control Automation
Plan contingencies for ground operations with degraded position information	X			
Monitor navigation system and UA position/navigation information	X			
Detect degraded UA position/navigation reporting			X	
Identify action(s) required	X			
Communicate issue, contingency plan, and UA status with external agents	X			
Execute contingency plan	X			

7.10 DEGRADED AIRBORNE POSITION REPORTING CONTINGENCY

Task	RPIC	VO	Alerting Automation	Control Automation
Plan contingencies for flight operations with degraded position/navigation information	X			
Update contingency plan/procedure during flight, as necessary	X			
Monitor navigation system and UA position/navigation information	X			
Detect degraded UA position/navigation reporting			X	
Identify action(s) required, based on the current contingency plan/procedure	X			
Communicate issue, contingency plan, and UA status with external agents	X			
Execute contingency plan				X

7.11 LOSS OF CONTINGENCY FLIGHT PLANNING AUTOMATION

Task	RPIC	VO	Alerting Automation	Control Automation
Generate plan for airborne loss of contingency planning automation	X			
Detect loss of contingency planning capability	X			
Communicate with crew, VO, and/or ATC about loss of contingency planning automation and the plan that will be executed	X			
Execute plan/procedure for loss of contingency planning capability	X			
Monitor status of contingency automation capability	X			

7.12 VISUAL OBSERVER FAILURE CONTINGENCY

Task	RPIC	VO	Alerting Automation	Control Automation
Plan for loss of VO assistance	X			
Communicate with VO to monitor VO status	X			
Identify action(s) required, based on the current contingency plan	X			
Communicate issue and contingency plan with external agents	X			
Execute contingency plan	X			
Update ATC on status, as necessary	X			

7.13 HANDOVER OF CONTROL

Task	RPIC	VO	Alerting Automation	Control Automation
Receiving and transferring RPICs establish two-way voice communication	X			
Receiving and transferring RPICs coordinate handover procedure and timing	X			
Receiving RPIC retrieves UA status and settings	X			
Transferring RPIC provides handover briefing to the receiving RPIC	X			
Positive transfer of control from transferring CS to receiving CS	X			
Receiving RPIC confirms full control of the UA	X			
Transferring RPIC stands by as a backup	X			

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APPENDIX C—TASK CS-3: RECOMMENDATIONS FOR MINIMUM CONTROL STATION HUMAN FACTORS CONSIDERATIONS

Carl Pankok, Jr. and Ellen J. Bass

ACKNOWLEDGEMENTS

The authors would like to thank Douglas W. Lee and Ali Jazayeri for their assistance in collecting source data relevant to this work as well as with help with developing data analysis support. The authors also thank the subject matter expert pilot reviewers: Sean Moulton, Joe Cerreta, Paul Snyder, Amanda Brandt, Joseph Millette, Gary Ullrich, Reuben Burch, and Kurt Carraway. The authors would also like to thank individuals who reviewed earlier versions of this document including Joel Walker, Phil Smith, Richard S. Stansbury, and Stephen Luxion.

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EXECUTIVE SUMMARY

The objective of the work was to develop recommendations to support control station considerations for integrating unmanned aircraft systems (UAS) into the National Airspace System (NAS). The scope of the work was focused on the operation of fixed-wing UAS larger than 55 pounds and capable of using the existing NAS infrastructure in the following contexts: taxi, takeoff, landing, navigate, communicate, contingencies unique to unmanned operation, and handover of control.

To inform the effort, prior function allocation recommendations and a control station literature review composed of the Code of Federal Regulations (CFRs), incident and accident reviews, human factors UAS literature, and select fielded and research operational control stations were leveraged. These sources were used to create a database of potential information elements necessary for UAS operation in the NAS. Two taxonomies were created to categorize the information elements: one reflecting the level of availability of the information element, and one identifying the agent(s) with control over changing the information element. With respect to the display of information elements, the recommendations were developed using a five-level taxonomy including (1) the information element should be available and always displayed, (2) the information element should be available and displayed based on context, (3) the information element should be available and displayed by pilot request, (4) display of the information element is optional, and (5) the information element should be available from a source outside of the control station displays. With respect to control over the information element, the taxonomy included: (1) changes in the information element are controlled directly by the remote pilot in command (RPIC); (2) changes in the information element are influenced by an agent or force external to the UAS; (3) changes in the information element are influenced by a combination of RPIC actions and an external agent or force; and (4) the information element is unable to be changed by the RPIC or an external force or agent. The recommendations were reviewed by seven subject matter experts with a range of experience in various manned and unmanned operational roles but have not been objectively validated . The results of this independent research yielded one set of recommendations for control station considerations for minimum information elements for safe UAS operation in the NAS, as well as potential directions for future research.

1. INTRODUCTION

This document addresses Control Station Display Considerations for Aviate, Taxi, Takeoff, Landing, Navigate, Communicate, Contingency, and Handover Tasks. The objective of the tasks was to identify recommendations for minimum information elements to support safe unmanned aircraft system (UAS) operation in an integrated National Airspace System (NAS). The project scope included aviate, taxi, takeoff, landing, navigate, communicate, contingencies unique to unmanned aircraft operation, and handover of control. The sources analyzed (described in more detail below) contained information about the environment, such as airspace, terrain, and weather, so recommendations related to the environment are included. General information elements are also included, such as time of day.

The remainder of the document describes the assumptions that refine the context of the scope of the work (Section 2), the methodology employed (Section 3), analysis of the information elements (Section 4), recommendations for information requirements (Section 5), and potential directions for future work (Section 6).

2. SCOPE

The recommendations were developed under the following assumptions:

- The unmanned aircraft (UA) is a fixed-wing aircraft larger than 55 lb.
- The UAS is capable of flying instrument flight rules (IFR) in an integrated NAS, including standard takeoff and approach procedures.
- The UA flies beyond visual line of sight (BVLOS).
- The remote pilot in command (RPIC) does not have visual sight lines of the airport taxiways and runways.
- A visual observer (VO) is required and is located at the airport to communicate with the RPIC and to monitor the UA as it performs taxi, takeoff, approach, and landing tasks.
- The UAS Integration into the NAS Concept of Operations (Federal Aviation Administration, 2012) requires all UAS to be equipped with Automatic Dependent Surveillance-Broadcast (Out) capability, so the recommendations assume that the UAS, at minimum, uses this technology for navigation.
- The UA is operated in Visual Meteorological Conditions (VMC), so the impact of weather conditions such as cloud coverage, cloud height, icing, precipitation, convective weather, and visibility are not addressed in the recommendations.
- The different types of turbulence (caused by the environment or other aircraft) are not accounted for in the recommendations.
- Automation for ground and air sense-and-avoid tasks was not part of the scope of this work.

The team considered the general requirements and assumptions published in the Federal Aviation Administration (2013) UAS integration roadmap listed below (note that roadmap assumptions are designated by the letter *R* followed by the assumption number).

R1. RPICs comply with existing, adapted, and/or new operating rules or procedures as a prerequisite for NAS integration

R2. Civil UAS operating in the NAS must obtain an appropriate airworthiness certificate while public users retain their responsibility to determine airworthiness.
R3. All UAS file and fly an Instrument Flight Rules (IFR) flight plan.
R4. All UAS are equipped with ADS-B (Out) and transponder with altitude-encoding capability. This requirement is independent of the FAA's rule-making for ADS-B (Out).
R5. UAS meet performance and equipage requirements for the environment in which they are operating and adhere to the relevant procedures.
R6. Each UAS has a flight crew appropriate to fulfill the operators' responsibilities, and includes a RPIC. Each RPIC controls only one UA.
R7. Fully autonomous operations are not permitted. The RPIC has full control, or override authority to assume control at all times during normal UAS operations.
R8. Communications spectrum is available to support UAS operations.
R9. No new classes or types of airspace are designated or created specifically for UAS operations.
R10. Federal Aviation Administration (FAA) policy, guidelines, and automation support air traffic decision-makers on assigning priority for individual flights (or flight segments) and providing equitable access to airspace and air traffic services.
R11. Air traffic separation minima in controlled airspace apply to UA.
R12. Air Traffic Control (ATC) is responsible for separation services as required by airspace class and type of flight plan for both manned and unmanned aircraft.
R13. The RPIC complies with all ATC instructions and uses standard phraseology per FAA Order 7110.65 and the Aeronautical Information Manual (Federal Aviation Administration, 2014).
R14. ATC has no direct link to the UAS for flight control purposes.

Based on input from the FAA and discussions about the document scope, additional assumptions were considered. These are listed below and are designated by the letter *A* preceding the assumption number.

A1. The RPIC does not simultaneously control any payload onboard the UA (note that activities related to aerial work are outside of the scope).
A2. VFR flight is permitted only when the UA is within visual line of sight (VLOS) of a VO (necessary for takeoff and landing at non-towered airports).
A3. Each UA has a maximum crosswind component capability that limits the conditions under which it can depart or land.
A4. The airport has sufficient infrastructure (e.g., reliable power source, ATC communication, etc.) for operating the UAS.
A5. While there may be UAS which use alternative methods for control, like differential engine output and rudder, this document assumes the use of traditional manned aircraft controls, including flaps.

Additional assumptions are related to communication tasks. These assumptions are designated by the letter *C* preceding the assumption number.

C1. Communication with VO always occurs via voice communication.
C2. We do not specify a communication medium between the RPIC and ATC (i.e., datalink vs. radio frequency). Selecting a recipient and communicating with the recipient (either with datalink or radio frequency) is considered the lowest level of communication automation.
C3. VOs are not required to have direct transmit capability with ATC but may have receiving capabilities.

Additional assumptions are related to handover tasks: transfer of control from one remote pilot at a control station (i.e., transferring CS) to a second remote pilot located at a second control station (i.e., receiving CS). The recommendations related to handover (designated by the letter *H* preceding the assumption number) are subject to the following assumptions with respect to the roles and communication:

H1. Voice communication is used to coordinate the handover.
H2. Synchronous communication occurs between the transferring and receiving control stations.
H3. Only the RPICs are actively involved in the handover. If the crew contains any sensor/mission operators, their workstations do not contain any critical functionality that would be required during a handover.
H4. At no point during the handover is there a loss of voice communication between the control stations.
H5. The CS contains, at minimum, three independent communication systems: one for communication with ATC, one for communication with VO, and one for communication with other CSs

The recommendations related to handover also assume that transfers will only occur under the following flight and airspace conditions:

H6. The UA is on straight and level flight; handover must be completed before the UA initiates any turns or changes in altitude.
H7. There should be a minimum altitude only above which transfer of control is permitted (except in the case of an emergency).
H8. There are no ATC instructions or compliance issues that need to be resolved.
H9. Handovers do not occur in congested airspace.
H10. Handovers do not occur during emergency or critical situations (unless the handover itself is part of the emergency or critical checklist sequence).

The handover recommendations assume limited UAS capability:

H11. The UA contains only one uplink and downlink connection and thus the handover of control and the transfer of relevant UA state information must be performed predominately via two-way communication between the RPICs located at the transferring and receiving CSs.

a. If there are two links, then the UAS has a primary and secondary link, and the links would need to be identified as such (i.e., primary link and secondary link).
b. The UA does not contain automation that checks the accuracy of the settings on the receiving CS. Procedures are required to ensure safety.

H12. The receiving UA does not have transfer of control override authority.

3. METHODOLOGY

To develop the recommendations, potential information elements were identified from various sources. A taxonomy was developed to refine the notion of "minimum" to categorize the information elements with respect to recommended availability. In addition, the information elements were analyzed with respect to control and feedback, and a second taxonomy was developed to categorize information elements for this purpose. Recommendations were reviewed by a collection of subject matter experts (SMEs) with a range of manned and unmanned experiences. The details of the methodology are described in the following subsections.

3.1 INFORMATION SOURCES

Information elements from a variety of sources were identified and used to develop the recommendations for the minimum information requirements as well as control and feedback requirements for safe unmanned aircraft system (UAS) operation in the NAS. The sources and associated descriptions are listed in the following subsections.

3.1.1 Relevant Federal Aviation Regulations

Potentially relevant Federal regulations under Code 14 (14 CFR) were identified. Since the focus of the project is on identifying minimum information elements for UAS operation in the NAS, 14 CFR Parts 23 (general aviation regulations), 25 (transport category aircraft regulations), and 91 (regulations for all aircraft operating in the NAS) were identified as relevant. Part 107 (Small Unmanned Aircraft Regulations) was reviewed but it did not contain information relevant to the recommendations for minimum information elements (due to the fact that Part 107 is limited to visual line of sight (VLOS) operation, while the scope of the current work includes BVLOS operation).

3.1.2 Control Station Review

Five current and research operational control stations were reviewed in Pankok, Bass, and Smith (2017). The control stations were selected for their range of designs, features, and functionality spanning potential UAS operation in the NAS. Information presented to the RPIC was identified for each control station, as well as the format of the information to inform design recommendations.

3.1.3 UAS Control Station Literature Review

A review of the human factors research literature related to UAS control stations was conducted (Pankok, Bass, & Smith, 2017), including the development of a taxonomy related to UAS control station design. A portion of the taxonomy was dedicated to information presented to the RPIC; this information was included as a source in support of the development of the recommendations for the minimum information requirements. HF-STD-001B "Human Factors Design Standard" (Federal Aviation Administration, 2016) was reviewed, which includes general design guidelines for air traffic control displays and referenced where applicable. Note that HF-STD-001B is geared toward application for air traffic control rather than flight decks or UAS control station design; its relevance for UAS control station design is explained when referenced.

3.1.4 Function Allocation Recommendations

Minimum UAS human-automation function allocation recommendations were developed in related tasks (Pankok, Bass, Smith, Dolgov, & Walker, 2017; Pankok, Bass, Smith, & Walker, 2017; Pankok, Bass, Walker, & Smith, 2017). Included in these recommendations, where applicable, was information to be provided to the RPIC to safely operate the UAS under the recommended automation level. These information elements are reported in Appendix C1, organized by a task analysis that was conducted to guide the function allocation recommendations.

3.2 TAXONOMIES FOR CATEGORIZING INFORMATION ELEMENTS

3.2.1 Information Element Availability

A taxonomy was developed to categorize each information element with respect to its recommended availability in the control station. The taxonomy and definitions for each level are provided in Table 1.

Table 1. Taxonomy characterizing information availability at the control station.

Recommendation of Information Availability	Description
Always Displayed	The information element is flight critical and must always be displayed to the RPIC. The information element cannot be hidden from the RPIC's field of view at any time.
Context Dependent	The information element is critical in some flight contexts and must be displayed to the RPIC, at minimum, during that context. The information element cannot be hidden from the RPIC's field of view during that context. Specific contexts for context dependent information elements are identified in Table 29.
Available at RPIC Request	The information element must be accessible to the RPIC in the control station. The information element need not be presented to the RPIC at all times.
Optional	The information element is not critical for safe operation, and thus represents a higher-than-minimum level of information. The information element has the potential to enhance RPIC and/or total system performance as well as to provide an additional layer of safety when available.
Available outside of Control Station displays	The information element can be obtained outside of the control station. Example methods of information acquisition include verbal communications with air traffic control, recorded information available on systems such as ATIS, and through documentation such as aeronautical charts.

3.2.2 Control and Feedback

Control and feedback related to the information elements identifies dependencies among the data elements and feedback that should be provided to the RPIC as a function of the changing values of the elements. The information elements can either be changeable by the RPIC or by an external agent or force (we refer to these information elements as *variable*) or unchangeable by any agent or force, internal or external to the UAS (we refer to these information elements as *constant*). Variable information items can be altered in one of three ways:

- information element is altered directly by the RPIC (i.e., a UAS control input),
- information element is altered by an agent or force external to the UAS (i.e. wind conditions), or
- information element is altered by a combination of RPIC actions and an agent or force external to the UAS.

Table 2 provides the rubric developed for recommendations based on control over the information elements, associated feedback on the value modified, and the subsequent effect on the UA. The terminology used in the *Type* column is identified in Section 4 to reference these recommended feedback options.

Table 2. Control and feedback taxonomy.

Type	Range	Control Agency	Feedback Recommended
RPIC	Variable	Information element is controlled directly by the RPIC.	• Feedback on input device • Subsequent effect on other information elements[1]
Other	Variable	Information element is influenced by an agent or force external to the UAS.	• External influence or force • Subsequent effect on other information elements[1]
Combination	Variable	Information element is influenced by a combination of RPIC actions and an agent or force external to the UAS.	• Feedback on the input device • External influence or force • Subsequent effect on other information elements[1]
Constant	Constant	Neither the RPIC nor any external agent or force can change the value of the information element.	• Value of the information element

[1]Other information elements altered by degree of control include flight parameters, route of flight, communications, and/or contingency plans.

Examples of the application of the taxonomy in Table 2 follow:

- *Pitch attitude* is variable and the target for its value can be changed directly by the RPIC. The RPIC should be able to view the commanded pitch attitude as well as the resultant changes in the affected variables based on the changes to the UA pitch, such as indicated airspeed (IAS), vertical speed, and indicated altitude.
- *Command/control link strength* is variable and influenced by an agent external to the UAS. The control station should contain the command/control (C2) link status as well as any associated contingency plans for lost C2 link.
- *Ground track* is variable and influenced by a combination of RPIC actions (e.g., UA commanded heading and IAS) and forces external to the UAS (e.g., wind direction and wind speed). Therefore, the control station should contain information on the ground track, UA heading, UA IAS, wind direction, and wind speed.
- *UA maximum certified altitude* is a fixed value; it is unable to be altered. Information elements that do not change values may necessitate the RPIC to have knowledge of them from memory, from a source outside of the control station, or by retrieval from the control station.

3.3 PROCEDURE

The first step in developing recommendations was to identify relevant sources of potential information elements. Information elements were identified from the relevant sources and concatenated in a custom Microsoft Access database, providing a structure for the information elements, the sources from which they were derived, and design guidance associated with the information element (where applicable). Since terminology varied across the information sources, the information elements were reviewed and revised to ensure consistent terminology. SQL queries were developed to identify sources for each information element; these SQL queries are reported in Appendix C2.

A taxonomy (Table 1) was developed to convey the level of information availability recommended for safe UAS operation in the NAS. Another taxonomy (Table 2) was developed reflecting the control and feedback attributes of each information element. The information elements were categorized via both taxonomies to inform the recommendations.

SMEs with a range of manned and unmanned flight experience reviewed the recommendations and provided their feedback. SMEs were instructed to review the information elements and their associated levels of availability and provide feedback if the element and/or the availability did not represent a minimum requirement.

3.4 SUBJECT MATTER EXPERT QUALIFICATIONS

Seven SMEs reviewed the minimum information recommendations; their operational experience is contained in Table 3. Feedback was solicited from SMEs with experience in varying roles of UAS operation, including but not limited to experience as a RPIC, control station designers, manned/unmanned flight instructors, manned/unmanned test pilots, FAA certified pilots, and RPICs with UAS research experience. Due to these diverse experiences, the collection of SMEs that reviewed the recommendations was able to provide feedback from the perspective of various stakeholders in the UAS community. While the SME input was invaluable to this work, the feedback was subjective to their individual opinions and does not necessarily represent the majority view of other UAS professionals.

Table 3. Subject matter expert professional experience.

ID	Operational Experience
1	Held various positions of authority for multiple manned and unmanned test programs. 50+ aircraft types flown. Chief Engineer/Test Pilot for Aurora Flight Science Centaur OPA/UAS (4,000+lbs). Pilot of world UAS endurance flight record: Aurora Flight Science Orion (80+ hours). Civilian and military instructor and evaluation pilot. Naval Test Pilot School graduate.
2	20 years of experience in the UAS industry, including as the UAS industry program manager at Embry Riddle Aeronautical University. Performed Shadow 200 user assessment. Qualified instructor for RQ-5 (Hunter) and RQ-7 (Shadow).
3	Boeing Insitu–Manufacturer certified ScanEagle UAS pilot. Flight instructor. FAA Designated Pilot Examiner (pilot and instructor). Certified commercial pilot.
4	1200 hours of UAS pilot experience on a diverse set of airframes including Aerostar, Viking 300, Tigershark, Hornet Maxi Helicopter, Scout Multi-Copter, Rave A sUAS, Leptron Avenger sUAS, SenseFly eBee Six years as Lead Safety Analyst/Risk Management for New Mexico State University's FAA UAS Test Site. Commercial pilot with instrument and multi-engine ratings.
5	UAS patent formation and design for pilot/cockpit technology deployment.
6	Led creation of the Global Hawk training program. Flight instructor and evaluator with vast international experience. Professor of flight operations courses at Kansas State University (KSU). Flight Operations Manager and Executive Director of KSU UAS Program. Contributed to the revision of the UAS degree curriculum at KSU.
7	Holds certificates as an Instructor/Evaluator Pilot for the RQ-4 UAS (Global Hawk), and as a Weapons Instructor Officer/Evaluator Pilot for the C-130/T-38/T-1. Rated for Commercial Instrument and Single and Multi-Engine. Formerly worked at Infoscitex as the UAS Research lead for the Air Force Research Lab and for Booz Allen Hamilton as the UAS Operation Lead for the Aeronautical Systems Center.

4. INFORMATION ELEMENT ANALYSIS

This section includes the information elements and their associated recommendations. Each entry includes the information element, the control and feedback attribute (labeled "Control Attribute"), and the information availability recommendation (labelled "Availability"). Section 4.1 presents information elements that span several contexts. In subsequent subsections, the elements are organized by flight regime (taxi, takeoff, aviate, landing), navigate, communicate, contingency tasks, environment information, and handover. If a SME disagreed with the consensus, the SME's input is documented and any response/rebuttal follows the SME comment.

4.1 INFORMATION SPANNING MULTIPLE CONTEXTS

4.1.1 Aircraft Identification

The RPIC needs to know the aircraft identifier for radio communications, filing flight plans and other activities in all contexts. Aircraft type is necessary for the flight plan. The values for these information elements would be fixed for a UA. Table 4 contains our recommendations.

Table 4. Information elements and recommendations for aircraft identification information.

Information Element	Control Attribute	Availability
Aircraft ID	Constant	Always Displayed
Aircraft type	Constant	Source Outside Control Station Displays

SME Comments—Regarding aircraft ID, one SME suggested that "This could be a placard or just a piece of tape, but it is usually in the flight station. It just does not need to be on the screen."

- Response/Rebuttal: The aircraft ID in a manned aircraft is visible during preflight (on the aircraft) and the manned aircraft pilot can interrogate it. However during the flight this is not possible for a manned aircraft. Interrogation is not possible for remote pilots even during preflight as they are not co-located with the aircraft.

Regarding aircraft type, one SME suggested it should be optional. "The system does not need to tell the RPIC the aircraft type/model. I should know the type/model, and it is in the manual."

- Response/Rebuttal: The recommendation does not require the aircraft type to be contained on the displays, but rather in an external medium (such as the manual).

4.1.2 Time

The RPIC needs to have accurate time information in all contexts. Regarding time of day: it is required per 14 CFR 91.205(d)(6). The values for time of day are not recommended to be modifiable by the RPIC. Table 5 contains our recommendations.

Table 5. Information elements and recommendations for time information.

Information Element	Control Attribute	Availability
Time of day	Other	Always Displayed
Time of day (origin)	Other	Optional
Time of day (destination)	Other	Optional

SME Comments—One SME suggested adding more information: "I suggest adding 'sunrise' and 'sunset' as optional, since some aircraft will have day and night restrictions."

- Response/Rebuttal: These information elements were not added, as presentation of time of day can be used to determine whether it is day or night.

4.1.3 Flight Parameters

Most flight parameters are recommended to always be displayed. However, ground speed and true airspeed are recommended to be optionally available. Table 6 contains our recommendations.

Table 6. Information elements and recommendations for flight parameters.

Information Element	Control Attribute	Availability			
		Taxi	Takeoff	Aviate	Landing
Altitude above ground level (absolute)	Combination	Always Displayed	Always Displayed	Always Displayed	Always Displayed
Angle of attack	RPIC	N/A	Optional	Optional	Optional
Density altitude	Combination	N/A	Optional	Optional	Optional
Ground speed	Combination	Available at RPIC Request	Available at RPIC Request	Available at RPIC Request	Available at RPIC Request
Ground track	Combination	Optional	Optional	Optional	Optional
Indicated airspeed	RPIC	Always Displayed	Always Displayed	Always Displayed	Always Displayed
Indicated altitude	Combination	Always Displayed	Always Displayed	Always Displayed	Always Displayed
Latitude	Combination	Always Displayed	Always Displayed	Always Displayed	Always Displayed
Longitude	Combination	Always Displayed	Always Displayed	Always Displayed	Always Displayed
Magnetic heading	RPIC	Always Displayed	Always Displayed	Always Displayed	Always Displayed
Pitch attitude	RPIC	Always Displayed	Always Displayed	Always Displayed	Always Displayed
Rate of turn	RPIC	N/A	Optional	Optional	Optional
Roll attitude/bank angle	RPIC	Always Displayed	Always Displayed	Always Displayed	Always Displayed
Slip/skid	RPIC	Always Displayed	Always Displayed	Always Displayed	Always Displayed
True airspeed	Combination	N/A	Optional	Optional	Optional
True heading[1]	Combination	Optional	Optional	Optional	Optional
Vertical speed	Combination	N/A	Always Displayed	Always Displayed	Always Displayed
Yaw attitude	RPIC	Optional	Optional	Optional	Optional

[1]True heading should be "always displayed" if magnetic heading is not presented to the RPIC in the control station. The control station should clearly indicate whether the heading being presented to the RPIC is the true heading or the magnetic heading.

SME Comments—There was a lack of consensus with respect to SME input regarding ground speed, altitude above ground level, true heading, and magnetic heading.

- Regarding ground speed: One SME indicated it should be optional across all phases of flight.
  - Response/Rebuttal: There could be instances for which the RPIC needs to know the ground speed, such as during approach and landing or during taxi, where the RPIC does not have the out-the-window visual cues that give an indication of UA ground speed that a manned pilot has.
- Regarding altitude above ground level, one SME indicated it should be optional.
  - Response/Rebuttal: Terrain awareness is an important factor in aviation safety and controlled flight into terrain (CFIT) continues to be a safety concern for manned aircraft (Boeing Company, 2015; International Air Transportation Association, 2015); removing the pilot from the cockpit (along with information from out-the-window view) can exacerbate the issue. If AGL is not presented, the RPIC will have to reference a static terrain map to calculate distance above ground. This is very different from manned operation, in which the RPIC can make a judgment on whether the aircraft is clear of terrain and obstacles by simply looking out the window during visual meteorological conditions. This reflects HF-STD-001B is meant for ATC design, but it is applicable here because Section 5.1.1.10 states that systems should avoid increasing demands for cognitive resources and Section 5.1.12.3 states that displays should provide information in a usable format (Federal Aviation Administration, 2016).
- Regarding true heading and magnetic heading, SME input ranged from always displayed to optional. One SME suggested that "Having either true heading or magnetic heading 'always displayed' is fine, but the control station would have to indicate which one it is so the RPIC would not have to search the control station displays further for that information." Another SME suggested that "Typical commands reference magnetic heading, so this should be 'Available at RPIC Request'."
  - Response/Rebuttal: The recommendation for true heading is "optional" with the caveat that true heading should be "always displayed" (and labeled clearly to ensure the RPIC knows it is true heading) if the control station does not present the RPIC with the magnetic heading.

4.1.4 Targets

Flight targets can support RPIC awareness of the state of the UA compared to the desired state, but are not considered a minimum information need as recommended in Table 7.

Table 7. Information elements and recommendations for targets.

Information Element	Control Attribute	Availability		
		Takeoff	Aviate	Landing
Altitude target	RPIC	Optional	Optional	Optional
Heading target	RPIC	Optional	Optional	Optional
Indicated airspeed target	RPIC	Optional	Optional	Optional
Vertical speed target	RPIC	Optional	Optional	Optional
Roll attitude/bank angle target	RPIC	Optional	Optional	Optional
Pitch angle target	RPIC	Optional	Optional	Optional

4.1.5 Constraints and V-Speeds

Constraints should be available as appropriate for their context. For example, landing gear and flaps information may not be critical if they are not being used. Note that some constraints are dependent on the aircraft type; for example, we did not include minimum control speed (V_{MC}) since it assumes an aircraft with multiple powerplants. Table 8 contains our recommendations.

Table 8. Information elements and recommendations for constraints and V-speeds.

Information Element	Control Attribute	Availability		
		Takeoff	Aviate	Landing
Maximum altitude	Constant	Optional	Optional	Optional
Maximum flaps extended speed (V_{FE})	Constant	Always Displayed	Always Displayed	Always Displayed
Maximum landing gear extended speed (V_{LE})	Constant	Context Dependent	Context Dependent	Context Dependent
Maximum landing gear operating speed (V_{LO})	Constant	Always Displayed	Always Displayed	Always Displayed
Maximum operating limit speed (V_{MO})	Constant	Always Displayed	Always Displayed	Always Displayed
Maximum operating maneuvering speed (V_O)	Constant	Always Displayed	Always Displayed	Always Displayed
Maximum speed for normal operations (V_{NO})	Constant	Always Displayed	Always Displayed	Always Displayed
Never-exceed speed (V_{NE})	Constant	Always Displayed	Always Displayed	Always Displayed
Optimal climb rate	Combination	Optional	Optional	Optional
Optimal cruise speed	Combination	N/A	Optional	N/A
Optimal descent rate	Combination	Optional	Optional	Optional
Rotation speed (V_R)	Combination	Context Dependent	N/A	N/A
Stall speed (V_S)	Constant	Always Displayed	Always Displayed	Always Displayed
Stall speed in landing configuration (V_{S0})	Constant	Always Displayed	Always Displayed	Always Displayed
Takeoff decision speed (V_1)	Combination	Context Dependent	N/A	N/A
Takeoff safety speed (V_2)	Combination	Context Dependent	N/A	N/A

4.1.6 UA Device Control

Device control can be specific to phase of flight but some devices are used across contexts. For example, wheel braking is not relevant when not on the ground. Flight mode annunciation is included to represent an indication of which flight mode(s) are engaged and disengaged at any time. Since the flight mode is specific to the aircraft type and its equipment, we do not list all possible flight modes but instead use this term for all related annunciations. Table 9 contains our recommendations.

Table 9. Information elements and recommendations for UA device control information.

Information Element	Control Attribute	Availability			
		Taxi	**Takeoff**	**Aviate**	**Landing**
Throttle position	RPIC	Always Displayed	Always Displayed	Always Displayed	Always Displayed
Thrust level	RPIC	Optional	Optional	Optional	Optional
Thrust reverser position	RPIC	Always Displayed	Always Displayed	Always Displayed	Always Displayed
Flight surface positions	RPIC	Optional	Optional	Optional	Optional
Control device position[1]	RPIC	Always Displayed	Always Displayed	Always Displayed	Always Displayed
Trim device position	RPIC	Always Displayed	Always Displayed	Always Displayed	Always Displayed
Landing gear control position	RPIC	Always Displayed	Always Displayed	Always Displayed	Always Displayed
Landing gear status	Combination	Always Displayed	Always Displayed	Always Displayed	Always Displayed
Lift/drag device position	RPIC	Always Displayed	Always Displayed	Always Displayed	Always Displayed
Lift/drag device position target	RPIC	Always Displayed	Always Displayed	Always Displayed	Always Displayed
Wheel brake position[2]	RPIC	Context Dependent	Context Dependent	N/A	Context Dependent
Flight mode annunciation[3]	RPIC	Always Displayed	Always Displayed	Always Displayed	Always Displayed

[1]Since this work is control device agnostic, this information element refers to the position of any control device contained in the control station, including but not limited to a yoke, pedals, joystick, or on-screen interface.
[2]Although context dependent, this information is recommended to always be provided when the landing gear is down.
[3]The modes used by a manufacturer may differ but what modes are engaged and not engaged should be annunciated

SME Comments—There was disagreement among the SMEs for flight mode annunciation. One SME commented: “I suggest making this optional. Or, if you are referring to alerting, I suggest making this context-dependent.”

- Response/Rebuttal: Mode awareness is a known safety issue for automated aircraft (Sarter & Woods, 1995). For aircraft that have multiple autopilot modes, it is critical that the mode is apparent to the RPIC. 14 CFR 25.1302(c) states that operationally-relevant behavior of the installed equipment must be (1) predictable and unambiguous, and (2) designed to enable the flightcrew to intervene in a manner appropriate to the task. In other words, operationally relevant system behavior should be predictable and unambiguous, enabling a qualified flightcrew to know what the system is doing and why (Yeh, Jo, Donovan, & Gabree, 2013).

4.1.7 Airport

Because there will be a VO, Airport information can be obtained from the VO, ATIS, and other sources outside of the control station. However, Recommendation 1 in the subsequent cognitive walkthrough research (Task CS-5, Appendix E), conducted based on the information recommendations developed here, suggested that the CS should contain a dynamic map of the airport surface with UA position overlaid on the map. For this reason, we recommended that airport configuration be available at RPIC request (rather than being available on a source outside the control station, which was the recommendation prior to conducting the cognitive walkthrough). Table 10 contains our recommendations.

Table 10. Information elements and recommendations for airport information.

Information Element	**Control Attribute**	**Availability**		
		Taxi	**Takeoff**	**Landing**
Runway status	Combination	Source Outside of Control Station Displays	Source Outside of Control Station Displays	Source Outside of Control Station Displays
Runway elevation (altitude)	Constant (once the runway has been selected)	Source Outside of Control Station Displays	Source Outside of Control Station Displays	Source Outside of Control Station Displays
Airport configuration	Constant	Available at RPIC Request	Available at RPIC Request	Available at RPIC Request

4.1.8 Onboard Equipment

This section reflects recommendations for onboard equipment, settings, and status relevant across flight contexts. Table 11 contains our recommendations.

Table 11. Information elements and recommendations for onboard equipment.

Information Element	Control Attribute	Availability
Altimeter setting	RPIC	Always Displayed
Aircraft external lights status	RPIC	Always Displayed
Transponder code[1]	RPIC	Always Displayed
Transponder status	Other	Always Displayed

[1]In this work, installation and maintenance are not addressed. There are many information elements associated with transponders such as the address and mode and they could change if a transponder is moved from one aircraft to another.

4.2 TAXI

Steering angle refers to the angle that the aircraft is steering while taxiing; a generic term is used since the method of aircraft taxi is dependent on the aircraft. For aircraft that are taxied via nose wheel steering, this refers to the nose wheel angle. For aircraft that are taxied via thrust and brakes, this refers to the angle that the aircraft is turning. Table 12 contains our recommendations.

Table 12. Information elements and recommendations for taxi.

Information Element	Control Attribute	Availability
Position relative to taxiway centerline	Combination	Source Outside of Control Station Displays
Steering angle	RPIC	Context Dependent
Taxiway status	Other	Source Outside of Control Station Displays

SME Comments—One SME had a suggestion for additional information to be added: “I suggest adding ‘position relative to my taxi plan’ because many times, being in the center of the taxiway is not where you want to taxi.”

- Response/Rebuttal: This information element is included in the Section 4.4.2.

4.3 APPROACH AND LANDING

In addition to the information elements presented in Section 4.1, the recommendations below are for the approach and landing phases of flight. Table 13 contains our recommendations.

Table 13. Information elements and recommendations for approach and landing.

Information Element	Control Attribute	Availability
Position relative to desired glidepath	Combination	Context Dependent
Position relative desired path over ground	Combination	Context Dependent

4.4 NAVIGATE

The information in this section refers to recommendations for navigation in the air as well as navigation while taxiing.

4.4.1 Flight Plan

In addition to information contained in Section 4.7 (e.g., airspace, terrain, and weather information), the information elements that follow are recommended for route planning. The flight time information element is a temporal representation of the aircraft range, accounting for fuel onboard or maximum battery life. Table 14 contains our recommendations.

Table 14. Information elements and recommendations for flight plan information.

Information Element	Control Attribute	Availability
Flight time elapsed	Combination	Optional
Origin	RPIC	Source Outside of Control Station Displays
Destination	RPIC	Source Outside of Control Station Displays
Alternate airport	RPIC	Source Outside of Control Station Displays
Flight plan type (IFR vs. VFR)	RPIC	Source Outside of Control Station Displays
Departure time	RPIC	Source Outside of Control Station Displays
Estimated time enroute	RPIC	Optional
Estimated arrival time	RPIC	Source Outside of Control Station Displays
Planned cruise altitude	RPIC	Source Outside of Control Station Displays
Route of flight	RPIC	Source Outside of Control Station Displays
Pilot identification data	RPIC	Source Outside of Control Station Displays
Active flight plan	RPIC	Source Outside of Control Station Displays
Inactive flight plan(s)	RPIC	Source Outside of Control Station Displays
Charts/terminal procedures	Constant	Source Outside of Control Station Displays
Taxi route	RPIC	Source Outside of Control Station Displays

SME Comments—One SME commented about the alternate airport: "If the RPIC has an emergency, the alternate airport should be 'pushed' to the operator. This would result in one less thing to consider when the heat is on."

- Response/Rebuttal: Since the alternate airport is accessible to the RPIC (e.g., via the filed flight plan), the added step of "pushing" the information to the RPIC can be considered higher than minimum. "Pushing" the information could interrupt the RPIC's emergency procedure, which counters Yeh et al. (2013) assertion that routine information may be stored and presented at an appropriate time so as not to disrupt the flightcrew in performing other critical tasks.

4.4.2 Flight Progress Monitoring

Aircraft position relative to filed flight route and planned taxi route account for the lateral, vertical, and temporal dimensions. Regarding the planned taxi route, the lateral position is the aircraft position relative to taxiway centerline. Table 15 contains our recommendations.

Table 15. Information elements and recommendations for flight progress monitoring.

Information Element	Control Attribute	Availability
Time to destination	Combination	Optional
Distance to destination	Combination	Optional
Estimated flight range remaining	Combination	Optional
Time to next waypoint	Combination	Optional
Distance to next waypoint	Combination	Optional
Position relative to desired flight route	Combination	Optional
Position relative to desired taxi route	Combination	Optional

SME Comments—Regarding time to next waypoint, one SME commented: "Time to any waypoint should be accessible. The RPIC may want to know where and when (s)he is currently and will be in the future."

- Response/Rebuttal: Since this information is not flight critical and can be derived from other information elements available to the RPIC, it is "optional."

4.4.3 Navigation Equipment

Navigation equipment is platform specific; some UAS are equipped with ground-based navigation equipment while others use only satellite-based navigation equipment. The terms in the table that follow are meant to account for both types of navigation. Table 16 contains our recommendations.

Table 16. Information elements and recommendations for navigation equipment.

Information Element	Control Attribute	Availability
Selected navigation aid	RPIC	Context Dependent
Navigation aid status	Other	Context Dependent
Quality of information reported by navigation aid	Other	Context Dependent
Source of the reported UA position information	Combination	Available at RPIC Request

SME Comments—One SME suggested "…adding 'available navigation aids' as a context-dependent information element."

- Response/Rebuttal: This would require the UAS to have a database of navigation aids, making this higher than a minimum requirement. Therefore, the information element was not added to the recommendations.

4.5 COMMUNICATE

This section contains information items for communication with external human agents (such as a VO or air traffic control) as well as communication between the control station and UA. With respect to communication, this work assumes that voice communications are accomplished via radios. It is recommended that the RPIC know what radio is active and its status and settings. Communication with the UA is through commands sent from the control station to the UA. Table 17 contains our recommendations.

Table 17. Information elements and recommendations for communication information.

Information Element	Control Attribute	Availability
Active communication radio	RPIC	Always Displayed
ATC clearance	Combination	Source Outside of Control Station Displays
ATC contact information	Constant	Source Outside of Control Station Displays
Communication channel (ATC)	RPIC	Always Displayed
Communication frequency (ATC)	RPIC	Always Displayed
Communication radio signal strength (ATC)	Other	Optional
Communication channel (VO)	RPIC	Context Dependent
Communication frequency (VO)	RPIC	Context Dependent
Communication radio signal strength (VO)	Other	Optional
Command sent status	Other	Always Displayed

SME Comments—While all SMEs agreed with the recommendations, they also made suggestions for additional items.

- One SME suggested “I am not sure if it is an FAA requirement, but some radios also have ‘last radio selected’ and ‘loaded radio’ representing the next radio the RPIC wants.”
    - Response/Rebuttal: This is not a flight critical function and is considered higher than a minimum requirement, so it was not added to the recommendations.
- One SME suggested “This list looks like it is referring to one radio. I suggest changing it to reflect a primary and secondary radio.”
    - Response/Rebuttal: The minimum requirement for manned IFR flight is one radio (14 CFR 91.205(d)(2)), so no changes were made to the recommendations.
- One SME suggested “Some UAS will start using DataComm instead of voice communications. Perhaps that should be considered in this section as well”
    - Response/Rebuttal: Data communication capability is not a flight critical function and is considered a higher level of automation than voice communication. Therefore, it was not added to the recommendations.
- One SME suggested “Contact information for ATC should be provided and should be context-dependent”

- Response/Rebuttal: ATC contact information was added to the list of information elements, but since it is available in mediums outside the control station, such as via communication channels and aeronautical charts, it has been assigned an availability of "Source Outside Control Station."

4.6 CONTINGENCY

The contingencies addressed in the scope of this work are

a) degraded UA position reporting,
b) loss of command/control link,
c) loss of contingency flight planning automation, and
d) VO failure (VO unavailable or loss of communication).

Below, first the items relevant to all four contingency areas are presented and then each is addressed.

4.6.1 All Contingencies

For each of the contingencies, it is recommended that the RPIC be able to determine the active contingency plan and to review the procedure. If the issue cannot be rectified, it is recommended that the RPIC have available the loiter and ditch information. Table 18 contains our recommendations.

Table 18. Information elements and recommendations for all contingencies.

Information Element	Control Attribute	Availability
Active contingency plan(s)	RPIC	Optional
Emergency landing area(s)	RPIC	Optional
Loiter area(s)	RPIC	Optional
Loiter waypoint direction	RPIC	Context Dependent
Loiter waypoint radius	RPIC	Optional
Loiter waypoint time	RPIC	Optional
Procedure	RPIC	Optional

4.6.2 Degraded UA Position Contingency

For the degraded UA position reporting contingency, it is recommended that the RPIC know the status of the system such as whether it is operational and its accuracy. Table 19 contains our recommendations.

Table 19. Information elements and recommendations for degraded UA position reporting.

Information Element	Control Attribute	Availability
Aircraft position reporting system status	Other	Context Dependent

4.6.3 Loss of Command/Control Link Contingency

The information elements in this subsection refer to the command/control link with the UA, and not communication radios. For the loss of command/control link contingency, it is recommended that the RPIC know the C2 link status, including the signal frequency and strength. If there is a loss of command/control link, it is recommended that the RPIC know how long the loss has occurred in order to initiate associated procedures. Table 20 contains our recommendations.

Table 20. Information elements and recommendations for loss of command/control link.

Information Element	Control Attribute	Availability
Command/control downlink signal strength	Other	Always Displayed
Command/control link frequency	RPIC	Always Displayed
Command/control link strength safe operating range/location	Other	Always Displayed
Command/control uplink signal strength	Other	Always Displayed
Lost command/control link elapsed time	Other	Context Dependent

SME Comments—There was some disagreement on the recommendations.

- General Comment: "It may not be a bad idea to call out 'secondary links.' Larger UAS may have more than one C2 link, and a minimum requirement would be 'context-dependent.' So, the first four items would be 'primary' and another four would be listed as 'secondary'."
    - Response/Rebuttal: Having multiple links is considered higher than a minimum requirement, so the suggested changes were not made to the recommendations.
- Regarding command/control downlink signal strength: "This could potentially be changed to 'context-dependent' such that the RPIC is alerted when signal strength is degraded."
    - Response/Rebuttal: While the function allocation recommendation for lost command/control link is to alert the RPIC when the signal degrades (Pankok, Bass, Walker, et al., 2017), RPIC awareness of C2 link strength is crucial for safe operation, so the recommendation has not changed based on this comment.
- Regarding lost command/control link elapsed time: "This should be changed to 'optional.' The RPIC can start a timer if the alert/warning comes on."
    - Response/Rebuttal: The function allocation recommendation for lost C2 link is to alert the RPIC when the lost link exceeds a threshold amount of time (Pankok, Bass, Walker, et al., 2017), so in accordance with the SME comment, this recommendation has remained unchanged since the information is presented to the pilot when the context is degraded C2 link.

4.6.4 Loss of Flight Planning Automation Contingency

For the loss of flight planning automation contingency, it is recommended that the RPIC has access to status information in order to know about the need to initiate associated procedures. If the RPIC discovers that the contingency flight planning automation is inoperative at a time when it is needed (e.g.,, when the command/control link is lost), there may be insufficient time to address the problem. Therefore, the contingency flight planning automation system status should be always displayed, so that when the automation becomes inoperative, the RPIC can address the issue before a contingency plan is required. Table 21 contains our recommendations.

Table 21. Information elements and recommendations for time.

Information Element	Control Attribute	Availability
Contingency flight planning automation system status	Other	Always Displayed

4.7 ENVIRONMENT

4.7.1 Airspace

Airspace information would help the pilot avoid areas in which the UA should not be operated. This type of information could also be addressed outside of the control station displays, such as with aeronautical charts. With respect to representation, this type of information could be overlaid onto an egocentric navigation display or displayed in a static digital chart or map. Table 22 contains our recommendations.

Table 22. Information elements and recommendations for airspace information.

Information Element	Control Attribute	Availability
Airspace boundaries	Other	Source Outside of Control Station Displays
Special use airspace boundaries	Other	Source Outside of Control Station Displays

4.7.2 Terrain

It is recommended that terrain information be available when the UA is near the ground. While this information could be addressed outside of the control station displays, safety could be compromised as the RPIC lacks the robust out-the-window view that a traditional manned pilot has during visual meteorological conditions. Table 23 contains our recommendations.

Table 23. Information elements and recommendations for terrain information.

Information Element	Control Attribute	Availability
Terrain/obstacle height	Other	Optional

SME Comments—One SME commented "This should be optional. Pilots do this in IFR all the time. I have shot many approaches where only the runway lights could be seen through the fog or I broke out at 200ft. I had to determine my height above ground from other information (chart, altimeter, location on approach, etc.). If there was a working radar altimeter, that was extra."

- Response/Rebuttal: Assuming the altitude AGL is displayed in the control station, the terrain/obstacle height should be optional.

4.7.3 Weather

In both visual and instrument meteorological conditions, the RPIC could benefit from some real-time weather data to determine whether the UA is flying in visual or instrument meteorological conditions. This information could be received using data sources outside of the control station. The RPIC would benefit from wind speed and direction information, especially when flying near the ground. RPICs flying below 18,000 feet require atmospheric pressure. RPICs concerned about the potential for icing would benefit from air temperature information. Table 24 contains our recommendations.

Table 24. Information elements and recommendations for weather information.

Information Element	Control Attribute	Availability
Air temperature (static or outside)	Other	Context Dependent
Atmospheric pressure	Other	Source Outside of Control Station Displays
Cloud cover/height	Other	Source Outside of Control Station Displays
Dew point	Other	Source Outside of Control Station Displays
Precipitation	Other	Source Outside of Control Station Displays
Runway visual range	Other	Source Outside of Control Station Displays
Visibility	Other	Source Outside of Control Station Displays
Wind direction	Other	Source Outside of Control Station Displays
Wind speed	Other	Source Outside of Control Station Displays

SME Comments—One SME disagreed with the recommendations for wind speed and wind direction: “Since speeds are so closely tied to winds, I recommend they be ‘always displayed’.”

- Response/Rebuttal: Myriad weather information is available to inform pilot decision-making, including observations of wind conditions on the ground such as Meteorological Terminal Aviation Routine Weather Reports (METAR); observations of winds aloft such as Pilot Weather Reports (PIREP); and wind condition forecasts such as the Terminal Aerodrome Forecast (TAF), Aviation Area Forecast (FA), Winds and Temperatures Aloft Forecast (FB), Airmen’s Meteorological Information (AIRMET), Significant Meteorological Information (SIGMET), and Convective SIGMETs. Since these sources are already available to the RPIC, adding these information sources to the control station would be considered higher than a minimum requirement.

4.8 HANDOVER OF CONTROL

The handover task analysis and function allocation recommendations indicated that there are three types of associated information. One set of information is associated with the status of the communication links between the CS and the UA. Another set of information is associated with the communication between the two RPICs. The third set of information is associated with the communication content between the RPICs. With respect to the former, it is recommended that these information elements are always displayed. Table 25 contains our recommendations.

Table 25. Information elements and recommendations for handover link status.

Information Element	Control Attribute	Availability
Command/control downlink connection status	Combination	Always Displayed
Command/control uplink connection status	Combination	Always Displayed

With respect to the communication between the RPICs, the communication channels and frequencies are recommended to be context dependent, but the radio signal strength is optional since the signal strength can be determined via the clarity of the line. Table 26 contains our recommendations.

Table 26. Information elements and recommendations for handover communication.

Information Element	Control Attribute	Availability
Communication channel (CS)	RPIC	Context Dependent
Communication frequency (CS)	RPIC	Context Dependent
Communication radio signal strength (CS)	Other	Optional

With respect to the content of the information that is communicated between the receiving RPIC and the transferring RPIC, no new information elements were identified that were not already identified as part of the other tasks. While there will be UA-specific information elements to be verbally communicated, the table below lists the information elements that are recommended to be available for all UAS handovers. Table 27 contains our recommendations.

Table 27. Information elements and recommendations for handover information.

Information Element	Control Attribute	Availability
Active contingency plan(s)	RPIC	Optional
Altitude above ground level (absolute)	Combination	Always Displayed
ATC clearance	Combination	Source Outside of Control Station Displays
Command/control downlink signal strength	Other	Always Displayed
Command/control uplink signal strength	Other	Always Displayed
Indicated altitude	Combination	Always Displayed
Indicated airspeed	RPIC	Always Displayed
Magnetic heading	RPIC	Always Displayed

<u>SME Comments</u>: SMEs generally agreed with the information recommendations, with a few exceptions detailed in the following bullets.

- Regarding altitude, one SME suggested that altitude above ground level should be always displayed as well as altitude above mean sea level.
  - Response/rebuttal: Altitude above ground level has been added since it was already always displayed in the control station (see Section 4.1.3).

- Regarding the ATC clearances, one SME indicated, "While this information is nice, I do not believe it should be always displayed. It is not required in manned aircraft."
    - Response/rebuttal: We have changed the availability of "ATC clearance" to "Source Outside Control Station" in accordance with the comment.
- Regarding information deemed safety critical by the pilot that is handing over control, one SME indicated, "Based on my experience, determining safety critical information should be an institutional decision, not an RPIC decision. Standardization across the crew force is important here."
    - Response/rebuttal: This comment addresses procedures and not automation or information requirements, so no changes were made to the recommendations in accordance with this comment.
- One SME recommended additional information elements for UA status: next waypoint, ATC frequency, and secondary command link integrity.
    - Response/rebuttal: Per the CS-3 recommendations, "route of flight" and "ATC communication frequency" are available to the RPIC, so the recommendation was not changed. Regarding "secondary link integrity", the assumptions state that the UA contains a single uplink/downlink connection, so this information element was not added.
- One SME commented that the CS should display the uplink/downlink connection status of the other CS- "This information should be made available inside the CS."
    - Response/rebuttal: This information can be conveyed via voice communication, so this suggestion reflects a higher than minimum information requirement. The recommendation was not changed.

5. RECOMMENDATIONS

The recommendations to support control station considerations for integrating UAS flying in the NAS can be summarized based on the characteristics of the information elements described in this report and summarized in Table 31.

Information elements that are recommended to always be displayed (Table 28) would yield recommendations like the following:

> It is recommended the control station have the capability to display <*information element*> at all times.

Table 28. Information elements that should be displayed at all times.

Information Element: Always Displayed
Active communication radio
Aircraft external lights status
Aircraft ID
Altimeter setting
Altitude above ground level (absolute)
Command sent status

Command/control downlink connection status
Command/control downlink signal strength
Command/control link frequency
Command/control link strength safe operating range/location
Command/control uplink connection status
Command/control uplink signal strength
Communication channel (ATC)
Communication frequency (ATC)
Contingency flight planning automation system status
Control device position
Flight mode annunciation
Indicated airspeed
Indicated altitude
Landing gear control position
Landing gear status
Latitude
Lift/drag device position
Lift/drag device position target
Longitude
Magnetic heading
Maximum flaps extended speed (V_{FE})
Maximum landing gear operating speed (V_{LO})
Maximum operating limit speed (V_{MO})
Maximum operating maneuvering speed (V_{O})
Maximum speed for normal operations (V_{NO})
Never-exceed speed (V_{NE})
Pitch attitude
Roll attitude/bank angle
Slip/skid
Stall speed (V_{S})
Stall speed in landing configuration (V_{S0})
Throttle position
Thrust reverser position
Time of day
Transponder code
Transponder status
Trim device position
Vertical speed

Information elements that are recommended to be displayed during specific contexts (Table 29) would yield recommendations like the following:

> The control station is recommended to have the capability to always display <*information element*> when <*context*>.

Table 29. Information elements that are context dependent.

Information Element	**Context**
Air temperature (static or outside)	For reciprocating engine-powered airplanes
Aircraft position reporting system status	When the quality of the information being reported has degraded
Communication channel (CS)	When communication with another CS is required
Communication channel (VO)	When communication with a VO is required
Communication frequency (CS)	When communication with another CS is required
Communication frequency (VO)	When communication with a VO is required
Loiter waypoint direction	When loiter area is used
Lost command/control link elapsed time	When loss of command/control link
Maximum landing gear extended speed (V_{LE})	When in takeoff, final approach and landing phases
Navigation aid status	When navigation aid is selected
Position relative desired path over ground	When in final approach and landing phases
Position relative to desired glidepath	When in final approach and landing phases
Quality of information reported by navigation aid	When navigation aid is selected
Rotation speed (V_R)	Takeoff
Selected navigation aid	When navigation aid is selected
Steering angle	Taxi
Takeoff decision speed (V_1)	Takeoff
Takeoff safety speed (V_2)	Takeoff
Wheel brake position	Taxi

Information elements that are recommended to be displayed at the RPIC's request (Table 30) would yield recommendations like the following:

> The control station is recommended to have the capability to display <*information element*> at the pilot's request.

Table 30. Information elements that are available at RPIC request.

Information Element: RPIC Request
Airport configuration
Ground speed
Source of the reported UA position information

Information elements that are optional would not lead to specific recommendations but could lead to design guidance or suggestions.

Information elements that can be obtained outside of the control station displays would not lead to recommendations.

Information elements that can be controlled directly by the RPIC would yield two types of recommendations like the following:

> The control station is recommended to have the capability for the pilot to enter a value for <*information element*> for upload to the UA.
>
> The control station is recommended to have the capability for the pilot to view the commanded value for <*information element*>.

In addition, for every information element that can be controlled directly by the RPIC, the design recommendation is for the display to include the value of related information elements that change as a result. For example, if the RPIC changes the landing gear control position, the control station display is recommended to make the landing gear status visible to the RPIC. For information elements that are influenced by an agent or force external to the UAS, or those influenced in combination, the design recommendation is for the display to include the value of related information elements that change as a result.

A summary of the categorizations for all of the information elements is contained in Table 31.

Table 31. Summary of information element characteristics informing recommendations.

Recommended Availability	**Control Attribute**	**Information Element**
Optional	Combination	Density altitude
		Distance to destination
		Distance to next waypoint
		Estimated flight range remaining
		Flight time elapsed
		Ground track
		Optimal climb rate
		Optimal cruise speed
		Optimal descent rate
		Position relative to desired flight route
		Position relative to desired taxi route
		Time to destination
		Time to next waypoint
		True airspeed
		True heading
Optional	Constant	Maximum altitude

Optional	Other	Communication radio signal strength (ATC) Communication radio signal strength (CS) Communication radio signal strength (VO) Terrain/obstacle height Time of day (destination) Time of day (origin)
Optional	RPIC	Active contingency plan(s) Altitude target Angle of attack Emergency landing area(s) Estimated time enroute Flight surface positions Heading target Indicated airspeed target Loiter area(s) Loiter waypoint radius Loiter waypoint time Pitch angle target Procedure Rate of turn Roll attitude/bank angle target Thrust level Vertical speed target Yaw attitude
Context Dependent	Combination	Position relative desired path over ground Position relative to desired glidepath Rotation speed (V_R) Takeoff decision speed (V_1) Takeoff safety speed (V_2)
Context Dependent	Constant	Maximum landing gear extended speed (V_{LE})
Context Dependent	Other	Air temperature (static or outside) Aircraft position reporting system status Lost command/control link elapsed time Navigation aid status Quality of information reported by navigation aid
Context Dependent	RPIC	Communication channel (CS) Communication channel (VO) Communication frequency (CS) Communication frequency (VO) Loiter waypoint direction Selected navigation aid Steering angle Wheel brake position

Always Displayed	Combination	Altitude above ground level (absolute) Command/control downlink connection status Command/control uplink connection status Indicated altitude Landing gear status Latitude Longitude Vertical speed
Always Displayed	Constant	Aircraft ID Maximum flaps extended speed (V_{FE}) Maximum landing gear operating speed (V_{LO}) Maximum operating limit speed (V_{MO}) Maximum operating maneuvering speed (V_O) Maximum speed for normal operations (V_{NO}) Never-exceed speed (V_{NE}) Stall speed (V_S) Stall speed in landing configuration (V_{S0})
Always Displayed	Other	Command sent status Command/control downlink signal strength Command/control link strength safe operating range Command/control uplink signal strength Contingency flight planning automation system status Time of day Transponder status
Always Displayed	RPIC	Active communication radio Aircraft external lights status Altimeter setting Command/control link frequency Communication channel (ATC) Communication frequency (ATC) Control device position Flight mode annunciation Indicated airspeed Landing gear control position Lift/drag device position Lift/drag device position target Magnetic heading Pitch attitude Roll attitude/bank angle Slip/skid Throttle position Thrust reverser position Transponder code Trim device position

Available at RPIC Request	Combination	Ground speed Source of the reported UA position information
Available at RPIC Request	Constant	Airport configuration
Source Outside of Control Station Displays	Combination	ATC clearance Position relative to taxiway centerline Runway status
Source Outside of Control Station Displays	Constant	Aircraft type ATC contact information Charts/terminal procedures Runway elevation (altitude)
Source Outside of Control Station Displays	Other	Airspace boundaries Atmospheric pressure Cloud cover/height Dew point Precipitation Runway visual range Special use airspace boundaries Taxiway status Visibility Wind direction Wind speed
Source Outside of Control Station Displays	RPIC	Active flight plan Alternate airport Departure time Destination Estimated arrival time Flight plan type (IFR vs. VFR) Inactive flight plan(s) Origin Pilot identification data Planned cruise altitude Route of flight Taxi route

6. FUTURE RESEARCH AREAS

The work presented in this document presents recommendations for minimum information content as well as control and feedback recommendations for UAS operation in the NAS. More work is required to validate the recommendations, including empirical testing and human-in-the-loop testing. This process should also be iterated with other relevant roles, such as for VOs and air traffic control.

A significant portion of the Certified Federal Regulations and operational control stations reviewed focused on system health and status information elements for manned and unmanned aircraft.

Since these information elements are aircraft-specific, future work should identify additional information recommendations to ensure that the RPIC is continually informed of the status of the various systems required to operate the aircraft, including (but not limited to): powerplant, fuel system, electrical system, hydraulic system, pitot tube, and oil system.

Further work is required for other items that are aircraft-specific as well, such as indication of control modes, since there is a wide range of automation and modes that could be available to the RPIC dependent on the platform. Similarly, control devices are UAS-specific, so future work should investigate how the recommendations may differ across potential control devices. Navigation equipment is also platform-specific; future work should investigate how information needs differ as a function of onboard navigation equipment.

The current work focused on UAS operation in VMC, so future work should address how information needs differ for non-VMC conditions.

Future work should also assess information needs not accounted for in the scope of this work, including needs for unmanned rotorcraft or vertical takeoff and landing UA larger than 55 lb., or fixed-wing aircraft that are not capable of flying standard takeoff or landing procedures.

One of the most significant differences between operating manned and unmanned aircraft is the lack of an out-the-window view of the environment. Future work should investigate information that is acquired by manned pilots via the out-the-window view of the aircraft (such as airport configuration, terrain, and environmental conditions) and the best way to incorporate that information into a UAS control station.

Future work should also address the information needs for situations in which the RPIC has visual contact with the UA.

The current work addressed information needs assuming the RPIC communicates with the VO and ATC via voice radio communication. Information needs may differ for other communication mediums, such as direct voice contact or data communications.

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8. APPENDIX C1: INFORMATION ELEMENTS DERIVED FROM FUNCTION ALLOCATION RECOMMENDATIONS

The tables in this appendix present the information elements derived from the Projects A7 and A10 function allocation recommendations. All information elements are organized by task, which resulted from a task analysis conducted as part of the work.

A7 TASK 6: AVIATE

Task	Information Content	Category
Manipulate required aircraft lights	Aircraft external lights status	Aviate
Manage horizontal flight path	Latitude	Aviate
Manage horizontal flight path	Longitude	Aviate
Manage horizontal flight path	Position relative to desired flight route	Aviate
Manage horizontal flight path	Magnetic heading	Aviate
Manage horizontal flight path	True heading	Aviate
Manage altitude	Indicated altitude	Aviate
Manage altitude	Indicated altitude target	Aviate
Manage altitude	Maximum altitude	Aviate
Manage vertical speed	Vertical speed	Aviate
Manage airspeed	Indicated airspeed	Aviate
Manage airspeed	Indicated airspeed target	Aviate
Manage airspeed	Optimal climb speed	Aviate
Manage airspeed	Optimal cruise speed	Aviate
Manage airspeed	Optimal descent speed	Aviate
Manage airspeed	Stall speed (V_S)	Aviate
Manage airspeed	Stall speed in landing configuration (V_{S0})	Aviate
Manage airspeed	Maximum speed for normal operations (V_{NO})	Aviate
Manage airspeed	Never-exceed speed (V_{NE})	Aviate
Set altimeter for transition level/altitude	Indicated altitude	Aviate
Set altimeter for transition level/altitude	Altimeter setting	Aviate
Configure aircraft for appropriate phase of flight	Flight surface positions	Aviate

A10 TASK CS-1: TAXI, TAKEOFF, AND LANDING

Task	Information Content	Category
Obtain taxi route	Active flight plan	Taxi
Obtain taxi route	Airport configuration	Taxi
Perform brake check	Wheel brake position	Taxi
Perform brake check	Ground speed	Taxi

Control aircraft speed along taxi route	Ground speed	Taxi
Control aircraft speed along taxi route	Wheel brake position	Taxi
Control aircraft speed along taxi route	Thrust level	Taxi
Control aircraft track along taxi route	Position relative to desired taxi route	Taxi
Control aircraft track along taxi route	Position relative to taxiway centerline	Taxi
Monitor aircraft trajectory for obstacles	Obstacle(s) along taxi route	Taxi
Configure aircraft for appropriate phase of flight	Flight surface positions	Taxi
Check for proper flight control surface movement	Flight surface positions	Taxi
Manipulate required aircraft lights	Aircraft external lights status	Taxi
Position aircraft for takeoff in appropriate configuration	Position relative to runway centerline	Takeoff
Smoothly advance power to takeoff (full) thrust	Throttle position	Takeoff
Smoothly advance power to takeoff (full) thrust	Wheel brake position	Takeoff
Observe aircraft indicators operating normally	Aircraft engine indication(s)	Takeoff
Observe aircraft indicators operating normally	Aircraft performance indication(s)	Takeoff
Maintain runway centerline	Position relative to runway centerline	Takeoff
Maintain runway centerline	Magnetic heading	Takeoff
Maintain runway centerline	True heading	Takeoff
Monitor aircraft airspeed in relation to scheduled takeoff speeds	Indicated airspeed	Takeoff
Monitor aircraft airspeed in relation to scheduled takeoff speeds	Takeoff decision speed (V1)	Takeoff
Monitor aircraft airspeed in relation to scheduled takeoff speeds	Takeoff safety speed (V2)	Takeoff
Monitor aircraft airspeed in relation to scheduled takeoff speeds	Rotation speed (VR)	Takeoff
Lift off/rotate	Throttle position	Takeoff
Lift off/rotate	Pitch attitude	Takeoff
Lift off/rotate	Pitch angle target	Takeoff
Check for positive rate of climb	Vertical speed	Takeoff
Check for positive rate of climb	Indicated altitude	Takeoff
Monitor airspeed in comparison to configuration-based airspeed limits	Indicated airspeed	Takeoff
Monitor airspeed in comparison to configuration-based airspeed limits	Optimal climb speed	Takeoff

Monitor airspeed in comparison to configuration-based airspeed limits	Maximum flap operating speed (VFO)	Takeoff
Monitor airspeed in comparison to configuration-based airspeed limits	Maximum flaps extended speed (VFE)	Takeoff
Monitor airspeed in comparison to configuration-based airspeed limits	Maximum landing gear operating speed (VLO)	Takeoff
Monitor airspeed in comparison to configuration-based airspeed limits	Maximum landing gear extended speed (VLE)	Takeoff
Landing decision	Altitude above ground level (absolute)	Landing
Landing decision	Indicated airspeed	Landing
Landing decision	Position relative to desired path over ground	Landing
Reduce power to thrust required for landing	Throttle position	Landing
Ensure aircraft is in safe location for landing	Position relative to runway centerline	Landing
Perform landing/touchdown	Throttle position	Landing
Perform landing/touchdown	Pitch attitude	Landing
Perform landing/touchdown	Pitch angle target	Landing
Slow aircraft to taxi speed	Ground speed	Landing
Determine runway turn-off	Taxi route	Landing
Determine runway turn-off	Position relative to desired taxi route	Landing
Determine runway turn-off	Airport configuration	Landing
Turn aircraft off runway	Position relative to desired taxi route	Landing

A10 TASK CS-2: NAVIGATE, COMMUNICATE, CONTINGENCY, AND HANDOVER

Task	Information Content	Category
Verify top of climb	Top of climb	Navigate
Communicate with external agents	Communication channel	Communicate
Communicate with external agents	Communication frequency	Communicate
Communicate with external agents	Active communication radio	Communicate
Obtain airport data	Wind direction	Navigate
Obtain airport data	Wind speed	Navigate
Obtain airport data	Runway status	Navigate
Obtain airport data	Precipitation	Navigate
Determine descent profile	Wind direction	Navigate
Determine descent profile	Wind speed	Navigate
Determine descent profile	Weather conditions	Navigate
Determine descent profile	Optimal descent rate	Navigate
Determine descent profile	Airspace conditions	Navigate

Determine descent profile	Terrain/obstacle height	Navigate
Determine top of descent	Wind direction	Navigate
Determine top of descent	Wind speed	Navigate
Determine top of descent	Weather conditions	Navigate
Determine top of descent	Optimal descent rate	Navigate
Determine top of descent	Indicated altitude	Navigate
Determine top of descent	Position relative to desired path over ground	Navigate
Determine top of descent	Indicated airspeed	Navigate
Identify touchdown target on first third of runway	Charts/terminal procedures	Landing
Identify touchdown target on first third of runway	Position relative to desired path over ground	Landing
Determine approach profile	Charts/terminal procedures	Landing
Determine approach profile	Wind direction	Landing
Determine approach profile	Wind speed	Landing
Determine approach profile	Weather conditions	Landing
Determine approach profile	Optimal descent rate	Landing
Determine approach profile	Airspace conditions	Landing
Determine approach profile	Terrain/obstacle height	Landing
Tune applicable navigation avionics	Position relative to desired flight route	Navigate
Tune applicable navigation avionics	Selected navigation aid	Navigate
Monitor aircraft position along route	Latitude	Navigate
Monitor aircraft position along route	Longitude	Navigate
Monitor aircraft position along route	Position relative to desired flight route	Navigate
Command aircraft heading	Latitude	Navigate
Command aircraft heading	Longitude	Navigate
Command aircraft heading	Magnetic heading	Navigate
Command aircraft heading	True heading	Navigate
Command aircraft heading	Heading target/clearance	Navigate
Monitor aircraft altitude along route	Indicated altitude	Navigate
Monitor aircraft altitude along route	Altitude target/clearance	Navigate
Implement route change(s)	Chosen route alternative	Navigate
Pre-flight systems management and checks	System status	Manage Systems
Pre-flight systems management and checks	System safe operating range	Manage Systems
Monitor system health and status	System status	Manage Systems
Monitor system health and status	System safe operating range	Manage Systems
Perform system health and status intervention	Procedure	Manage Systems
Lost command and/or control link	Command/control downlink signal strength	Contingency

Lost command and/or control link	Command/control uplink signal strength	Contingency
Lost command and/or control link	Command/control link strength safe operating range/location	Contingency
Lost command and/or control link	Lost command/control link elapsed time	Contingency
Lost command and/or control link	Procedure	Contingency
Degraded aircraft position reporting	Aircraft position reporting system status	Contingency
Degraded aircraft position reporting	Procedure	Contingency
Loss of contingency flight plan automation	Contingency flight planning automation system status	Contingency
Loss of contingency flight plan automation	Procedure	Contingency
Visual observer failure	Communication frequency	Contingency
Visual observer failure	Procedure	Contingency
Positive transfer of control from transferring CS to receiving CS occurs	Command/control uplink connection status	Handover
Positive transfer of control from transferring CS to receiving CS occurs	Command/control downlink connection status	Handover

9. APPENDIX C2: STRUCTURED QUERY LANGUAGE QUERIES

This appendix contains SQL queries used to retrieve all the information elements that were consolidated from the various sources into the Microsoft Access Database.

FEDERAL AVIATION REGULATIONS

```
(SELECT DISTINCT Part_23_Regulation AS Regulations
FROM cfr_tbl
WHERE Information_Content LIKE '*' & [Information Element] & '*')
UNION
(SELECT DISTINCT Part_25_Regulation
FROM cfr_tbl
WHERE Information_Content LIKE '*' & [Information Element] & '*')
UNION (SELECT DISTINCT Part_91_Regulation
FROM cfr_tbl
WHERE Information_Content LIKE '*' & [Information Element] & '*');
```

OPERATIONAL CONTROL STATION REVIEW

```
SELECT DISTINCT operational_cs_tbl.Source
FROM operational_cs_tbl
WHERE Information_Content Like '*' & [Information Element] & '*';
```

LITERATURE REVIEW

```
SELECT Authors & " (" & Pub_Year & ") " & Title
FROM (SELECT DISTINCT Authors, Pub_Year, Title
        FROM cs_lit_tbl
        WHERE Information_Content LIKE '*' & [Information Element] & '*');
```

FUNCTION ALLOCATION RECOMMENDATIONS

```
SELECT DISTINCT Source
FROM fa_rec_tbl
WHERE Information_Content LIKE '*' & [Information Element] & '*';
```

APPLICABILITY

```
SELECT DISTINCT Applicability
FROM cfr_tbl
WHERE Information_Content LIKE '*' & [Information Element] & '*';
```

FAR DESIGN GUIDANCE

```
SELECT DISTINCT Design_Guidance
FROM cfr_tbl
WHERE Information_Content LIKE '*' & [Information Element] & '*';
```

OPERATIONAL CONTROL STATION DESIGN GUIDANCE

```
SELECT DISTINCT Design_Guidance
FROM operational_cs_tbl
WHERE Information_Content LIKE '*' & [Information Element] & '*';
```

10. APPENDIX C3: INFORMATION ELEMENT SOURCES

This appendix contains tables that provide all of the sources containing the information source (which is in bold above the table). The tables provide sources of the information element, applicability if necessary, and design recommendations.

Active communication radio

Relevant Certified Federal Regulation(s): • 91.135(b) • 91.205(d)(2)
Function Allocation Recommendation Tasks: • Communicate with external agents

Active contingency plan(s)

Operational Control Stations: • Advanced Cockpit Ground Control Station
Function Allocation Recommendation Tasks: • Determine necessary route change(s)
Design Recommendation: Formats in operational control stations: • Text • Text in a grid

Active flight plan

Operational Control Stations: • X-Gen Control Station

Air temperature (static or outside)

Relevant Certified Federal Regulation(s):
- 23.1303(d)
- 23.1305(b)(1)
- 25.1303(a)(1)
- 25.1305(b)(1)

Applicability:
- For reciprocating engine-powered airplanes
- Minimum required flight and navigation instrument for reciprocating engine-powered airplanes of more than 6,000 pounds maximum weight and turbine engine powered airplanes

Aircraft external lights status

Relevant Certified Federal Regulation(s):
- 25.1383(c)

Operational Control Stations:
- Advanced Cockpit Ground Control Station

Function Allocation Recommendation Tasks:
- Manipulate required aircraft lights

Design Recommendation:
Formats in operational control stations:
- Color-coded indicator

Aircraft ID

Operational Control Stations:
- Advanced Cockpit Ground Control Station
- SenseFly eMotion Control Station

Literature:
- F. Friedman-Berg, J. Rein and N. Racine (2014) Minimum visual information requirements for detect and avoid in unmanned aircraft systems
- R. Arteaga, R. Kotcher, M. Cavalin and M. Dandachy (2016) Application of an ADS-B Sense and Avoid Algorithm

Design Recommendation:
Formats in operational control stations:
- Text

Aircraft position reporting system status

Function Allocation Recommendation Tasks: • Degraded aircraft position reporting

Aircraft type

Literature: • Federal Aviation Administration (2017). Aeronautical Information Manual.

Airport configuration

Function Allocation Recommendation Tasks: • Obtain taxi route • Determine runway turn-off

Airspace boundaries

Literature: • Federal Aviation Administration (2017). Aeronautical Information Manual.

Alternate airport

Operational Control Stations: • Advanced Cockpit Ground Control Station • Piccolo Command Center • Procerus Virtual Cockpit • SenseFly eMotion Control Station
Literature: • B. Donmez, H. Graham and M. Cummings (2008) Assessing the Impact of Haptic Peripheral Displays for UAV Operators • B. Donmez, M. L. Cummings and H. D. Graham (2009) Auditory decision aiding in supervisory control of multiple unmanned aerial vehicles • C. Fuchs, C. Borst, G. C. de Croon, M. R. van Paassen and M. Mulder (2014) An ecological approach to the supervisory control of UAV swarms • C. Kenny, R. J. Shively and K. Jordan (2014) Unmanned Aircraft System (UAS) Delegation of Separation in NextGen Airspace • C. Santiago and E. R. Mueller (2015) Pilot Evaluation of a UAS Detect-and-Avoid System's Effectiveness in Remaining Well Clear • G. L. Calhoun, C. A. Miller, T. C. Hughes and M. H. Draper (2014) UAS sense and avoid system interface design and evaluation

- G. L. Calhoun, M. Draper, C. Miller, H. Ruff, C. Breeden and J. Hamell (2013) Adaptable automation interface for multi-unmanned aerial systems control: Preliminary usability evaluation
- H. Graham and M. Cummings (2007) Assessing the Impact of Auditory Peripheral Displays for UAV Operators
- J. Haber and J. Chung (2016) Assessment of UAV Operator Workload in A Reconfigurable Multi-Touch Ground Control Station Environment
- K. Monk, R. J. Shively, L. Fern and R. C. Rorie (2015) Effects of Display Location and Information Level on UAS Pilot Assessments of a Detect and Avoid System
- K. W. Williams (2012) An Investigation of Sensory Information, Levels of Automation, and Piloting Experience on Unmanned Aircraft Pilot Performance
- L. Damilano, G. Guglieri, F. Quagliotti and I. Sale (2012) FMS for unmanned aerial systems: HMI issues and new interface solutions
- L. Fern and J. Shively (2011) Designing airspace displays to support rapid immersion for UAS handoffs
- L. Fern, C. A. Kenny, R. J. Shively and W. Johnson (2012) UAS integration into the NAS: an examination of baseline compliance in the current airspace system
- L. Fern, R. C. Rorie, J. S. Pack, R. J. Shively and M. H. Draper (2015) An evaluation of Detect and Avoid (DAA) displays for unmanned aircraft systems: The effect of information level and display location on pilot performance
- M. B. Cook, H. S. Smallman, F. C. Lacson and D. I. Manes (2009) Design and validation of a synthetic task environment to study dynamic unmanned aerial vehicle re-planning
- M. B. Cook, H. S. Smallman, F. C. Lacson and D. I. Manes (2010) Situation displays for dynamic UAV replanning: Intuitions and performance for display formats
- M. F. L. De Vries, G. J. M. Koeners, F. D. Roefs, H. T. A. Van Ginkel and E. Theunissen (2006) Operator support for time-critical situations: Design and evaluation
- M. H. Draper, J. S. Pack, S. J. Darrah, S. N. Moulton and G. L. Calhoun (2014) Human-Machine Interface development for common airborne sense and avoid program
- R. C. Rorie and L. Fern (2014) UAS measured response the effect of GCS control mode interfaces on pilot ability to comply with ATC clearances
- R. C. Rorie and L. Fern (2015) The impact of integrated maneuver guidance information on UAS pilots performing the Detect and Avoid task
- R. C. Rorie, L. Fern and J. Shively (2016) The Impact of Suggestive Maneuver Guidance on UAS Pilot Performing the Detect and Avoid Function
- S. Watza, E. Mueller and C. Santiago (2016) Piloted Well Clear Performance Evaluation of Detect and Avoid Systems with Suggestive Guidance
- X. Yuan, J. M. Histon and S. Waslander (2014) Survey of Operators' Information Requirements on Individually Operated Unmanned Aircraft Systems

Function Allocation Recommendation Tasks:

- Loss of contingency flight plan automation
- Monitor aircraft position along route

Design Recommendation: Formats in operational control stations: • Line format (solid, dashed, or translucent) • Lines connecting waypoints • Ownship symbol relative to route • Route overlaid on map • Text in a grid • Text

Altimeter Setting

Function Allocation Recommendation Tasks: • Set altimeter for transition level/altitude

Altitude above ground level (absolute)

Function Allocation Recommendation Tasks: • Landing decision

Altitude target

Operational Control Stations: • Advanced Cockpit Ground Control Station • Piccolo Command Center • Procerus Virtual Cockpit • SenseFly eMotion Control Station • X-Gen Control Station
Function Allocation Recommendation Tasks: • Monitor aircraft altitude along route
Design Recommendation: Formats in operational control stations: • Text • Text and bug • Text in pop-up window

Angle of attack

Operational Control Stations: • Advanced Cockpit Ground Control Station • X-Gen Control Station
Design Recommendation: Formats in operational control stations: • Text • Text and AOA tape

ATC clearance

Literature: • Federal Aviation Administration (2017). Aeronautical Information Manual.

ATC contact information

This information element was suggested by a subject matter expert.

Atmospheric pressure

Operational Control Stations: • Advanced Cockpit Ground Control Station • X-Gen Control Station
Design Recommendation: Formats in operational control stations: • Color-coded text and color-coded gauge • Text • Text and color-coded scale

Charts/terminal procedures

Function Allocation Recommendation Tasks: • Determine approach profile

Cloud cover/height

Literature: • Federal Aviation Administration (2017). Aeronautical Information Manual.

Command sent status

Operational Control Stations:

- Advanced Cockpit Ground Control Station
- Piccolo Command Center
- Procerus Virtual Cockpit
- SenseFly eMotion Control Station
- X-Gen Control Station

Literature:

- A. C. Trujillo, R. W. Ghatas, R. Mcadaragh, D. W. Burdette, J. R. Comstock, L. E. Hempley and H. Fan (2015) Small Unmanned Aircraft Systems Integration into the National Airspace System Visual-Line-of-Sight Human-in-the-Loop Experiment
- B. Donmez, H. Graham and M. Cummings (2008) Assessing the Impact of Haptic Peripheral Displays for UAV Operators
- C. Fuchs, C. Borst, G. C. de Croon, M. R. van Paassen and M. Mulder (2014) An ecological approach to the supervisory control of UAV swarms
- C. Kenny, R. J. Shively and K. Jordan (2014) Unmanned Aircraft System (UAS) Delegation of Separation in NextGen Airspace
- C. Santiago and E. R. Mueller (2015) Pilot Evaluation of a UAS Detect-and-Avoid System's Effectiveness in Remaining Well Clear
- F. Friedman-Berg, J. Rein and N. Racine (2014) Minimum visual information requirements for detect and avoid in unmanned aircraft systems
- G. R. Arrabito, G. Ho, Y. Li, W. Giang, C. M. Burns, M. Hou and P. Pace (2013) Multimodal Displays for Enhancing Performance in a Supervisory Monitoring Task Reaction Time to Detect Critical Events
- H. Graham and M. Cummings (2007) Assessing the Impact of Auditory Peripheral Displays for UAV Operators
- J. D. Stevenson, S. O'Young and L. Rolland (2015) Assessment of alternative manual control methods for small unmanned aerial vehicles
- J. Haber and J. Chung (2016) Assessment of UAV Operator Workload in A Reconfigurable Multi-Touch Ground Control Station Environment
- J. S. Pack, M. H. Draper, S. J. Darrah, M. P. Squire and A. Cooks (2015) Exploring Performance Differences Between UAS Sense-and-Avoid Displays
- K. Monk, R. J. Shively, L. Fern and R. C. Rorie (2015) Effects of Display Location and Information Level on UAS Pilot Assessments of a Detect and Avoid System
- L. Fern, C. A. Kenny, R. J. Shively and W. Johnson (2012) UAS integration into the NAS: an examination of baseline compliance in the current airspace system
- L. Fern, R. C. Rorie, J. S. Pack, R. J. Shively and M. H. Draper (2015) An evaluation of Detect and Avoid (DAA) displays for unmanned aircraft systems: The effect of information level and display location on pilot performance
- M. F. L. De Vries, G. J. M. Koeners, F. D. Roefs, H. T. A. Van Ginkel and E. Theunissen (2006) Operator support for time-critical situations: Design and evaluation
- R. C. Rorie and L. Fern (2014) UAS measured response the effect of GCS control mode interfaces on pilot ability to comply with ATC clearances

- R. C. Rorie and L. Fern (2015) The impact of integrated maneuver guidance information on UAS pilots performing the Detect and Avoid task

Command/control downlink connection status

Function Allocation Recommendation Tasks:
- Positive transfer of control from transferring CS to receiving CS occurs

Command/control downlink signal strength

Function Allocation Recommendation Tasks:
- Lost command and/or control link

Command/control link frequency

Operational Control Stations:
- Advanced Cockpit Ground Control Station

Literature:
- A. Hobbs and B. Lyall (2015). Human factors guidelines for unmanned aircraft system ground control stations

Command/control link strength safe operating range

Function Allocation Recommendation Tasks:
- Lost command and/or control link

Command/control uplink connection status

Function Allocation Recommendation Tasks:
- Positive transfer of control from transferring CS to receiving CS occurs

Command/control uplink signal strength

Function Allocation Recommendation Tasks:
- Lost command and/or control link

Communication channel (ATC)

Operational Control Stations: • Advanced Cockpit Ground Control Station
Function Allocation Recommendation Tasks: • Communicate with external agents
Design Recommendation: Formats in operational control stations: • Text

Communication channel (CS)

Operational Control Stations: • Advanced Cockpit Ground Control Station
Function Allocation Recommendation Tasks: • Communicate with external agents
Design Recommendation: Formats in operational control stations: • Text

Communication channel (VO)

Operational Control Stations: • Advanced Cockpit Ground Control Station
Function Allocation Recommendation Tasks: • Communicate with external agents
Design Recommendation: Formats in operational control stations: • Text

Communication frequency (ATC)

Operational Control Stations: • Advanced Cockpit Ground Control Station
Function Allocation Recommendation Tasks: • Communicate with external agents • Visual observer failure

Design Recommendation: Formats in operational control stations: • Text

Communication frequency (CS)

Operational Control Stations: • Advanced Cockpit Ground Control Station
Function Allocation Recommendation Tasks: • Communicate with external agents • Visual observer failure
Design Recommendation: Formats in operational control stations: • Text

Communication frequency (VO)

Operational Control Stations: • Advanced Cockpit Ground Control Station
Function Allocation Recommendation Tasks: • Communicate with external agents • Visual observer failure
Design Recommendation: Formats in operational control stations: • Text

Communication radio signal strength (ATC)

Operational Control Stations: • Advanced Cockpit Ground Control Station
Design Recommendation: Formats in operational control stations: • Text

Communication radio signal strength (CS)

Operational Control Stations: • Advanced Cockpit Ground Control Station
Design Recommendation: Formats in operational control stations: • Text

Communication radio signal strength (VO)

Operational Control Stations: • Advanced Cockpit Ground Control Station
Design Recommendation: Formats in operational control stations: • Text

Contingency flight planning automation system status

Function Allocation Recommendation Tasks: • Loss of contingency flight plan automation

Control device position

Operational Control Stations: • Advanced Cockpit Ground Control Station • X-Gen Control Station
Literature: • A. C. Trujillo, R. W. Ghatas, R. Mcadaragh, D. W. Burdette, J. R. Comstock, L. E. Hempley and H. Fan (2015) Small Unmanned Aircraft Systems Integration into the National Airspace System Visual-Line-of-Sight Human-in-the-Loop Experiment • C. Kenny, R. J. Shively and K. Jordan (2014) Unmanned Aircraft System (UAS) Delegation of Separation in NextGen Airspace • C. Santiago and E. R. Mueller (2015) Pilot Evaluation of a UAS Detect-and-Avoid System's Effectiveness in Remaining Well Clear • F. Friedman-Berg, J. Rein and N. Racine (2014) Minimum visual information requirements for detect and avoid in unmanned aircraft systems • J. D. Stevenson, S. O'Young and L. Rolland (2015) Assessment of alternative manual control methods for small unmanned aerial vehicles • J. S. Pack, M. H. Draper, S. J. Darrah, M. P. Squire and A. Cooks (2015) Exploring Performance Differences Between UAS Sense-and-Avoid Displays

- K. Monk, R. J. Shively, L. Fern and R. C. Rorie (2015) Effects of Display Location and Information Level on UAS Pilot Assessments of a Detect and Avoid System
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- L. Fern, R. C. Rorie, J. S. Pack, R. J. Shively and M. H. Draper (2015) An evaluation of Detect and Avoid (DAA) displays for unmanned aircraft systems: The effect of information level and display location on pilot performance
- R. C. Rorie and L. Fern (2014) UAS measured response the effect of GCS control mode interfaces on pilot ability to comply with ATC clearances
- R. C. Rorie and L. Fern (2015) The impact of integrated maneuver guidance information on UAS pilots performing the Detect and Avoid task

Density altitude

Operational Control Stations:

- Advanced Cockpit Ground Control Station

Design Recommendation:

Formats in operational control stations:

- Text

Departure time

Operational Control Stations:

- Advanced Cockpit Ground Control Station
- Piccolo Command Center
- Procerus Virtual Cockpit
- SenseFly eMotion Control Station

Literature:

- B. Donmez, H. Graham and M. Cummings (2008) Assessing the Impact of Haptic Peripheral Displays for UAV Operators
- B. Donmez, M. L. Cummings and H. D. Graham (2009) Auditory decision aiding in supervisory control of multiple unmanned aerial vehicles
- C. Fuchs, C. Borst, G. C. de Croon, M. R. van Paassen and M. Mulder (2014) An ecological approach to the supervisory control of UAV swarms
- C. Kenny, R. J. Shively and K. Jordan (2014) Unmanned Aircraft System (UAS) Delegation of Separation in NextGen Airspace
- C. Santiago and E. R. Mueller (2015) Pilot Evaluation of a UAS Detect-and-Avoid System's Effectiveness in Remaining Well Clear
- G. L. Calhoun, C. A. Miller, T. C. Hughes and M. H. Draper (2014) UAS sense and avoid system interface design and evaluation

- G. L. Calhoun, M. Draper, C. Miller, H. Ruff, C. Breeden and J. Hamell (2013) Adaptable automation interface for multi-unmanned aerial systems control: Preliminary usability evaluation
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- L. Fern and J. Shively (2011) Designing airspace displays to support rapid immersion for UAS handoffs
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- M. B. Cook, H. S. Smallman, F. C. Lacson and D. I. Manes (2010) Situation displays for dynamic UAV replanning: Intuitions and performance for display formats
- M. F. L. De Vries, G. J. M. Koeners, F. D. Roefs, H. T. A. Van Ginkel and E. Theunissen (2006) Operator support for time-critical situations: Design and evaluation
- M. H. Draper, J. S. Pack, S. J. Darrah, S. N. Moulton and G. L. Calhoun (2014) Human-Machine Interface development for common airborne sense and avoid program
- R. C. Rorie and L. Fern (2014) UAS measured response the effect of GCS control mode interfaces on pilot ability to comply with ATC clearances
- R. C. Rorie and L. Fern (2015) The impact of integrated maneuver guidance information on UAS pilots performing the Detect and Avoid task
- R. C. Rorie, L. Fern and J. Shively (2016) The Impact of Suggestive Maneuver Guidance on UAS Pilot Performing the Detect and Avoid Function
- S. Watza, E. Mueller and C. Santiago (2016) Piloted Well Clear Performance Evaluation of Detect and Avoid Systems with Suggestive Guidance
- X. Yuan, J. M. Histon and S. Waslander (2014) Survey of Operators' Information Requirements on Individually Operated Unmanned Aircraft Systems

Function Allocation Recommendation Tasks:

- Loss of contingency flight plan automation
- Monitor aircraft position along route

Design Recommendation: Formats in operational control stations: • Line format (solid, dashed, or translucent) • Lines connecting waypoints • Ownship symbol relative to route • Route overlaid on map • Text in a grid • Text

Destination

Operational Control Stations: • Advanced Cockpit Ground Control Station • Piccolo Command Center • Procerus Virtual Cockpit • SenseFly eMotion Control Station
Literature: • B. Donmez, H. Graham and M. Cummings (2008) Assessing the Impact of Haptic Peripheral Displays for UAV Operators • B. Donmez, M. L. Cummings and H. D. Graham (2009) Auditory decision aiding in supervisory control of multiple unmanned aerial vehicles • C. Fuchs, C. Borst, G. C. de Croon, M. R. van Paassen and M. Mulder (2014) An ecological approach to the supervisory control of UAV swarms • C. Kenny, R. J. Shively and K. Jordan (2014) Unmanned Aircraft System (UAS) Delegation of Separation in NextGen Airspace • C. Santiago and E. R. Mueller (2015) Pilot Evaluation of a UAS Detect-and-Avoid System's Effectiveness in Remaining Well Clear • G. L. Calhoun, C. A. Miller, T. C. Hughes and M. H. Draper (2014) UAS sense and avoid system interface design and evaluation • G. L. Calhoun, M. Draper, C. Miller, H. Ruff, C. Breeden and J. Hamell (2013) Adaptable automation interface for multi-unmanned aerial systems control: Preliminary usability evaluation • H. Graham and M. Cummings (2007) Assessing the Impact of Auditory Peripheral Displays for UAV Operators • J. Haber and J. Chung (2016) Assessment of UAV Operator Workload in A Reconfigurable Multi-Touch Ground Control Station Environment • K. Monk, R. J. Shively, L. Fern and R. C. Rorie (2015) Effects of Display Location and Information Level on UAS Pilot Assessments of a Detect and Avoid System • K. W. Williams (2012) An Investigation of Sensory Information, Levels of Automation, and Piloting Experience on Unmanned Aircraft Pilot Performance • L. Damilano, G. Guglieri, F. Quagliotti and I. Sale (2012) FMS for unmanned aerial systems: HMI issues and new interface solutions

- L. Fern and J. Shively (2011) Designing airspace displays to support rapid immersion for UAS handoffs
- L. Fern, C. A. Kenny, R. J. Shively and W. Johnson (2012) UAS integration into the NAS: an examination of baseline compliance in the current airspace system
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- R. C. Rorie and L. Fern (2014) UAS measured response the effect of GCS control mode interfaces on pilot ability to comply with ATC clearances
- R. C. Rorie and L. Fern (2015) The impact of integrated maneuver guidance information on UAS pilots performing the Detect and Avoid task
- R. C. Rorie, L. Fern and J. Shively (2016) The Impact of Suggestive Maneuver Guidance on UAS Pilot Performing the Detect and Avoid Function
- S. Watza, E. Mueller and C. Santiago (2016) Piloted Well Clear Performance Evaluation of Detect and Avoid Systems with Suggestive Guidance
- X. Yuan, J. M. Histon and S. Waslander (2014) Survey of Operators' Information Requirements on Individually Operated Unmanned Aircraft Systems

Function Allocation Recommendation Tasks:

- Loss of contingency flight plan automation
- Monitor aircraft position along route

Design Recommendation:

Formats in operational control stations:

- Line format (solid, dashed, or translucent)
- Lines connecting waypoints
- Ownship symbol relative to route
- Route overlaid on map
- Text in a grid
- Text

Dew point

Literature:
- Federal Aviation Administration (2017). Aeronautical Information Manual.

Distance to destination

Operational Control Stations:
- Piccolo Command Center

Design Recommendation:
Formats in operational control stations:
- Text

Distance to next waypoint

Operational Control Stations:
- Procerus Virtual Cockpit
- X-Gen Control Station

Literature:
- C. Fuchs, C. Borst, G. C. de Croon, M. R. van Paassen and M. Mulder (2014) An ecological approach to the supervisory control of UAV swarms
- C. Kenny, R. J. Shively and K. Jordan (2014) Unmanned Aircraft System (UAS) Delegation of Separation in NextGen Airspace
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- L. Fern, C. A. Kenny, R. J. Shively and W. Johnson (2012) UAS integration into the NAS: an examination of baseline compliance in the current airspace system

Design Recommendation:
Formats in operational control stations:
- Text

Emergency landing area(s)

Operational Control Stations:
- Advanced Cockpit Ground Control Station
- Piccolo Command Center
- Procerus Virtual Cockpit
- SenseFly eMotion Control Station

Literature:

- B. Donmez, H. Graham and M. Cummings (2008) Assessing the Impact of Haptic Peripheral Displays for UAV Operators
- B. Donmez, M. L. Cummings and H. D. Graham (2009) Auditory decision aiding in supervisory control of multiple unmanned aerial vehicles
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Function Allocation Recommendation Tasks: • Loss of contingency flight plan automation • Monitor aircraft position along route
Design Recommendation: Formats in operational control stations: • Line format (solid, dashed, or translucent) • Lines connecting waypoints • Ownship symbol relative to route • Route overlaid on map • Text in a grid • Text

Estimated arrival time

Operational Control Stations: • Advanced Cockpit Ground Control Station • Piccolo Command Center • Procerus Virtual Cockpit • SenseFly eMotion Control Station
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- X. Yuan, J. M. Histon and S. Waslander (2014) Survey of Operators' Information Requirements on Individually Operated Unmanned Aircraft Systems

Function Allocation Recommendation Tasks:

- Loss of contingency flight plan automation
- Monitor aircraft position along route

Design Recommendation: Formats in operational control stations: • Line format (solid, dashed, or translucent) • Lines connecting waypoints • Ownship symbol relative to route • Route overlaid on map • Text in a grid • Text

Estimated flight range remaining

Operational Control Stations: • SenseFly eMotion Control Station
Design Recommendation: Formats in operational control stations: • Text

Estimated time enroute

Operational Control Stations: • Piccolo Command Center
Design Recommendation: Formats in operational control stations: • Text

Flight mode annunciation

Operational Control Stations: • Advanced Cockpit Ground Control Station • Piccolo Command Center • Procerus Virtual Cockpit • SenseFly eMotion Control Station • X-Gen Control Station
Design Recommendation: Formats in operational control stations: • Color-coded indicator • Data tag text • Text

Flight plan type (IFR vs. VFR)

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Function Allocation Recommendation Tasks: • Loss of contingency flight plan automation • Monitor aircraft position along route
Design Recommendation: Formats in operational control stations: • Line format (solid, dashed, or translucent) • Lines connecting waypoints • Ownship symbol relative to route • Route overlaid on map • Text in a grid • Text

Flight surface positions

Operational Control Stations: • Advanced Cockpit Ground Control Station
Design Recommendation: Formats in operational control stations: • Color-coded text • Text and up/down arrow

Flight time elapsed

Operational Control Stations:
- SenseFly eMotion Control Station

Literature:
- B. Donmez, H. Graham and M. Cummings (2008) Assessing the Impact of Haptic Peripheral Displays for UAV Operators
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- T. H. Kamine and G. A. Bendrick (2009) Visual Display Angles of Conventional and a Remotely Piloted Aircraft

Design Recommendation:
Formats in operational control stations:
- Text

Ground speed

Operational Control Stations:
- Advanced Cockpit Ground Control Station
- Procerus Virtual Cockpit
- SenseFly eMotion Control Station
- X-Gen Control Station

Function Allocation Recommendation Tasks:
- Control aircraft speed along taxi route
- Perform brake check
- Slow aircraft to taxi speed

Design Recommendation:
Formats in operational control stations:
- Text

Ground track

Operational Control Stations:
- X-Gen Control Station

Literature:
- C. Santiago and E. R. Mueller (2015) Pilot Evaluation of a UAS Detect-and-Avoid System's Effectiveness in Remaining Well Clear
- F. Friedman-Berg, J. Rein and N. Racine (2014) Minimum visual information requirements for detect and avoid in unmanned aircraft systems
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Function Allocation Recommendation Tasks:
- Manage horizontal flight path

Heading target

Operational Control Stations:
- Piccolo Command Center

Function Allocation Recommendation Tasks:
- Command aircraft heading

Design Recommendation:
Formats in operational control stations:
- Text
- Text in pop-up window

Inactive flight plan(s)

Operational Control Stations:
- X-Gen Control Station

Indicated airspeed

Relevant Certified Federal Regulation(s): • 23.1303(a) • 23.1303(e) • 23.1303(g)(1) • 23.1543(b)(2) • 23.1543(b)(3) • 23.1543(b)(4) • 23.1543(b)(5) • 23.1543(c) • 23.1543(d) • 25.1303(b)(1) • 25.1303(c)(1) • 25.1303(c)(2) • 25.1563 • 91.205(b)(1) • 91.603
Operational Control Stations: • Advanced Cockpit Ground Control Station • Piccolo Command Center • Procerus Virtual Cockpit • SenseFly eMotion Control Station • X-Gen Control Station
Literature: • A. C. Trujillo, R. W. Ghatas, R. Mcadaragh, D. W. Burdette, J. R. Comstock, L. E. Hempley and H. Fan (2015) Small Unmanned Aircraft Systems Integration into the National Airspace System Visual-Line-of-Sight Human-in-the-Loop Experiment • B. Donmez, H. Graham and M. Cummings (2008) Assessing the Impact of Haptic Peripheral Displays for UAV Operators • C. Fuchs, C. Borst, G. C. de Croon, M. R. van Paassen and M. Mulder (2014) An ecological approach to the supervisory control of UAV swarms • C. Kenny, R. J. Shively and K. Jordan (2014) Unmanned Aircraft System (UAS) Delegation of Separation in NextGen Airspace • C. Santiago and E. R. Mueller (2015) Pilot Evaluation of a UAS Detect-and-Avoid System's Effectiveness in Remaining Well Clear • F. Friedman-Berg, J. Rein and N. Racine (2014) Minimum visual information requirements for detect and avoid in unmanned aircraft systems • G. R. Arrabito, G. Ho, Y. Li, W. Giang, C. M. Burns, M. Hou and P. Pace (2013) Multimodal Displays for Enhancing Performance in a Supervisory Monitoring Task Reaction Time to Detect Critical Events • H. Graham and M. Cummings (2007) Assessing the Impact of Auditory Peripheral Displays for UAV Operators

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Function Allocation Recommendation Tasks:

- Determine top of descent
- Landing decision
- Manage airspeed
- Monitor aircraft airspeed in relation to scheduled takeoff speeds
- Monitor airspeed in comparison to configuration-based airspeed limits

Applicability:

- Commuter category airplanes for which airspeed limitations vary with altitude
- For (1) Turbine engine powered airplanes and (2) Other airplanes for which VMO/MMO and VD/MD are established under 23.335(b)(4) and 23.1505(c) if VMO/MMO is greater than 0.8 VD/MD
- For airplanes for which a maximum operating speed VMO/MMO is established
- For airplanes with compressibility limitations not otherwise indicated to the pilot by the airspeed indicating system
- For large and transport category aircraft
- For reciprocating multiengine-powered airplanes of 6,000 pounds or less maximum weight
- For VFR flight during the day or night, IFR flight, and night vision goggle operations
- If VNE or VNO vary with altitude

• Minimum required flight and navigation instrument
Design Recommendations: Design guidance in FARs: • Aural alert • Aural warning • Blue radial line • Green arc with lower limit at VS1 with maximum weight and landing gear and flaps retracted, and the upper limit at the maximum structural cruising speed VNO • Red radial line for VMO/MMO must be made at the lowest value of VMO/MMO established for any altitude up to the maximum operating altitude for the airplane • White arc with the lower limit at VSO at the maximum weight and the upper limit at the flaps-extended speed VFE • Yellow arc extending from the red line specified in (b)(1) to the upper limit of the green arc specified in (b)(3) Formats in operational control stations: • Color coded text and color coded speed tape • Tape and text • Text • Text and bug • Text and speed tape • Text in pop-up window

Indicated airspeed target

Operational Control Stations: • Piccolo Command Center • Procerus Virtual Cockpit • SenseFly eMotion Control Station • X-Gen Control Station
Function Allocation Recommendation Tasks: • Manage airspeed
Design Recommendation: Formats in operational control stations: • Text • Text and bug • Text in pop-up window

Indicated altitude

Relevant Certified Federal Regulation(s): • 23.1303(b) • 23.1303(g)(1) • 23.1305(b)(5) • 23.1543(c) • 23.1543(d) • 25.1303(b)(2) • 25.1305(b)(3) • 91.205(b)(2) • 91.205(b)(8) • 91.205(d)(5) • 91.205(h)(7) • 91.219(b)(1)
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Literature: • A. C. Trujillo, R. W. Ghatas, R. Mcadaragh, D. W. Burdette, J. R. Comstock, L. E. Hempley and H. Fan (2015) Small Unmanned Aircraft Systems Integration into the National Airspace System Visual-Line-of-Sight Human-in-the-Loop Experiment • B. Donmez, H. Graham and M. Cummings (2008) Assessing the Impact of Haptic Peripheral Displays for UAV Operators • C. Fuchs, C. Borst, G. C. de Croon, M. R. van Paassen and M. Mulder (2014) An ecological approach to the supervisory control of UAV swarms • C. Kenny, R. J. Shively and K. Jordan (2014) Unmanned Aircraft System (UAS) Delegation of Separation in NextGen Airspace • C. Santiago and E. R. Mueller (2015) Pilot Evaluation of a UAS Detect-and-Avoid System's Effectiveness in Remaining Well Clear • F. Friedman-Berg, J. Rein and N. Racine (2014) Minimum visual information requirements for detect and avoid in unmanned aircraft systems • G. L. Calhoun, C. A. Miller, T. C. Hughes and M. H. Draper (2014) UAS sense and avoid system interface design and evaluation • G. R. Arrabito, G. Ho, Y. Li, W. Giang, C. M. Burns, M. Hou and P. Pace (2013) Multimodal Displays for Enhancing Performance in a Supervisory Monitoring Task Reaction Time to Detect Critical Events • H. Graham and M. Cummings (2007) Assessing the Impact of Auditory Peripheral Displays for UAV Operators

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- M. Hou, G. Ho, G. R. Arrabito, S. Young and S. Yin (2013) Effects of display mode and input method for handheld control of micro aerial vehicles for a reconnaissance mission
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- S. Watza, E. Mueller and C. Santiago (2016) Piloted Well Clear Performance Evaluation of Detect and Avoid Systems with Suggestive Guidance
- X. Yuan, J. M. Histon and S. Waslander (2014) Survey of Operators' Information Requirements on Individually Operated Unmanned Aircraft Systems

Function Allocation Recommendation Tasks:

- Check for positive rate of climb
- Determine top of descent

• Manage altitude • Monitor aircraft altitude along route • Set altimeter for transition level/altitude
Applicability: • Commuter category airplanes for which airspeed limitations vary with altitude • For airplanes for which a maximum operating speed VMO/MMO is established • For reciprocating engine-powered airplanes • For turbojet-powered civil airplanes • For VFR flight during the day or night, IFR flight, and night vision goggle operations • If VNE or VNO vary with altitude • IFR flight • Minimum required flight and navigation instrument • Night vision goggle operations
Design Recommendation: Design guidance in CFRs: • Red radial line for VMO/MMO must be made at the lowest value of VMO/MMO established for any altitude up to the maximum operating altitude for the airplane • Sequence of both aural and visual signals in sufficient to establish level flight Formats in operational control stations: • Color coded text and color coded altitude tape • Color-coded route segments • Data tag text • Route overlaid on vertical profile • Tape and text • Text • Text and altitude tape • Text and bug • Text in a grid • Text in pop-up window

Landing gear control position

Operational Control Stations: • Advanced Cockpit Ground Control Station
Design Recommendation: Formats in operational control stations: • Scale

Landing gear status

Relevant Certified Federal Regulation(s):
- 91.205(b)(10)

Operational Control Stations:
- Advanced Cockpit Ground Control Station
- X-Gen Control Station

Applicability:
For VFR flight during the day or night, IFR flight, and night vision goggle operations

Design Recommendation:
Formats in operational control stations:
- Color-coded indicator
- Text

Latitude

Relevant Certified Federal Regulation(s):
- Piccolo Command Center
- Procerus Virtual Cockpit
- SenseFly eMotion Control Station
- X-Gen Control Station

Function Allocation Recommendation Tasks:
- Command aircraft heading
- Ensure aircraft is in safe location for landing
- Identify touchdown target on first third of runway
- Manage horizontal flight path
- Monitor aircraft position along route
- Turn aircraft off runway

Design Recommendation:
Formats in operational control stations:
- Text
- Text in pop-up window
- UA symbol on map

Lift/drag device position

Relevant Certified Federal Regulation(s):
- 23.1305(b)(3)
- 23.1543(b)(4)

- 23.207(a)
- 23.677(a)
- 23.699(a)
- 23.729(f)
- 25.1305(b)(2)
- 25.1563
- 25.207(a)
- 25.677(b)
- 25.699(a)
- 25.729(e)(2)-(3), (7)
- 25.1563

Operational Control Stations:

- Advanced Cockpit Ground Control Station
- Piccolo Command Center
- Procerus Virtual Cockpit

Function Allocation Recommendation Tasks:

- Monitor airspeed in comparison to configuration-based airspeed limits

Applicability:

- For reciprocating engine-powered commuter category airplanes
- if (1) any flap position other than retracted or fully extended is used to show compliance with performance requirements
- "Unless (a) a direct operating mechanism provides a sense of ""feel and position; or (2) The flap position is readily determined without seriously detracting from other piloting duties"

Design Recommendation:

Design guidance in CFRs:

- Aural warning
- Visual warning itself is not acceptable
- Warning may be furnished either through the inherent aerodynamic qualities of the airplane or by a device that will give clearly distinguishable indications under expected conditions of flight.
- White arc with the lower limit at VSO at the maximum weight and the upper limit at the flaps-extended speed VFE

Formats in operational control stations:

- Color-coded text
- Scale
- Text and scale
- Text in pop-up window

Lift/drag device position target

Operational Control Stations: • Piccolo Command Center
Design Recommendation: Formats in operational control stations: • Text in pop-up window

Loiter area(s)

Operational Control Stations: • Piccolo Command Center
Design Recommendation: Formats in operational control stations: • Circular routes overlaid on map

Loiter waypoint direction

Operational Control Stations: • Piccolo Command Center
Design Recommendation: Formats in operational control stations: • Text in pop-up window

Loiter waypoint radius

Operational Control Stations: • Piccolo Command Center
Design Recommendation: Formats in operational control stations: • Text in pop-up window

Loiter waypoint time

Operational Control Stations: • Piccolo Command Center

Design Recommendation: Formats in operational control stations: • Text in pop-up window

Longitude

Relevant Certified Federal Regulation(s): • Piccolo Command Center • Procerus Virtual Cockpit • SenseFly eMotion Control Station • X-Gen Control Station
Function Allocation Recommendation Tasks: • Command aircraft heading • Ensure aircraft is in safe location for landing • Identify touchdown target on first third of runway • Manage horizontal flight path • Monitor aircraft position along route • Turn aircraft off runway
Design Recommendation: Formats in operational control stations: • Text • Text in pop-up window • UA symbol on map

Lost command/control link elapsed time

Function Allocation Recommendation Tasks: • Lost command and/or control link

Magnetic heading

Relevant Federal Aviation Regulation(s): • 25.1303(a)(3) • 25.1303(b)(6) • 23.1303(c) • 23.1327 • 25.1327 • 91.205(b)(3) • 91.205(d)(9)

Operational Control Stations:

- Advanced Cockpit Ground Control Station
- Piccolo Command Center
- Procerus Virtual Cockpit
- SenseFly eMotion Control Station
- X-Gen Control Station

Literature:

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- W. Rodes and L. Gugerty (2012) Effects of electronic map displays and individual differences in ability on navigation performance
- X. Yuan, J. M. Histon and S. Waslander (2014) Survey of Operators' Information Requirements on Individually Operated Unmanned Aircraft Systems

Function Allocation Recommendation Tasks:

- Command aircraft heading
- Maintain runway centerline
- Manage horizontal flight path

Applicability:

- For VFR flight during the day or night, IFR flight, and night vision goggle operations
- IFR flight
- Installed at each pilot station
- Minimum required flight and navigation instrument
- Must be visible from each pilot station

Design Recommendation:

Design guidance in CFRs:

- Gyroscopically stabilized, magnetic, or non-magnetic)
- Non-stabilized magnetic compass

Formats in operational control stations:

- Text
- Text and compass rose
- Text and heading tape
- Text in pop-up window

Maximum altitude

Operational Control Stations: • SenseFly eMotion Control Station
Function Allocation Recommendation Tasks: • Manage altitude
Design Recommendation: Formats in operational control stations: • Text

Maximum flaps extended speed (V_{FE})

Function Allocation Recommendation Tasks: • Monitor airspeed in comparison to configuration-based airspeed limits

Maximum landing gear extended speed (V_{LE})

Function Allocation Recommendation Tasks: • Monitor airspeed in comparison to configuration-based airspeed limits

Maximum landing gear operating speed (V_{LO})

Relevant Certified Federal Regulation(s): • 23.1563(b)
Function Allocation Recommendation Tasks: • Monitor airspeed in comparison to configuration-based airspeed limits

Maximum operating limit speed (V_{MO})

Relevant Certified Federal Regulation(s): • 23.1303(g)(1) • 23.1543(d) • 25.1563 • 25.1563 • 91.603
Function Allocation Recommendation Tasks: • Manage airspeed

Applicability: • Commuter category airplanes for which airspeed limitations vary with altitude • For airplanes for which a maximum operating speed V_{MO}/M_{MO} is established • For large and transport category aircraft
Design Recommendation: Design guidance in CFRs: • Aural alert • Red radial line for V_{MO}/M_{MO} must be made at the lowest value of V_{MO}/M_{MO} established for any altitude up to the maximum operating altitude for the airplane

Maximum operating maneuvering speed (V_O)

Relevant Certified Federal Regulation(s): • 23.1351(d)(2) • 23.1563(a) • 25.1351(b)(6) • 25.1351(b)(6)- similar
Operational Control Stations: • Advanced Cockpit Ground Control Station • Piccolo Command Center • Procerus Virtual Cockpit • SenseFly eMotion Control Station • X-Gen Control Station
Applicability: • For commuter category airplanes
Design Recommendation: Formats in operational control stations: • Color-coded text and color-coded gauge • Text • Text and color-coded scale • Text and scale

Maximum speed for normal operations (V_{NO})

Function Allocation Recommendation Tasks: • Manage airspeed

Navigation aid status

Operational Control Stations: • Advanced Cockpit Ground Control Station • SenseFly eMotion Control Station
Design Recommendation: Formats in operational control stations: • Line format (solid, dashed, and translucent) • Text

Never-exceed speed (V_{NE})

Relevant Certified Federal Regulation(s): • 23.1543(b)(1) • 25.1563
Function Allocation Recommendation Tasks: • Manage airspeed
Design Recommendation: Design guidance in CFRs: • Red radial line

Optimal climb speed

Function Allocation Recommendation Tasks: • Manage airspeed • Monitor airspeed in comparison to configuration-based airspeed limits

Optimal cruise speed

Function Allocation Recommendation Tasks: • Manage airspeed

Optimal descent speed

Function Allocation Recommendation Tasks: • Manage airspeed • Determine approach profile

Origin

Operational Control Stations: • Advanced Cockpit Ground Control Station • Piccolo Command Center • Procerus Virtual Cockpit • SenseFly eMotion Control Station
Literature: • B. Donmez, H. Graham and M. Cummings (2008) Assessing the Impact of Haptic Peripheral Displays for UAV Operators • B. Donmez, M. L. Cummings and H. D. Graham (2009) Auditory decision aiding in supervisory control of multiple unmanned aerial vehicles • C. Fuchs, C. Borst, G. C. de Croon, M. R. van Paassen and M. Mulder (2014) An ecological approach to the supervisory control of UAV swarms • C. Kenny, R. J. Shively and K. Jordan (2014) Unmanned Aircraft System (UAS) Delegation of Separation in NextGen Airspace • C. Santiago and E. R. Mueller (2015) Pilot Evaluation of a UAS Detect-and-Avoid System's Effectiveness in Remaining Well Clear • G. L. Calhoun, C. A. Miller, T. C. Hughes and M. H. Draper (2014) UAS sense and avoid system interface design and evaluation • G. L. Calhoun, M. Draper, C. Miller, H. Ruff, C. Breeden and J. Hamell (2013) Adaptable automation interface for multi-unmanned aerial systems control: Preliminary usability evaluation • H. Graham and M. Cummings (2007) Assessing the Impact of Auditory Peripheral Displays for UAV Operators • J. Haber and J. Chung (2016) Assessment of UAV Operator Workload in A Reconfigurable Multi-Touch Ground Control Station Environment • K. Monk, R. J. Shively, L. Fern and R. C. Rorie (2015) Effects of Display Location and Information Level on UAS Pilot Assessments of a Detect and Avoid System • K. W. Williams (2012) An Investigation of Sensory Information, Levels of Automation, and Piloting Experience on Unmanned Aircraft Pilot Performance • L. Damilano, G. Guglieri, F. Quagliotti and I. Sale (2012) FMS for unmanned aerial systems: HMI issues and new interface solutions • L. Fern and J. Shively (2011) Designing airspace displays to support rapid immersion for UAS handoffs • L. Fern, C. A. Kenny, R. J. Shively and W. Johnson (2012) UAS integration into the NAS: an examination of baseline compliance in the current airspace system • L. Fern, R. C. Rorie, J. S. Pack, R. J. Shively and M. H. Draper (2015) An evaluation of Detect and Avoid (DAA) displays for unmanned aircraft systems: The effect of information level and display location on pilot performance • M. B. Cook, H. S. Smallman, F. C. Lacson and D. I. Manes (2009) Design and validation of a synthetic task environment to study dynamic unmanned aerial vehicle re-planning • M. B. Cook, H. S. Smallman, F. C. Lacson and D. I. Manes (2010) Situation displays for dynamic UAV replanning: Intuitions and performance for display formats

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Function Allocation Recommendation Tasks:
- Loss of contingency flight plan automation
- Monitor aircraft position along route

Design Recommendation:
Formats in operational control stations:
- Line format (solid, dashed, or translucent)
- Lines connecting waypoints
- Ownship symbol relative to route
- Route overlaid on map
- Text in a grid
- Text

Pilot identification data

Literature:
- Federal Aviation Administration (2017). Aeronautical Information Manual.

Pitch angle target

Function Allocation Recommendation Tasks:
- Lift off/rotate
- Perform landing/touchdown

Pitch attitude

Relevant Certified Federal Regulation(s):
- 23.1305(b)(8)

- 23.1305(e)(2)
- 23.677(a)
- 25.1303(b)(5)
- 25.1305(e)(1)
- 25.677(b)
- 91.205(d)(8)
- 91.205(h)(5)

Operational Control Stations:
- Advanced Cockpit Ground Control Station
- Piccolo Command Center
- Procerus Virtual Cockpit
- SenseFly eMotion Control Station
- X-Gen Control Station

Literature:
- A. C. Trujillo, R. W. Ghatas, R. Mcadaragh, D. W. Burdette, J. R. Comstock, L. E. Hempley and H. Fan (2015) Small Unmanned Aircraft Systems Integration into the National Airspace System Visual-Line-of-Sight Human-in-the-Loop Experiment
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- T. H. Kamine and G. A. Bendrick (2009) Visual Display Angles of Conventional and a Remotely Piloted Aircraft

Function Allocation Recommendation Tasks:
- Lift off/rotate
- Perform landing/touchdown

Applicability:
- For reciprocating engine-powered airplanes
- For turbopropeller-powered airplanes
- IFR flight and night vision goggle operations
- Installed at each pilot station

Design Guidance:
Design guidance in CFRs:
- Artificial horizon

Formats in operational control stations: • Attitude indicator • Attitude indicator and scale • Text

Planned cruise altitude

Operational Control Stations: • Advanced Cockpit Ground Control Station • Piccolo Command Center • Procerus Virtual Cockpit • SenseFly eMotion Control Station • X-Gen Control Station
Function Allocation Recommendation Tasks: • Monitor aircraft altitude along route
Design Recommendation: Formats in operational control stations: • Text • Text and bug • Text in pop-up window

Position relative to desired flight route

Operational Control Stations: • Advanced Cockpit Ground Control Station • SenseFly eMotion Control Station
Function Allocation Recommendation Tasks: • Command aircraft heading
Design Recommendation: Formats in operational control stations: • Navigation display • Text

Position relative to desired glidepath

Operational Control Stations: • Advanced Cockpit Ground Control Station • Piccolo Command Center

Design Recommendation: Formats in operational control stations: • Glideslope indicator (scale)

Position relative to desired path over ground

Operational Control Stations: • Advanced Cockpit Ground Control Station • Piccolo Command Center
Design Recommendation: Formats in operational control stations: • Localizer indicator (scale)

Position relative to desired taxi route

Function Allocation Recommendation Tasks: • Determine runway turn-off • Turn aircraft off runway

Position relative to taxiway centerline

Function Allocation Recommendation Tasks: • Control aircraft track along taxi route

Precipitation

Literature: • Federal Aviation Administration (2017). Aeronautical Information Manual.

Procedure

Operational Control Stations: • Advanced Cockpit Ground Control Station
Function Allocation Recommendation Tasks: • Perform system health and status intervention • Degraded aircraft position reporting • Loss of contingency flight plan automation • Lost command and/or control link

• Visual observer failure
Design Recommendation: Formats in operational control stations: • Text

Quality of information reported by navigation aid

Operational Control Stations: • Procerus Virtual Cockpit • SenseFly eMotion Control Station
Design Recommendation: Formats in operational control stations: • Color-coded indicator • Signal strength symbol • Text

Rate of turn

Relevant Certified Federal Regulation(s): • 25.1303(b)(f) • 91.205(d)(3)
Applicability: • IFR flight • Installed at each pilot station

Roll attitude/bank angle

Relevant Certified Federal Regulation(s): • 23.1305(b)(5) • 25.1303(b)(5) • 25.1305(b)(3) • 91.205(d)(8) • 91.205(h)(5)
Operational Control Stations: • Advanced Cockpit Ground Control Station • Piccolo Command Center • Procerus Virtual Cockpit • SenseFly eMotion Control Station

• X-Gen Control Station
Literature: • A. C. Trujillo, R. W. Ghatas, R. Mcadaragh, D. W. Burdette, J. R. Comstock, L. E. Hempley and H. Fan (2015) Small Unmanned Aircraft Systems Integration into the National Airspace System Visual-Line-of-Sight Human-in-the-Loop Experiment • C. Kenny, R. J. Shively and K. Jordan (2014) Unmanned Aircraft System (UAS) Delegation of Separation in NextGen Airspace • F. Friedman-Berg, J. Rein and N. Racine (2014) Minimum visual information requirements for detect and avoid in unmanned aircraft systems • G. R. Arrabito, G. Ho, Y. Li, W. Giang, C. M. Burns, M. Hou and P. Pace (2013) Multimodal Displays for Enhancing Performance in a Supervisory Monitoring Task Reaction Time to Detect Critical Events • L. Fern, C. A. Kenny, R. J. Shively and W. Johnson (2012) UAS integration into the NAS: an examination of baseline compliance in the current airspace system • T. H. Kamine and G. A. Bendrick (2009) Visual Display Angles of Conventional and a Remotely Piloted Aircraft
Function Allocation Recommendation Tasks: • Lift off/rotate • Perform landing/touchdown
Applicability: • For reciprocating engine-powered airplanes • IFR flight and night vision goggle operations • Installed at each pilot station
Design Recommendation: Design guidance in CFRs: • Artificial horizon Formats in operational control stations: • Attitude indicator • Attitude indicator and scale • Text • Text in pop-up window

Roll attitude/bank angle target

Operational Control Stations: • Piccolo Command Center
Design Recommendation: Formats in operational control stations: • Text in pop-up window

Rotation speed (V_R)

Function Allocation Recommendation Tasks: • Monitor aircraft airspeed in relation to scheduled takeoff speeds

Route of flight

Operational Control Stations: • Advanced Cockpit Ground Control Station • Piccolo Command Center • Procerus Virtual Cockpit • SenseFly eMotion Control Station
Literature: • B. Donmez, H. Graham and M. Cummings (2008) Assessing the Impact of Haptic Peripheral Displays for UAV Operators • B. Donmez, M. L. Cummings and H. D. Graham (2009) Auditory decision aiding in supervisory control of multiple unmanned aerial vehicles • C. Fuchs, C. Borst, G. C. de Croon, M. R. van Paassen and M. Mulder (2014) An ecological approach to the supervisory control of UAV swarms • C. Kenny, R. J. Shively and K. Jordan (2014) Unmanned Aircraft System (UAS) Delegation of Separation in NextGen Airspace • C. Santiago and E. R. Mueller (2015) Pilot Evaluation of a UAS Detect-and-Avoid System's Effectiveness in Remaining Well Clear • G. L. Calhoun, C. A. Miller, T. C. Hughes and M. H. Draper (2014) UAS sense and avoid system interface design and evaluation • G. L. Calhoun, M. Draper, C. Miller, H. Ruff, C. Breeden and J. Hamell (2013) Adaptable automation interface for multi-unmanned aerial systems control: Preliminary usability evaluation • H. Graham and M. Cummings (2007) Assessing the Impact of Auditory Peripheral Displays for UAV Operators • J. Haber and J. Chung (2016) Assessment of UAV Operator Workload in A Reconfigurable Multi-Touch Ground Control Station Environment • K. Monk, R. J. Shively, L. Fern and R. C. Rorie (2015) Effects of Display Location and Information Level on UAS Pilot Assessments of a Detect and Avoid System • K. W. Williams (2012) An Investigation of Sensory Information, Levels of Automation, and Piloting Experience on Unmanned Aircraft Pilot Performance • L. Damilano, G. Guglieri, F. Quagliotti and I. Sale (2012) FMS for unmanned aerial systems: HMI issues and new interface solutions • L. Fern and J. Shively (2011) Designing airspace displays to support rapid immersion for UAS handoffs • L. Fern, C. A. Kenny, R. J. Shively and W. Johnson (2012) UAS integration into the NAS: an examination of baseline compliance in the current airspace system • L. Fern, R. C. Rorie, J. S. Pack, R. J. Shively and M. H. Draper (2015) An evaluation of Detect and Avoid (DAA) displays for unmanned aircraft systems: The effect of information level and display location on pilot performance

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- R. C. Rorie and L. Fern (2015) The impact of integrated maneuver guidance information on UAS pilots performing the Detect and Avoid task
- R. C. Rorie, L. Fern and J. Shively (2016) The Impact of Suggestive Maneuver Guidance on UAS Pilot Performing the Detect and Avoid Function
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- X. Yuan, J. M. Histon and S. Waslander (2014) Survey of Operators' Information Requirements on Individually Operated Unmanned Aircraft Systems

Function Allocation Recommendation Tasks:

- Determine runway turn-off
- Loss of contingency flight plan automation
- Monitor aircraft position along route
- Obtain taxi route
- Turn aircraft off runway

Design Recommendation:

Formats in operational control stations:

- Line format (solid, dashed, or translucent)
- Lines connecting waypoints
- Ownship symbol relative to route
- Route overlaid on map
- Text
- Text and symbol
- Text in a grid
- Text in pop-up window

Runway elevation (altitude)

Function Allocation Recommendation Tasks:

- Determine approach profile

Runway status

Function Allocation Recommendation Tasks:
- Obtain airport data

Runway visual range

Literature:
- Federal Aviation Administration (2017). Aeronautical Information Manual.

Selected navigation aid

Operational Control Stations:
- X-Gen Control Station

Function Allocation Recommendation Tasks:
- Tune applicable navigation avionics

Design Recommendation:
Formats in operational control stations:
- Text

Slip/skid

Relevant Certified Federal Regulation(s):
- 25.1303(b)(f)
- 91.205(d)(4)

Applicability:
- IFR flight
- Installed at each pilot station

Special use airspace boundaries

Relevant Certified Federal Regulation(s):
- 14 CFR Part 73

Literature:
- Federal Aviation Administration (2017). Aeronautical Information Manual.

Stall speed (V_S)

Relevant Certified Federal Regulation(s): • 14 CFR 1.1
Function Allocation Recommendation Tasks: • Manage airspeed

Stall speed in landing configuration (V_{S0})

Relevant Certified Federal Regulation(s): • 14 CFR 1.1
Function Allocation Recommendation Tasks: • Manage airspeed

Steering angle

Operational Control Stations: • Advanced Cockpit Ground Control Station
Design Recommendation: Formats in operational control stations: • Text

Takeoff decision speed (V_1)

Function Allocation Recommendation Tasks: • Monitor aircraft airspeed in relation to scheduled takeoff speeds

Takeoff safety speed (V_2)

Function Allocation Recommendation Tasks: • Monitor aircraft airspeed in relation to scheduled takeoff speeds

Taxi route

Literature: • K. W. Williams (2004). A summary of unmanned aircraft accident/incident data: Human factors implications.

Function Allocation Recommendation Tasks:

- Control aircraft track along taxi route
- Determine runway turn-off
- Turn aircraft off runway

Taxiway status

Literature:

- G. R. Arrabito, G. Ho, Y. Li, W. Giang, C. M. Burns, M. Hou and P. Pace (2013) Multimodal Displays for Enhancing Performance in a Supervisory Monitoring Task Reaction Time to Detect Critical Events
- H. A. Ruff, M. H. Draper, L. G. Lu, M. R. Poole and D. W. Repperger (2000) Haptic feedback as a supplemental method of alerting UAV operators to the onset of turbulence

Function Allocation Recommendation Tasks:

- Control aircraft track along taxi route
- Determine runway turn-off
- Turn aircraft off runway

Terrain/obstacle height

Operational Control Stations:

- Advanced Cockpit Ground Control Station
- Piccolo Command Center
- SenseFly eMotion Control Station

Literature:

- G. L. Calhoun, M. Draper, C. Miller, H. Ruff, C. Breeden and J. Hamell (2013) Adaptable automation interface for multi-unmanned aerial systems control: Preliminary usability evaluation
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• M. F. L. De Vries, G. J. M. Koeners, F. D. Roefs, H. T. A. Van Ginkel and E. Theunissen (2006) Operator support for time-critical situations: Design and evaluation • R. C. Rorie and L. Fern (2014) UAS measured response the effect of GCS control mode interfaces on pilot ability to comply with ATC clearances • S. R. Dixon, C. D. Wickens and D. Chang (2005) Mission control of multiple unmanned aerial vehicles: A workload analysis • W. Rodes and L. Gugerty (2012) Effects of electronic map displays and individual differences in ability on navigation performance
Function Allocation Recommendation Tasks: • Determine approach profile • Determine descent profile
Design Recommendation: Formats in operational control stations: • Color map overlay • Enhanced vision system • Graphic overlay • Out-window view • Synthetic visualization • Vertical profile display

Throttle position

Relevant Certified Federal Regulation(s): • 23.729(f) • 25.729(e)(2)-(3), (7)
Operational Control Stations: • Piccolo Command Center
Function Allocation Recommendation Tasks: • Source • Lift off/rotate • Perform landing/touchdown • Reduce power to thrust required for landing • Smoothly advance power to takeoff (full) thrust
Design Recommendation: Design guidance in CFRs: • Aural warning Formats in operational control stations:

- Text and color-coded scale

Thrust level

Relevant Certified Federal Regulation(s):
- 23.1305(d)(1)
- 23.1305(d)(2)
- 25.1305(d)(1)
- 25.1305(d)(2)
- 25.1331(k)

Applicability:
For turbojet/turbofan engine-powered airplanes

Thrust reverser position

Relevant Certified Federal Regulation(s):
- 23.1305(d)(2)
- 25.1305(d)(2)

Applicability:
For turbojet/turbofan engine-powered airplanes

Time of day

Relevant Certified Federal Regulation(s):
- 25.1303(a)(2)
- 91.205(d)(6)

Operational Control Stations:
- Advanced Cockpit Ground Control Station

Applicability:
- IFR flight
- Must be visible from each pilot station

Design Recommendation:
Design guidance in CFRs:
- Display hours, minutes, and seconds with a sweep-second pointer or digital presentation
- Sweep-second pointer or digital presentation

Formats in operational control stations: • Text

Time of day (destination)
This information element was suggested by a subject matter expert.

Time of day (origin)
This information element was suggested by a subject matter expert.

Time to destination

Operational Control Stations: • SenseFly eMotion Control Station
Literature: • B. Donmez, H. Graham and M. Cummings (2008) Assessing the Impact of Haptic Peripheral Displays for UAV Operators • H. Graham and M. Cummings (2007) Assessing the Impact of Auditory Peripheral Displays for UAV Operators
Design Recommendation: Formats in operational control stations: • Text

Time to next waypoint

Operational Control Stations: • Procerus Virtual Cockpit
Design Recommendation: Formats in operational control stations: • Text

Transponder code

Operational Control Stations: • Advanced Cockpit Ground Control Station
Design Recommendation: Formats in operational control stations: • Text

Transponder status

Literature: • Access 5 (2005) Step 1: Human System Integration (HSI) FY05 Pilot-Technology Interface Requirements for Command, Control, and Communications (C3)

Trim device position

Relevant Certified Federal Regulation(s): • 23.677(a) • 25.677(b)
Operational Control Stations: • Advanced Cockpit Ground Control Station
Design Recommendation: Formats in operational control stations: • Text • Scale

True airspeed

Relevant Certified Federal Regulation(s): • 23.1323(a)
Operational Control Stations: • Advanced Cockpit Ground Control Station • X-Gen Control Station

True heading

Relevant Certified Federal Regulation(s): • 25.1303(a)(3) • 25.1303(b)(6) • 23.1303(c) • 23.1327 • 25.1327 • 91.205(b)(3) • 91.205(d)(9)
Operational Control Stations: • Advanced Cockpit Ground Control Station • Piccolo Command Center

- Procerus Virtual Cockpit
- SenseFly eMotion Control Station
- X-Gen Control Station

Literature:

- A. C. Trujillo, R. W. Ghatas, R. Mcadaragh, D. W. Burdette, J. R. Comstock, L. E. Hempley and H. Fan (2015) Small Unmanned Aircraft Systems Integration into the National Airspace System Visual-Line-of-Sight Human-in-the-Loop Experiment
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- X. Yuan, J. M. Histon and S. Waslander (2014) Survey of Operators' Information Requirements on Individually Operated Unmanned Aircraft Systems

Function Allocation Recommendation Tasks:

- Command aircraft heading
- Maintain runway centerline
- Manage horizontal flight path

Applicability:

- For VFR flight during the day or night, IFR flight, and night vision goggle operations
- IFR flight
- Installed at each pilot station
- Minimum required flight and navigation instrument
- Must be visible from each pilot station

Design Recommendation:

Design guidance in CFRs:

- Gyroscopically stabilized, magnetic, or non-magnetic)
- Non-stabilized magnetic compass

Formats in operational control stations:

- Text
- Text and compass rose
- Text and heading tape
- Text in pop-up window

Vertical speed

Relevant Certified Federal Regulation(s):
- 23.1543(b)(5)
- 25.1303(b)(3)

Operational Control Stations:
- Piccolo Command Center

Function Allocation Recommendation Tasks:
- Check for positive rate of climb
- Manage vertical speed

Applicability:
- Installed at each pilot station
- For reciprocating multiengine-powered airplanes of 6,000 pounds or less maximum weight

Design Recommendation:
Design guidance in CFRs:
- Blue radial line

Formats in operational control stations:
- Text in pop-up window
- Vertical speed tape

Visibility

Literature:
- Federal Aviation Administration (2017). Aeronautical Information Manual.

Wheel brake position

Operational Control Stations:
- Advanced Cockpit Ground Control Station
- X-Gen Control Station

Function Allocation Recommendation Tasks:
- Control aircraft speed along taxi route
- Perform brake check
- Smoothly advance power to takeoff (full) thrust

Design Recommendation:
Formats in operational control stations:
- Text

- Scale
- Color-coded indicator

Wind direction

Operational Control Stations:

- Procerus Virtual Cockpit
- SenseFly eMotion Control Station
- X-Gen Control Station

Literature:

- B. Kayayurt and I. Yayla (2013) Application of STANAG 4586 standard for Turkish Aerospace Industries UAV systems
- C. Fuchs, C. Borst, G. C. de Croon, M. R. van Paassen and M. Mulder (2014) An ecological approach to the supervisory control of UAV swarms
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- S. R. Dixon, C. D. Wickens and D. Chang (2005) Mission control of multiple unmanned aerial vehicles: A workload analysis
- W. Rodes and L. Gugerty (2012) Effects of electronic map displays and individual differences in ability on navigation performance

Function Allocation Recommendation Tasks:

- Determine approach profile
- Determine descent profile
- Determine top of descent
- Obtain airport data

Design Recommendation:

Formats in operational control stations:

- Chevron direction
- Compass
- Text

Wind speed

Operational Control Stations:

- Procerus Virtual Cockpit
- SenseFly eMotion Control Station
- X-Gen Control Station

Literature:

- B. Kayayurt and I. Yayla (2013) Application of STANAG 4586 standard for Turkish Aerospace Industries UAV systems
- C. Fuchs, C. Borst, G. C. de Croon, M. R. van Paassen and M. Mulder (2014) An ecological approach to the supervisory control of UAV swarms
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- W. Rodes and L. Gugerty (2012) Effects of electronic map displays and individual differences in ability on navigation performance

Function Allocation Recommendation Tasks:

- Determine approach profile
- Determine descent profile
- Determine top of descent
- Obtain airport data

Design Recommendation:

Formats in operational control stations:

- Chevron direction
- Compass
- Text

Yaw attitude

Operational Control Stations:

- Advanced Cockpit Ground Control Station
- X-Gen Control Station

Design Recommendation:

Formats in operational control stations:

- Text
- Text and scale

Literature Referenced in Appendix C3

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APPENDIX D—TASK CS-4: DEVELOPMENT OF STORYBOARDS TO SUPPORT COGNITIVE WALKTHROUGHS

Philip J. Smith, Ron Storm, Andrew Shepherd, Joel Walker, Carl Pankok, Jr., Ellen J. Bass, and Amy Spencer

ACKNOWLEDGEMENTS

The authors want to thank Ashley Awwad, Richard S. Stansbury, and Stephen “Lux” Luxion for their feedback on earlier versions of this document.

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EXECUTIVE SUMMARY

In order to provide additional validation for the recommendations in CS-1 through CS-3, storyboards were prepared to support the completion of cognitive walkthroughs. The goal of these storyboards was to provide a concrete context to assist SMEs in generating scenarios and associated inputs or recommendations for minimum human factors requirements within the scope of A10.

This report describes the general process for conducting such cognitive walkthroughs and presents the three storyboards that were developed. Consistent with the methodology for conducting such walkthroughs, the scenarios contained in these storyboards represent normative paths through nominal cases. That is to say, they illustrate how these scenarios would play out if the people involved performed as intended by the UAS designers.

The slides or "scenes" for the three scenarios are presented in their entirety. Their focus areas are:

- Low Volume UAS Traffic from KSGH (an untowered Class G airport in Central Ohio) and Back to KSGH Using Fixed Wing UASs.
- Low Volume UAS Traffic from KSGH and Divert to KILN (a towered Class D airport in Central Ohio) Using Fixed Wing UASs.
- Low Volume UAS Traffic from KSGH and Ferry Flight to KBAK (a towered Class D airport in Indiana).

1. INTRODUCTION

The goal of CS-4 was to develop storyboards to support cognitive walkthroughs to be completed as part of CS-5. The cognitive walkthroughs are intended to provide data to help with the validation of the recommendations developed in CS-1, CS-2, and CS-3 and in some cases to provide input indicating the need to modify those recommendations or to develop additional recommendations for minimal human factors requirements within the scope of A10.

Below, we document the storyboards that were developed. First, however, we provide background regarding the rationale for this approach.

2. COGNITIVE WALKTHROUGHS - BACKGROUND

The approach that we have taken for the cognitive walkthroughs is based on the evolution of a method first proposed by Lewis and Wharton (1997). The original method they developed included five steps.

The first step involves identifying the full set of use cases relevant to a system design. A subset is then selected for use in cognitive walkthroughs since it is generally impractical (in terms of available resources) to study the full set. Each use case is defined in terms of a specific person/actor, a goal or task for that person to complete, and a description of the broader environment in which the task must be completed. Note that this definition of a use case is independent of a specific design solution.

The second step is to specify the normative path for each selected use case for a specific proposed system design. This normative path defines the sequence of steps/states that are traversed in order to move from some initial state to the goal state (completion of the specified task), assuming the person completes the task in the manner intended by the designer(s).

The third step is to translate this normative path into a storyboard, where the state associated with each step or scene is described in text (a semantic representation) or graphics (such as an information display) in order to convey that state. This storyboard provides a detailed step-by-step portrayal of the sequence required to complete the defined task as intended by the designer(s).

The fourth step is to actually complete the cognitive walkthrough. For this expert review, a domain expert is asked to walk through the storyboard one scene or step at a time and, after viewing each scene in the sequence, to predict potential success stories and failure stories (i.e., what could happen at that point in the sequence that would lead to a successful outcome - safe, efficient completion of the task - or an undesirable outcome).

Step five involves asking the expert to recommend design solutions for the predicted failure stories.

To assist with the prediction task, Lewis and Wharton ask the domain expert to consider the following questions after viewing the transition to the next scene:

- "Will the user be trying to achieve the right effect?"
- "Will the user notice that the correct action is available?"

- "Will the user associate the correct action with the desired effect?"
- "If the correct action is performed, will the user see that progress is being made?"

The rationale behind this approach is the assumption that, by viewing design implications *in context*, the expert is likely to generate insights that might be overlooked when more abstractly reviewing a set of recommendations.

The approach to cognitive walkthroughs described above as proposed by Lewis and Wharton was refined by Smith, Stone and Spencer (2006). They proposed a refinement of this method, suggesting the value of providing more detailed probes in order to further stimulate the thinking of the expert during such a review. They proposed the inclusion of certain psychological constructs in the list of prompts presented to the expert for consideration after viewing the transition to each scene (in addition to the questions posed by Lewis and Wharton). This list included:

- "**Selective Attention:** What are the determinants of attention? What is most salient in the display? Where will the user's focus of attention be drawn?…"
- "**Perception:** How will perceptual processes influence the user's interpretation?…"
- "**Memory:** How will the user's prior knowledge influence selective attention and interpretation? Does the knowledge necessary to perform tasks reside in the world or in the user's mind? Will working memory limits be exceeded?…"
- "**Information Processing, Problem Solving, Decision Making, Mental Models and Situation Awareness:** What inferences/assumptions will the user make?"
- "**Design-Induced Error:** How could the product design and the context of use influence performance and induce errors?…"
- "**Motor Performance:** Can the controls be used efficiently and without error?…"
- "**Group Dynamics:** How will the system influence patterns of interaction among people?…"

In a three-year study for NASA, Rinehart, Smith and Spencer (2016) then further extended and evaluated this approach to the validation of a human-machine system design, including a larger set of prompts – including some focused specifically on aviation systems. Below is a small set of examples of the prompts used in this study, embedded in the instructions to consider these prompts when walking through the scenes in a storyboard:

> In reviewing the scenario and three associated variations to generate ideas for **pre-flight, ground and taxi operations, takeoff, enroute operations and landing,** please consider the following questions.
>
> **Can you envision <u>threats</u> that could contribute to an incident, near miss or accident?**
>
> For instance, for the following <u>environmental threats</u>, can you envision scenarios involving:
>
> - Unexpected Adverse Weather that could arise even though the forecast was for VMC conditions,
> - Terrain,

- Airport Conditions,
- Other Ground or Air Traffic, or
- Other Environmental Conditions?

Enter Scenario(s) here. Also, please indicate any changes in capabilities or procedures as described in this scenario that you think could eliminate or reduce the likelihood of such a scenario arising.

For instance, for the following flight deck based communication and coordination errors, can you envision specific related examples involving:

- RPIC Communication and Coordination with ATC,
- Crew Resource Management/Coordination and Communication (RPIC and VO),
- RPIC Communication and Coordination with Other Aircraft (manned and unmanned), or
- Other Communication and Coordination Errors?

Enter Scenario(s) here. Also, please indicate any changes in capabilities or procedures as described in this scenario that you think could eliminate or reduce the likelihood of such a scenario arising.

Does consideration of any of the following cognitive processes that could contribute to an incident, near miss or accident help you to generate any additional scenarios? If so, please describe examples of scenarios where they could arise.

- Slips (the person has the necessary expertise, but fails to apply it in a given instance),
- Ineffective attention management (the person does not look at and/or process relevant information),
- Incorrect or incomplete mental model of the situation,
- Inadequate knowledge of intent (Lack of awareness or understanding of one agent regarding the goals, plans or intended actions of other agents - automation or human),
- Inadequate vigilance (failure to maintain a sufficient level of alertness and attentiveness in order to detect and respond to some problem in a timely manner), and
- Excessive communication/response latency (the rate at which some action is initiated or completed is delayed relative to requirements for effective performance)

Enter Scenario(s) here. Also please indicate any changes in capabilities or procedures as described in this scenario that you think could eliminate or reduce the likelihood of such a scenario arising.

Does consideration of any of the following additional factors that could contribute to an incident, near miss or accident help you to generate any additional scenarios? If so, please describe examples of scenarios where they could arise.

- Fatigue, or
- Inadequate training or experience
  - With automation of other equipment,
  - With procedures,
  - With critical scenarios, or
  - With effective teamwork (communication and coordination)

The full set of probes used in the study are presented in the section on CS-5.

3. STORYBOARD DESIGN

Below, we present the three storyboards developed for this project.

Assumptions for All Three Scenarios

- Crew
  - Remote Pilot in Command (RPIC)
    - RPIC does not have visibility at the airports involved as he is part of a regional operation that flies UAs out of a number of airports in the region using pilots located at a remote hub located in Findlay OH
    - There are certified Visual Observers (VOs) available at all three of the airports involved
- Flight Conditions
  - IFR flight.

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Assumptions for All Three Scenarios

- Aircraft/RPIC Ground Control Workstation
  - is larger than 55 pounds.
  - is equipped with ADSB-Out.
  - is flown completely under manual control unless there is a lost signal.
  - fixed wing requiring runway for departure and landing.

- Assume the RPIC is completely reliant on the Visual Observer for input regarding the location/orientation of the aircraft relative to the runway and taxiways:
  - The aircraft is not equipped with a forward pointed camera.
  - The pilot ground control workstation display does not provide a top down view of the airport surface with an indication of the current UA location.
  - The workstation does not provide views of the airport surface from fixed cameras placed around the airport.

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Assumptions for All Three Scenarios

Further details on RPIC Ground Control Workstation

- All Phases of flight are manually controlled (stick/throttle/rudder)
  - Take-off, landing, enroute, mission area
- Ground Station Interface/Display shows
  - Aircraft position once airborne
  - Take-off and departure routing
  - Mission area points
  - Return and landing routing
  - Basic Primary Flight Information
    - Heading
    - Pitch
    - Bank
    - Airspeed
    - Altitude
    - VVI
- RPIC has only flight pub 'paper' products for reference
  - Information can be added to mission plan as time permits

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Scenario 1: Low Volume UAS Traffic From KSGH and Back to KSGH Using Fixed Wing UASs

Airport: Low volume airport at Springfield OH (KSGH)

- Two crossing runways.
- No active ATCT (Class G airspace).
- Only one runway is active at any given time. (Runway 24 is preferred if the winds are 20 kts or less.)
- Filed alternate airport is KILN

Traffic: Manned GA aircraft as well as UASs. (Some of these GA aircraft do not have transponders or radios.)

Mission:

Depart from KSGH.

Conduct aerial surveillance.

Return to KSGH

Leg (from)	Leg (to)	Length (nm)	Altitude (feet)	True Airspeed (kts)	Groundspeed (kts)	Time (minutes)	True Course (°) / WCA / Corrected Heading / Mag. Var.
KSGH	TOC	5.00	2500	110	110.00	2.73	174.84 / -0.0 / 181.29 / 6.45

Airport Identification	Type	Identification	Frequency
KSGH	A/D	DAYTON APP/DEP	118.85
	ASOS	AWSS	134.975
	ATIS	ATIS	25.787
	CTAF	CTAF	120.7
	GND	GND	121.7
	OPS	178 FW OPS	141.7
	TWR	TWR	120.7

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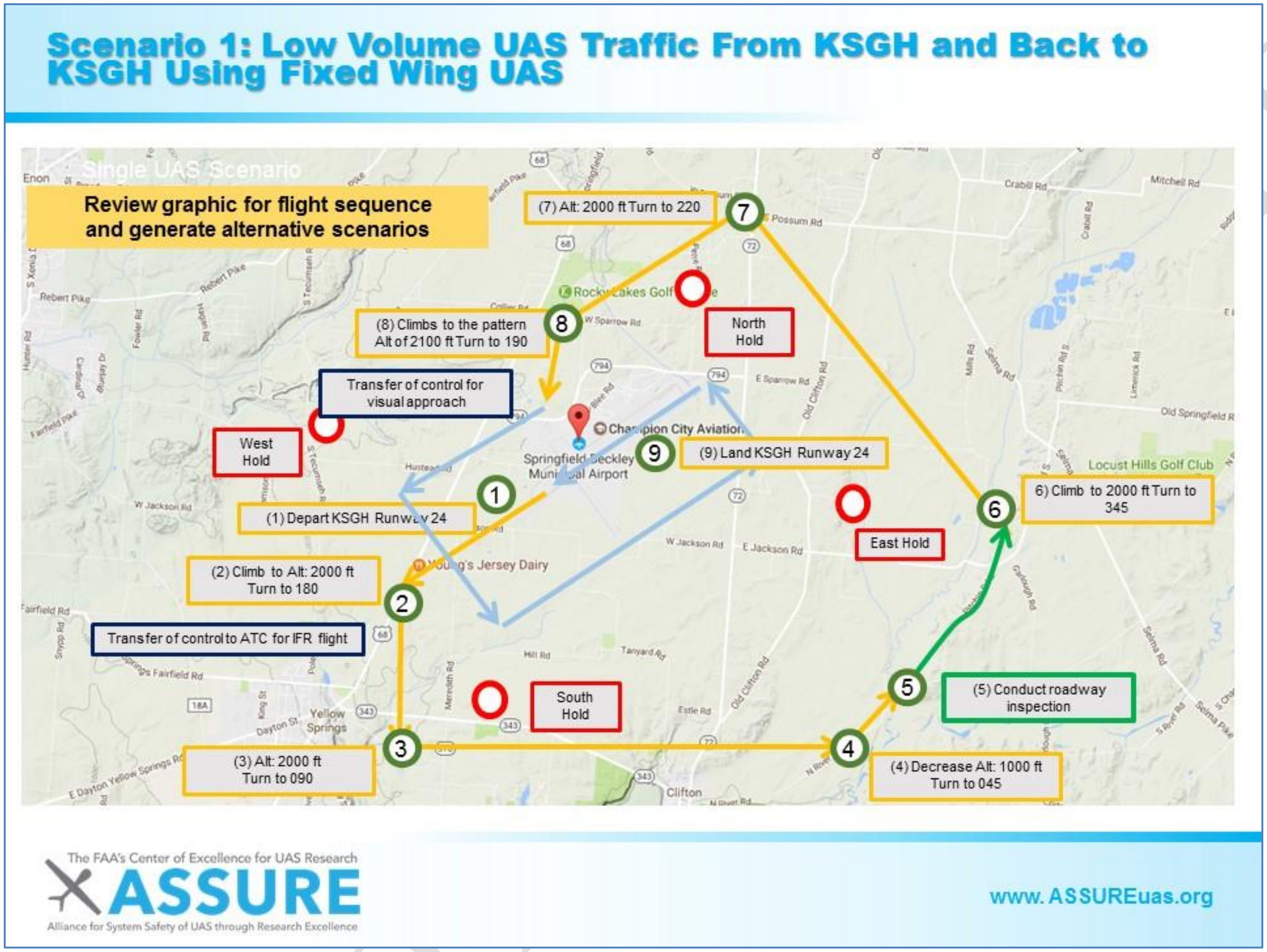
Scenario 1: Low Volume UAS Traffic From KSGH and Back to KSGH Using Fixed Wing UAS
Single UAS Scenario
Review graphic for flight sequence and generate alternative scenarios
(1) Depart KSGH Runway 24
(2) Climb to Alt: 2000 ft Turn to 180
(3) Alt: 2000 ft Turn to 090
(4) Decrease Alt: 1000 ft Turn to 045
(5) Conduct roadway inspection
6) Climb to 2000 ft Turn to 345
(7) Alt: 2000 ft Turn to 220
(8) Climbs to the pattern Alt of 2100 ft Turn to 190
(9) Land KSGH Runway 24
Transfer of control for visual approach
Transfer of control to ATC for IFR flight
North Hold
West Hold
East Hold
South Hold
Springfield-Beckley Municipal Airport
Champion City Aviation
Young's Jersey Dairy
Locust Hills Golf Club
Clifton
Yellow Springs
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Scenario 1: Low Volume UAS Traffic From KSGH and Back to KSGH Using Fixed Wing UASs

Variations on Visibility of RPIC into Operation:

- Assume that the RPIC can see the view provided by a forward pointed camera as well as get input from a Visual Observer during takeoff and landing. Does that generate any additional ideas regarding possible scenarios resulting in incidents, near misses or accidents? Does it solve any concerns highlighted by any of your earlier generated scenarios (which assumed only access to input from a Visual Observer)?
- Alternatively, assume that, on his display, the RPIC can see a top down view of the airport surface with an indication of the current UA location as well as get input from a Visual Observer (during takeoff and landing). Does that generate any additional ideas regarding possible scenarios resulting in incidents, near misses or accidents? Does it solve any concerns highlighted by any of your earlier generated scenarios (which assumed only access to input from a Visual Observer)?
- Finally, as another variation, assume that, on his display, the RPIC can see side views of the airport surface from fixed cameras placed around the airport, as well as get input from a Visual Observer (during takeoff and landing). Does that generate any additional ideas regarding possible scenarios resulting in incidents, near misses or accidents? Does it solve any concerns highlighted by any of your earlier generated scenarios (which assumed only access to input from a Visual Observer)?

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Scenario 2: Low Volume UAS Traffic From KSGH and Divert to KILN Using Fixed Wing UASs

Departing Airport: Low volume airport at Springfield OH (KSGH)

- Two crossing runways.
- No active ATCT (Class G airspace).
- Only one runway is active at any given time.
  (Runway 24 is preferred if the winds are 20 kts or less.)

Arriving Airport: Tower controlled airport in Wilmington, OH (KILN)

- Filed alternate airport is KILN
- Certified Visual Observers available at KSGH and KILN
  (Tower Controller serves as Visual Observer at KILN.)

Traffic: Manned GA aircraft as well as UASs at both airports.
(Some of the GA aircraft do not have transponders or radios.)

Platform - UASs: Fixed wing

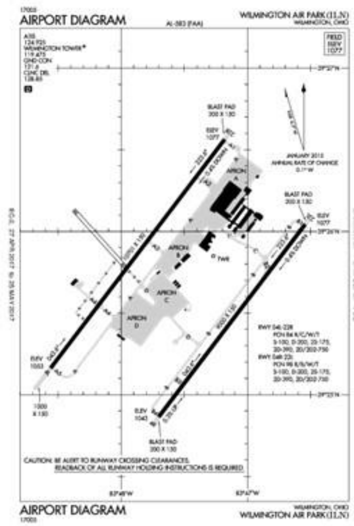
Mission:

Depart from KSGH.

Conduct aerial surveillance.

Divert to KILN

Leg (from)	Leg (to)	Length (nm)	Altitude (feet)	True Airspeed (kts)	Groundspeed (kts)	Time (minutes)	True Course (°) / WCA / Corrected Heading / Mag Var
TOC	KILN	19.82	2500	110	110.00	10.81	174.84 / -0.0 / 181.28 / 6.44



Airport Identification	Type	Identification	Frequency
KILN	A/D	DAYTON APP/DEP	118.85
	ASOS	ASOS	126.675
	ATIS	ATIS	124.925
	CLD	CLNC DEL	125.6
	CTAF	CTAF	119.475
	GND	GND	121.6
	TWR	WILMINGTON TWR	119.475

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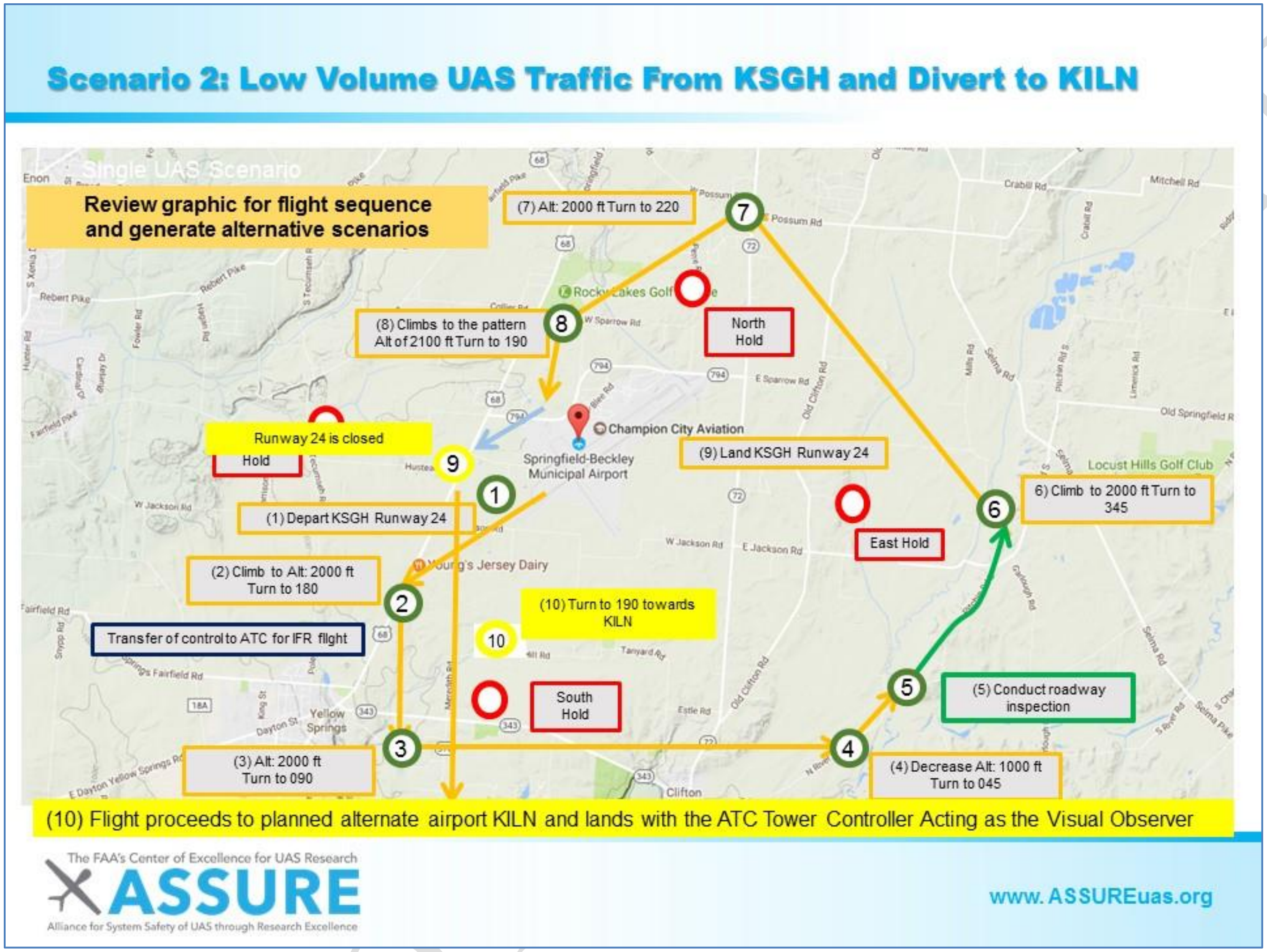
Scenario 2: Low Volume UAS Traffic From KSGH and Divert to KILN
Single UAS Scenario
Review graphic for flight sequence and generate alternative scenarios
(7) Alt: 2000 ft Turn to 220
(8) Climbs to the pattern Alt of 2100 ft Turn to 190
North Hold
Runway 24 is closed
Hold
Champion City Aviation
Springfield-Beckley Municipal Airport
(9) Land KSGH Runway 24
(1) Depart KSGH Runway 24
6) Climb to 2000 ft Turn to 345
East Hold
Young's Jersey Dairy
(2) Climb to Alt: 2000 ft Turn to 180
(10) Turn to 190 towards KILN
Transfer of control to ATC for IFR flight
South Hold
(5) Conduct roadway inspection
(3) Alt: 2000 ft Turn to 090
(4) Decrease Alt: 1000 ft Turn to 045
Locust Hills Golf Club
Yellow Springs
Clifton
(10) Flight proceeds to planned alternate airport KILN and lands with the ATC Tower Controller Acting as the Visual Observer
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Scenario 3: Low Volume UAS Traffic From KSGH and ferry flight to KBAK

Departing Airport: Low volume airport at Springfield OH (KSGH)

- Two crossing runways.
- No active ATCT (Class G airspace).
- Only one runway is active at any given time. (Runway 24 is preferred if the winds are 20 kts or less.)

Arriving Airport: Tower controlled airport in Columbus, IN (KBAK)

- Scheduled Visual Observer (Pre-planned flight)

Traffic: Manned GA aircraft as well as UASs at both the departure airport and destination airport. (Some of these GA aircraft do not have transponders or radios.)

Platform - UASs: Fixed wing

Mission:

Depart from KSGH.

Ferry to KBAK

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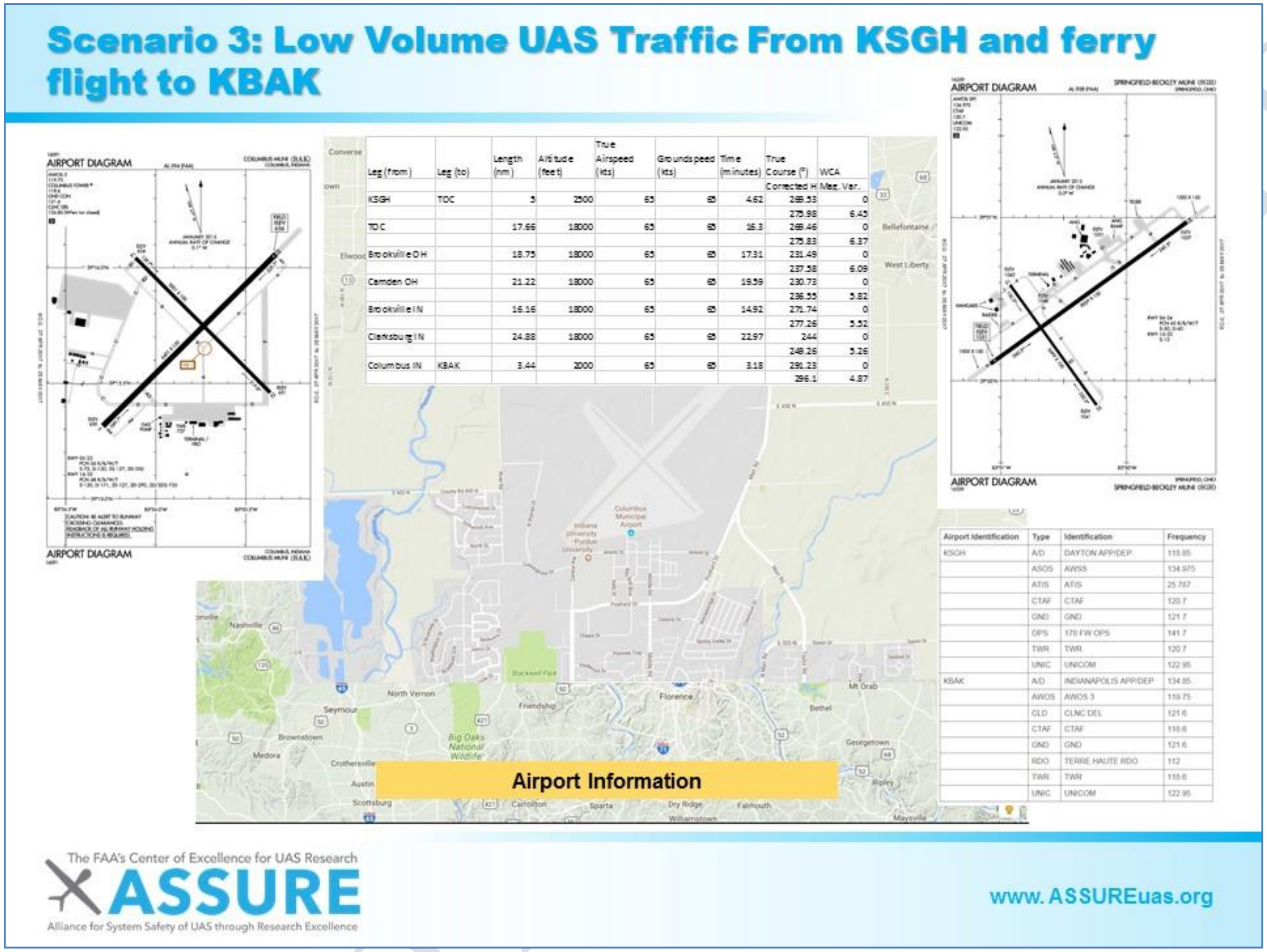
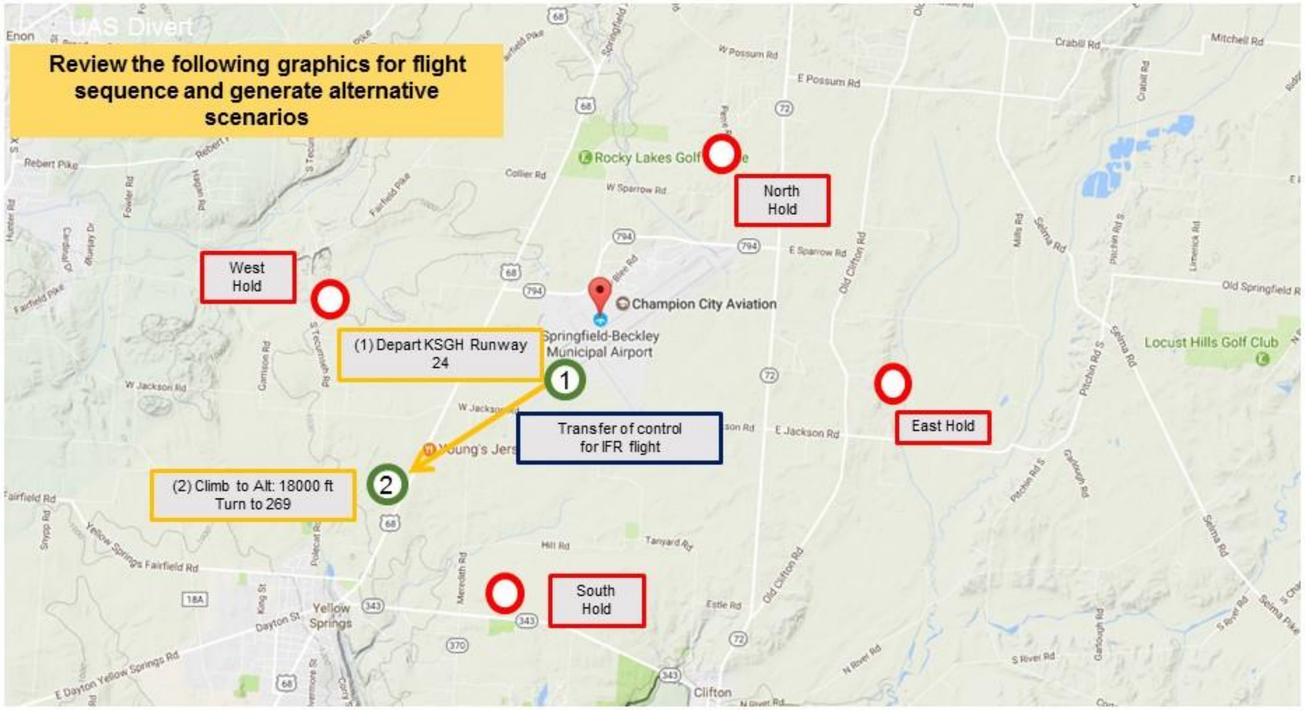


Leg (from)	Leg (to)	Length (nm)	Altitude (feet)	True Airspeed (kts)	Groundspeed (kts)	Time (minutes)	True Course (°)	WCA
							Corrected H	Mag. Var.
KSGH	TOC	5	2500	65	65	4.62	269.53	0
							275.98	6.45
TOC		17.66	18000	65	65	16.3	269.46	0
							275.83	6.37
Brookville OH		18.75	18000	65	65	17.31	231.49	0
							237.58	6.09
Camden OH		21.22	18000	65	65	19.59	230.73	0
							236.55	5.82
Brookville IN		16.16	18000	65	65	14.92	271.74	0
							277.26	5.52
Clarksburg IN		24.88	18000	65	65	22.97	244	0
							248.26	5.26
Columbus IN	KBAK	3.44	2000	65	65	3.18	291.23	0
							296.1	4.87

Airport Identification	Type	Identification	Frequency
KSGH	A/D	DAYTON APP/DEP	118.85
	ASOS	AWSS	134.975
	ATIS	ATIS	25.787
	CTAF	CTAF	120.7
	GND	GND	121.7
	OPS	178 FW OPS	141.7
	TWR	TWR	120.7
	UNIC	UNICOM	122.95
KBAK	A/D	INDIANAPOLIS APP/DEP	134.85
	AWOS	AWOS 3	119.75
	CLD	CLNC DEL	121.6
	CTAF	CTAF	118.6
	GND	GND	121.6
	RDO	TERRE HAUTE RDO	112
	TWR	TWR	118.6
	UNIC	UNICOM	122.95

Scenario 3: Low Volume UAS Traffic From KSGH and ferry flight to KBAK



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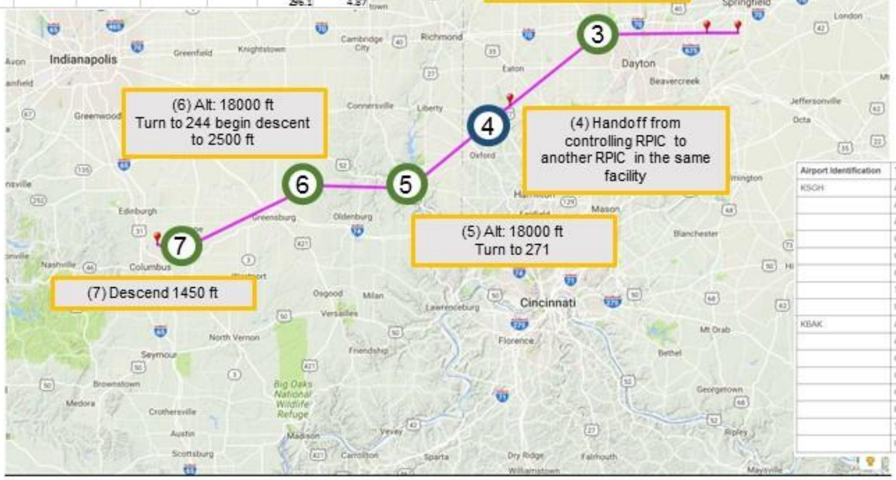

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	ASOS	AWSS	134.975
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	CTAF	CTAF	120.7
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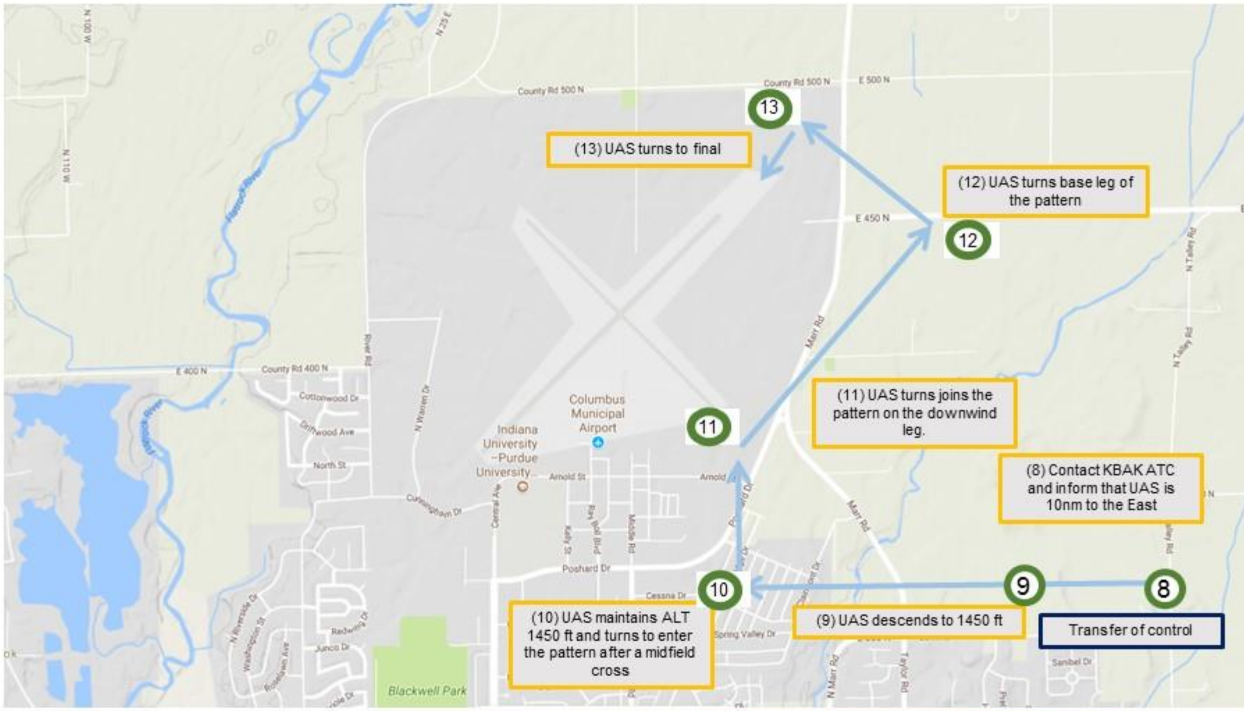
Scenario 3: Low Volume UAS Traffic From KSGH and ferry flight to KBAK



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These three storyboards thus constitute the output of CS-4, providing the materials necessary to complete the cognitive walkthroughs that are part of CS-5 as reported in the next section.

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APPENDIX E—TASK CS-5: REFINEMENT AND EXTENSION OF WORKSTATION DESIGN REQUIREMENTS AND GUIDELINES BASED ON COGNITIVE WALKTHROUGHS

Philip J. Smith, Ron Storm, Andrew Shepherd, Joel Walker, Carl Pankok, Jr., Ellen J. Bass, and Amy Spencer

ACKNOWLEDGMENTS

The authors want to thank Ashley Awwad, Stephen "Lux" Luxion, and Richard S. Stansbury for their feedback on earlier versions of this document. In addition, the authors thank the subject matter expert pilot reviewers: Joe Cerreta (Embry Riddle Aeronautical University), Sean Moulton, and Kurt Carraway (Kansas State University).

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EXECUTIVE SUMMARY

The objective of the work was to support the development of recommendations for minimum unmanned aircraft system (UAS) control station standards and guidelines. These recommendations focus on operation of fixed-wing unmanned aircraft (UA) larger than 55 lb. operated beyond visual line of sight in an integrated National Airspace System (NAS).

Prior to this research task (CS-5) which focused on cognitive walkthroughs, recommendations for minimum human-automation function allocation were developed and minimum information requirements for safe UAS operation in the NAS were identified (CS-1, CS-2, and CS-3). The goal of the cognitive walkthroughs was to provide further validation and refinement of the recommendations generated in the function allocation and information requirements research tasks.

In addition to presenting the SMEs with the storyboards produced in CS-4 to structure the cognitive walkthroughs, in CS-5 a set of probes was presented in order to trigger inputs beyond those that would have been generated by the SMEs simply by reviewing the contexts provided by the storyboards.

These prompts included aviation-specific prompts such as:

> In reviewing the scenario and three associated variations to generate ideas for **pre-flight, ground and taxi operations, takeoff, enroute operations and landing,** please consider the following questions.
>
> **Can you envision threats that could contribute to an incident, near miss or accident?**
>
> For instance, for the following environmental threats, can you envision scenarios involving:

- unexpected adverse weather that could arise even though the forecast was for visual meteorological conditions (VMC),
- terrain,
- airport conditions,
- other ground or air traffic, or
- other environmental conditions?

They also included probes focused on human performance such as:

> **Does consideration of any of the following cognitive processes that could contribute to an incident, near miss or accident help you to generate any additional scenarios?**

- Slips (the person has the necessary expertise, but fails to apply it for a given instance),
- Ineffective attention management (the person does not look at and/or process relevant information),
- Incorrect or incomplete mental model of the situation,

- Inadequate vigilance (failure to maintain a sufficient level of alertness and attentiveness in order to detect and respond to some problem in a timely manner),
- Fatigue, or
- Inadequate training or experience
  - with automation of other equipment,
  - with procedures,
  - with critical scenarios, or
  - with effective teamwork (communication and coordination).

Results and conclusions from cognitive walkthroughs with three subject matter experts (SMEs) are reported. The results include one recommendation that differs from a recommendation proposed from the prior information requirements research task (CS-3), six recommendations that are consistent with recommendations proposed from the function allocation and information requirements research tasks (CS-1, CS-2, and CS-3), and four new recommendations that were not covered in the function allocation and information requirements tasks (CS-1, CS-2, and CS-3). The results also provide additional input for efforts that extend beyond the scope of A10.

1. INTRODUCTION

As indicated in the section on CS-4, we used the above three storyboards as the basis for the cognitive walkthroughs. The Methods and Results are detailed below.

2. METHODS

This exercise was conducted asynchronously, asking via email that each subject matter expert (SME) review the storyboards individually. Below are the general instructions.

Thanks for agreeing to assist as an SME for this effort. The goal is to collect your insights regarding scenarios that could lead an incident, near miss or accident under operations meeting minimum human factors standards for unmanned aircraft systems (UASs) in order to provide insights for helping to determine those minimum standards.

Step 1. Please print out the attached slideshow.

Step 2. Please read the introductory material at the beginning of this slideshow.

Step 3. Please read through the description of Scenario 1 contained in this slideshow.

Step 4. Please use the attached Word document to help generate scenario ideas and to describe them, referring to the description of the scenario on the printed slides as necessary. Please focus your scenario ideas and recommendations on examples involving UASs.

Step 5. Repeat Steps 3-4 for Scenarios 2 and 3.

The word document provided further instructions and the full set of prompts presented to the SMEs. The full contents of this document are provided below in order to indicate the range of prompts used to help trigger ideas as the SMEs reviewed the storyboards.

2.1 INSTRUCTIONS FOR SME INPUT

In reviewing the scenario and three associated variations to generate ideas for **pre-flight, ground and taxi operations, takeoff, enroute operations and landing,** please consider the following questions.

Can you envision threats that could contribute to an incident, near miss or accident?

For instance, for the following environmental threats, can you envision scenarios involving:

- unexpected adverse weather that could arise even though there had been a forecast for Visual Meteorological Conditions (VMC),
- terrain,
- airport conditions,
- other ground or air traffic, or
- other environmental conditions?

Enter Scenario(s) here. Also please indicate any changes in capabilities or procedures as described in this scenario that you think could eliminate or reduce the likelihood of such a scenario arising.

For instance, for the following airline/aircraft threats can you envision specific related examples involving:

- operational pressure,
- aircraft malfunctions,
- ground maintenance,
- ground/ramp operations,
- manuals/charts, or
- other airline/aircraft threats?

Enter Scenario(s) here. Also please indicate any changes in capabilities or procedures as described in this scenario that you think could eliminate or reduce the likelihood of such a scenario arising.

Can you envision pilot ground control workstation related errors that could contribute to an incident, near miss or accident? If so, please describe scenarios where they could arise.

For instance, for the following factors that could influence pilot ground control workstation related errors, can you envision specific related examples involving:

- manual flying,
- instruments/radio communications/phone communications, or
- other pilot ground control workstation based errors?

Enter Scenario(s) here. Also please indicate any changes in capabilities or procedures as described in this scenario that you think could eliminate or reduce the likelihood of such a scenario arising.

For instance, for the following procedural errors, can you envision specific related examples involving:

- checklist completion,
- briefing and callout (i.e., remote pilot in command (RPIC)/visual observer (VO) coordination),
- documentation, or
- other procedural errors?

Enter Scenario(s) here. Also please indicate any changes in capabilities or procedures as described in this scenario that you think could eliminate or reduce the likelihood of such a scenario arising.

For instance, for the following flight deck based communication and coordination errors, can you envision specific related examples involving:

- RPIC communication and coordination with air traffic control (ATC),
- crew resource management/coordination and communication (RPIC and VO),
- RPIC communication and coordination with other aircraft (manned and unmanned), or
- other communication and coordination errors?

Enter Scenario(s) here. Also please indicate any changes in capabilities or procedures as described in this scenario that you think could eliminate or reduce the likelihood of such a scenario arising.

Can you envision airport/airspace based threats that could contribute to an incident, near miss or accident? If so, please describe examples of scenarios where they could arise.

For instance, for the following airport/airspace based external threats, can you envision specific examples related to:

- airport layout,
- navigation aids,
- airspace infrastructure/design, or
- other airport/airspace based external threats?

Enter Scenario(s) here. Also please indicate any changes in capabilities or procedures as described in this scenario that you think could eliminate or reduce the likelihood of such a scenario arising.

Does consideration of any of the following cognitive processes that could contribute to an incident, near miss or accident help you to generate any additional scenarios? If so, please describe examples of scenarios where they could arise.

- Slips (the person has the necessary expertise, but fails to apply it in a given instance),
- Mistakes (the person does not have the necessary expertise to perform appropriately),
- Ineffective attention management (the person does not look at and/or process relevant information),
- Incorrect or incomplete mental model of the situation,
- Inadequate knowledge of intent (Lack of awareness or understanding of one agent regarding the goals, plans or intended actions of other agents - automation or human),
- Inadequate vigilance (failure to maintain a sufficient level of alertness and attentiveness in order to detect and respond to some problem in a timely manner),
- Information overload (too many competing sources of information, making it difficult for the person to focus attention on all of the relevant information that is being displayed),
- High mental workload (excessive demands due to too many competing tasks or tasks that are too complex),
- Inadequate resource management (failure to manage or make adequate use of the full range of resources – human and automated – available to detect and/or deal with a problem. This includes inadequate teamwork.), or

- Excessive communication/response latency (the rate at which some action is initiated or completed is delayed relative to requirements for effective performance).

Enter Scenario(s) here. Also please indicate any changes in capabilities or procedures as described in this scenario that you think could eliminate or reduce the likelihood of such a scenario arising.

Does consideration of any of the following additional factors that could contribute to an incident, near miss or accident help you to generate any additional scenarios? If so, please describe examples of scenarios where they could arise.

- Fatigue,
- Inadequate training or experience
  - with automation of other equipment,
  - with procedures,
  - with critical scenarios, or
  - with effective teamwork (communication and coordination),
- Stress (including time stress), or
- Language barriers.

Enter Scenario(s) here. Also please indicate any changes in capabilities or procedures as described in this scenario that you think could eliminate or reduce the likelihood of such a scenario arising.

2.2 SME QUALIFICATIONS

The most relevant credentials of the three SMEs who completed the cognitive walkthrough are summarized below:

ID	Professional Experience
1	MS Systems Engineering MA Management BS Mechanical Engineering Remotely Piloted Aircraft/Unmanned Aerospace Systems Pilot (Approx. 500 RQ-4 hours) FAA Commercial/Instrument Pilot (264 hours); Master Navigator (2,476 total hours) 2008 – 2010: Commanded US Air Force's RQ-4 Global Hawk combat unit Global Hawk instructor and evaluator pilot certified in 5 unified Command theaters UAS Flight Operations Manager 2014 – 2016 UAS Executive Director, Kansas State University 07 / 2016 – Present.

2	Ph.D. in Business Administration Master of Aeronautical Science Assistant Professor, Embry-Riddle Aeronautical University 2015 – Present (teaching core technologies of unmanned aircraft systems (UAS); governmental and private sector applications of UAS to meet mission needs) AAI Corporation – Senior Program Manager 2011 – 2015 • Developed a UAS crewmember transition program of instruction for the US Army Shadow UAS fleet of aircraft to transition from RQ-7Bv1 to RQ-7Bv2 aircraft models • Responsible for the Shadow UAS Government Owned Contractor Operated (GOCO) program, including synthetic aperture radar capabilities, to expand organizational Intelligence, Surveillance, and Reconnaissance (ISR) fee-for-services strategic objective requirements • Co-authored the technical volume proposal development for logistics, training, and deployed labor execution plans for the Aerosonde UAS used in the Special Operations Command Mid-Endurance UAS (MEUAS) and Navy ISR Services fee-for-services programs • Planned and executed the MEUAS and Navy ISR Services fee-for-services programs including UAS crewmember training for more than 200 crewmembers, deployment of nine systems to Iraq, Afghanistan, and Africa AAI Corporation – Program Manager 2007 – 2011 • Program Manager for the GOCO ISR project to the US Special Operations Command (USSOCOM) • Planned and executed the MEUAS and Navy ISR Services fee-for-services programs including UAS crewmember training for more than 200 crewmembers, deployment of nine systems to Iraq, Afghanistan, and Africa • Designed and implemented Tactics, Techniques, and Procedures (TTPs) to provide persistent surveillance with 200% increase in ISR coverage and a 44% reduction in mishap rates compared to deployed Army and Marine Corps UAS units AAI Corporation – New Equipment Training Project Manager 2002 – 2007 • Established a UAS crewmember training program of instruction to transition the USMC from the RQ-2 Pioneer to the RQ-7A Shadow UAS, which trained over 150 US Marines • Developed an instructor program of instruction for US Army Soldiers for the RQ-7A/B Shadow UAS, which trained over 30 instructors • Developed a New Equipment Training (NET) program of instruction, which trained 117 Shadow 200 units from the US Army, Marine Corps, and Special Operations United States Army – UAS Institutional Training Program Director 1996 – 2002 • Chief Instructor Pilot for the US Army's Unmanned Aircraft System (UAS) crewmember training program as the proponent UAS • Standardization Instructor Pilot and Program Director, while transforming the US Army training strategy to the RQ-7A Shadow 200 UAS

	• Integrated new methods of UAS instruction, coordinated schedules and resources with the government Program Office, US Army
3	Instructor/Evaluator Pilot, RQ-4 UAS (Global Hawk) Weapons Instructor Officer/Evaluator Pilot C-130/T-38/T-1 FAA Commercial Instrument Rating FAA Single and Multi-Engine Rating AIR FORCE RESEARCH LAB 2012-2016 • Infoscitex - UAS Research Lead Multi Role Control Station (Vigilant Spirit) - development of next generation operator interfaces for single and multiple aircraft control operations AERONAUTICAL SYSTEMS CENTER 2007- 2012 • Booz Allen Hamilton - UAS Operation Lead Navy Broad Area Maritime Surveillance Airspace Integration and Safety Case Modeling and Simulation Integration Lead examining world-wide employment analysis • Lead UAS integrator for OSD Unmanned Aircraft System Airspace Integration into National Airspace Space, Joint Integrated Product Team (utilization of constructive and virtual modeling) • Global Hawk Ground Segment Re-architecture integration of next generation interfaces including electronic flight manual development, pilot map requirements, sensor operator upgrades and updated CONOPS • AF and Navy Joint Cockpit Evaluation Team member – evaluated and developed next generation ground station interfaces working directly with current qualified warfighters

3. RESULTS

As indicated above, three SMEs participated in the cognitive walkthroughs. They provided their input in writing, providing the following kinds of responses:

- detailed sample scenarios that served to illustrate situations that they think could arise that would differ from the normative paths described in the three scenarios described in Appendix D, and that would introduce additional cognitive complexity and the potential for error that could result in an incident, near miss or accident; and
- inputs regarding information requirements and recommendations for minimum human factors requirements.

Since responses from the three SMEs frequently clustered around specific topics, we have grouped them by topic in the presentation of the results below. For example, there were several inputs regarding the need for an airport surface display that dynamically indicates the current location of the unmanned aircraft (UA) on the airport surface, as well as three sample scenarios generated by one of the SMEs illustrating the complexities that could arise during landing and taxi in. These inputs and sample scenarios are grouped in the presentation below under the header of "Category 1. Airport Surface Displays".

Thus, within each such category, we report the relevant "Inputs" and "Sample Scenarios" as provided by the SMEs. At the end of this presentation of the results relevant to each category, we then provide "Recommendations" guided by these inputs.

In addition, because the responses provided by the SMEs sometimes went beyond the scope of A10 (due to the open-ended nature of this knowledge elicitation task), we have reported the findings under three major headings:

- inputs and sample scenarios that have implications for potential minimum human factors requirements within the scope of A10, with associated recommendations,
- inputs and sample scenarios relevant to non-human factors requirements and a scope broader than A10, and
- storyboard improvements.

These inputs, along with associated recommendations and comments are provided below.

3.1 INPUTS WITH RELEVANCE TO RECOMMENDATIONS FOR MINIMUM HUMAN FACTORS REQUIREMENTS WITHIN THE SCOPE OF A10

3.1.1 Category 1. Airport Surface Displays

The SMEs provided the following inputs and sample scenarios relevant to this category.

Input 1a. "Recommend a minimum requirement to have a top-down view of the airport surface area with the UA depiction on that view."

Input 1b. "Risk area. UA position should also include on the airport surface area as a minimum requirement."

Input 1c. "With a 2D display showing the UAs location on the surface, the RPIC would have awareness of the UAs movement."

Input 1d. Sample Scenario:

"Non-standard VO integration:

- Tiger 33 (a UA) is flying into Wilmington Airport (KILN) [GPS 22R final approach] during hours when the ATC tower is not open (so the RPIC must rely completely on a VO because RPIC is at a remote site).
- RPIC is manually flying the approach until 1 NM:
    - At 1 NM the VO will identify the aircraft.

- After positive identification, the VO will start issue commands for final approach and landing.

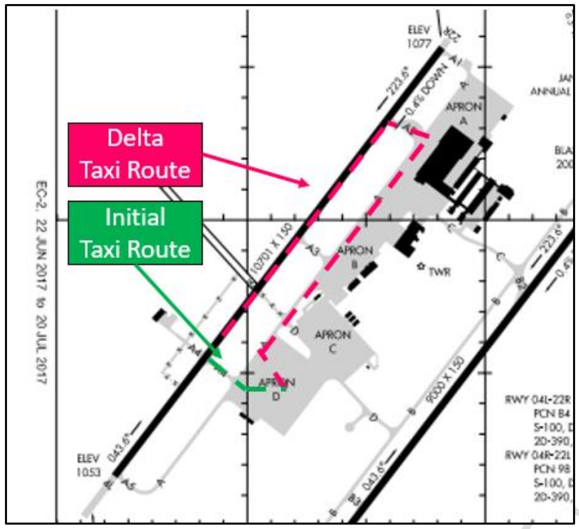
- Variation 1 - VO identifies Tiger 33 at 1.5 NM:
  - VO starts to tell the RPIC to make a "slight left turn."
    - RPIC makes a 5-degree left turn.
    - This correction is too large, the RPIC should have only turned 2-degrees [final approach and landing will require a high fidelity of corrections].

- Variation 2 - VO identifies Tiger 33 is off course to the right of centerline:
  - VO then tells the RPIC to "get back to course."
  - RPIC turns to wind correct course heading.
  - RPIC thinks he is back on course while VO still sees him right of centerline [an understanding of positional awareness is important during critical phases of flight]."

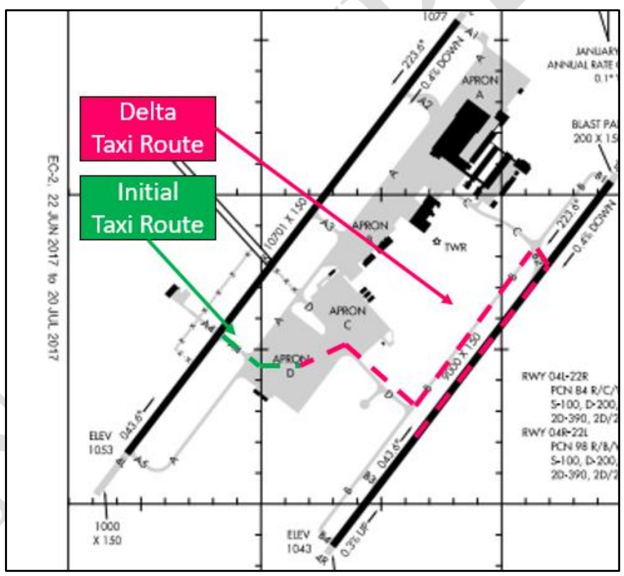
Input 1e. Sample Scenario:

"Taxi Changes with Complex Common Operating Picture

- Eagle 65 is preparing to land 04L at Wilmington Airport (KILN) during hours when the ATC tower is not open (so the RPIC must rely completely on a VO because RPIC is at a remote site):
  - Parking location is Apron C.
  - Taxi plan is A4 to Apron D.
  - Taxiway A3 is closed.
- Variation 1 - Aircraft lands slightly long, RPIC is slow to engage brakes:
  - Aircraft stops 200 feet past A4.
  - 180s turns on the runway are non-standard and could delay other aircraft.
  - Long taxi to A2 could also cause delays to inbound aircraft.
  - Long taxi through two additional aprons could be challenging.



- Variation 2 – Eagle 65 is directly to land on parallel runway 04R:
  - VO may have to give commands in potentially less than optimum pre-planned position.
  - Both options to taxi back to Apron D will be much more involved."

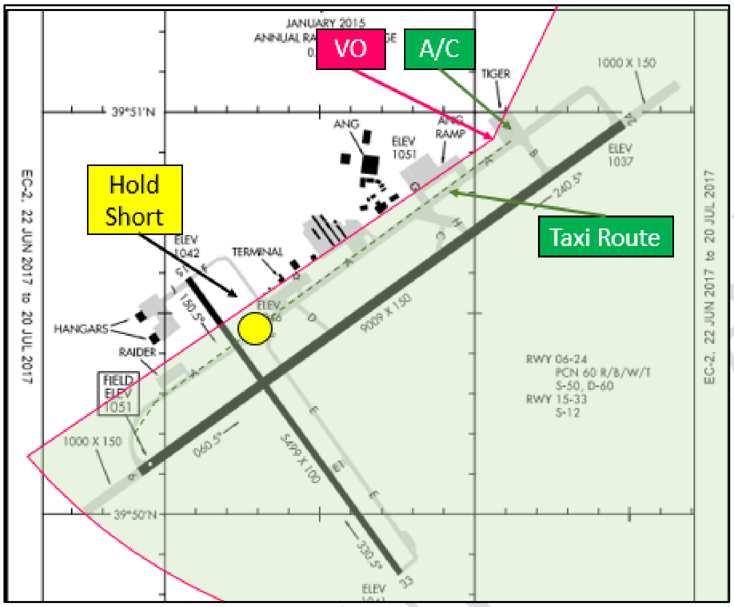


Input 1f. Sample Scenario –

"Runway Incursion:

- Robin 17 (an UA) is taxing to RWY 06 from Tiger Ramp via Taxiway A during hours when the ATC tower is not open (so the RPIC must rely completely on a VO because RPIC is at a remote site).
- Both runways are active (RWY 06 and RWY 15).
- Airfield is uncontrolled so aircrew are responsible for crossing both active runways.
- After taxi has commenced, VO hears Penguin 52 report 1 NM short final for RWY 15.

- Robin 17 is approaching RWY 15, due to the VO angle they can't tell exact position.
- VO directs the RPIC to stop taxi (instead of continuing and crossing RWY 15).
- Robin 17 stops just past the hold short line for RWY 15.
- Penguin sees Robin 17 stop and decides it is too close to the runway so they go-around."



Based on these data, we make the following recommendation:

> **Recommendation 1.** Require GS to include a display showing a top-down view of the airport surface with the UA's current position indicated dynamically on this surface display. Note that this requirement is more stringent than the one proposed in CS-3. CS-3 indicates that the relevant CS-3 information elements are:
>
> - UA latitude and longitude—required to be displayed at all times
> - Airport configuration—obtained from source outside control station
> - UA position relative to taxiway centerline—obtained from source outside control station

Thus, in CS-3 the minimum information requirements do not require a top-down view of the airport surface; rather, airport configuration is expected to be obtained from a source outside the control station (such as an airport diagram); similarly, the minimum requirement in CS-3 for UA position relative to centerline is that it should be obtained from a source outside the control station, such as via communication with the visual observer.

Based on these additional inputs and our human factors judgment, our recommendation is that the more stringent input described above in Recommendation 1 be required.

Note that the above scenarios have relevance for Category 2. Certification Requirements for VOs and Category 3. Phraseology for VOs and RPICs (below) as well.

3.1.2 Category 2. Certification Requirements for VOs

The SMEs provided the following inputs and sample scenarios relevant to this category.

Input 2a. “There is currently no certification for Visual Observers. This is a risk area.”

Input 2b. “Given the basic assumptions and potential limitations of a VO, there is a risk of an incursion between the intersecting runways.”

Input 2c. “Further, without two-way radio communication, the VO may not be able to communicate vectors to the RPIC/ OAC.”

Input 2d. Sample Scenario –

“Non-Standard Visual Observer (VO) Integration:

- Tiger 33 is flying into Wilmington Airport (KILN) [GPS 22R final approach] during hours when the ATC tower is not open (so the RPIC must rely completely on a VO because RPIC is at a remote site).
- RPIC is manually flying the approach until 1 NM:
  - At 1 NM the VO will identify the aircraft.
  - After positive identification, the VO will start issue commands for final approach and landing.

- Variation 1 - VO identifies Tiger 33 at 1.5 NM:
  - VO starts to tell the RPIC to make a “slight left turn.”
  - RPIC makes a 5-degree left turn.
  - This correction is too large, the RPIC should have only turned 2-degrees [final approach and landing will require a high fidelity of corrections].

- Variation 2 - VO identifies Tiger 33 is off course to the right of centerline:
  - VO then tells the RPIC to “get back to course.”
  - RPIC turns to wind correct course heading.
  - RPIC thinks he is back on course while VO still sees him right of centerline [common understanding of positional awareness should be standard during critical phases of flight].”

Input 2e. Sample Scenario –

“Standardized Terminology with VO:

- Robin 17 is taxing to RWY 06 from Tiger Ramp via Taxiway A during hours when the ATC tower is not open (so the RPIC must rely completely on a VO because RPIC is at a remote site).
- Final turn at the end of Taxiway A is a long gradual turn.

- VO directs RPIC to start a gradual turn entering initial curve.
- RPIC turns more than the VO is expecting.
- Due to the VOs angle at the far side of the field aircraft departs the taxi surface.

VO issues to be addressed:

- non-standardized terminology,
- delayed instructions for high fidelity inputs,
- lack of training,
- lack of 'currency' requirements,
- too many perspective angles to give appropriate instructions
  - pilots usually have a cockpit angle or north up angle,
- terminology definitions
  - heading vs left/right,
  - braking effort,
- line of sight issues
  - (that is why we have tall ATC towers), and
- taxi speeds
  - worse communication between RPIC/VO will result in lower taxi speeds
  - VO will not have a speed indication to make estimates."

Based on these data, we make the following recommendations:

Recommendation 2a. Require certification for VOs to ensure clear understanding of communication protocols, roles and responsibilities and an understanding of scenarios where risks are higher in order to increase vigilance for such scenarios. Note that, although CS-1 and CS-2 do not develop procedures or training/certification recommendations, the VO should be competent in the following tasks, to which our recommendations expect the VO to contribute:

- ensure instruments, avionics, and navigation equipment are working properly,
- monitor UA trajectory for obstacles (on the ground),
- check for proper flight control surface movement,
- ensure UA maintains runway centerline,
- ensure UA is above runway surface before touch down, and
- ensure separation during climb out and approach.

Recommendation 2b. Require reliable two way communication between the RPIC and VO. Note that the technological solutions to this are not directly human factors issues. Note also that the input “without two-way radio communication, the VO may not be able to communicate vectors to the RPIC/ OAC” indicates a particular technological solution, which may not be the best for all scenarios (such as when the RPIC is at a site remote from the departure or arrival airport). Thus, we have worded this more generally as a requirement for two-way communication and assume that the technological solution(s) will be specified in other forums. Note that this is consistent with the function allocation and control station work reported in CS-1 through CS-3, which includes assumptions stating that there is a direct line of communication between the VO and RPIC and that two-way communication is essential for all of the tasks that need to be performed by the VO, particularly separation responsibility.

Note that the above scenarios have relevance for Category 3. Phraseology for VOs and RPICs (below) as well.

3.1.3 Category 3. Phraseology for VOs and RPICs

The SMEs provided the following input relevant to this category:

Input 3: “The RPIC/OAC and VO must use standardized terminology when communication processes are being used. It may add risk to describe intruder aircraft callouts with regard to direction because the direction of the UA may be different than the direction of the VO.”

Based on these data, we make the following recommendation:

Recommendation 3. Establish and train RPICs and VOs on standardized vocabulary. Note that CS-1 through CS-3 do not address the subject of establishing standardized vocabulary between RPIC and VO.

3.1.4 Category 4. Backup Communication Channel

The SMEs provided the following inputs relevant to this category:

Input 4a. “Having two-way radio communications between the RPIC/OAC and the VO is better than no communications; however primary communications can fail and procedures for secondary communications may be required here.”

Input 4b. “The communications between RPIC/VO may be lost after the final go ahead for launch or landing and then an abort may become necessary. An open line that indicates communications is lost could serve as an automatic abort/wave off in this scenario.”

Input 4c. “Regarding crewmembers, the RPIC is ultimately responsible for the operation; however the RPIC may have operators at the controls at a launch and recovery site while the RPIC may be collocated with en-route operations site. Communications between the RPIC and Operator at the Controls is a risk area.”

Based on these data, we make the following recommendation:

> **Recommendation 4.** Require procedures and/or technological solutions that ensure that the detection of a loss of the primary communication channel between the RPIC and VO is noted and handled in a timely and appropriate fashion. Note that CS-2 covers recommendations for contingency planning for loss of VO, which includes loss of communication with the VO. The recommendation states that a plan must be created before takeoff, but does not require the use of advanced automation; i.e., the contingency plan could simply be a procedural solution, as opposed to a technological solution.

3.1.5 Category 5. Procedures to Handle Loss of Visibility

The SMEs provided the following inputs and sample scenario relevant to this category:

Input 5a. “VO LOS is subject to the movement of other aircraft/vehicles at the airport. Putting the VO in the tower might improve LOS, but not eliminate this possibility.”

Input 5b. “This assumes that the VO can see the UA throughout procedures requiring the VO. For example, the VO may not be able to observe the proximity of the UA on the airport surface area (during taxi).”

Input 5c. “The VO may not be able to observe the UA on the taxiway well enough to separate from other aircraft on larger airports”.

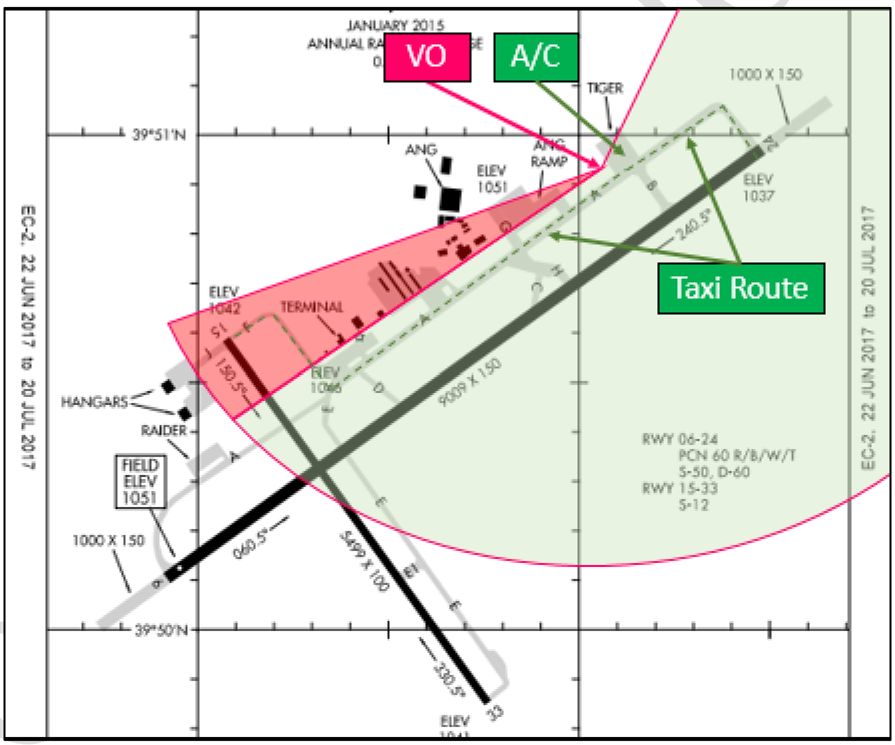
Input 5d. Sample Scenario:

“Visual Observer (VO) Limited Visibility on the Taxiway:

- Falcon 87 is preparing to taxi at Springfield Airport (KSGH).
    - Parking location is Tiger ramp.
    - Initial planned takeoff was RWY 24.

- VO is located on the corner of Taxiway A/B right near the Tiger ramp.
    - VO has a clear view from parking to RWY 24.
- Winds have changed during the last hour.
    - RPIC reviews the winds (140/10 gust 150.
    - RPIC recognizes these crosswinds are out of limits if utilizing RWY 33.
    - RWY 15 is the only option to takeoff within limits.
- Instead of a short taxi path from Tiger to RWY 24, there will be a long taxi to RWY 15.
- VO cannot see the final portion of the taxiway.

- Options are limited:
    - Wait until winds change (delayed mission).
    - Move VO to new position (pre-coordination required).
    - 2 VO for full taxi (personnel manning issues)."



Based on these data, we make the following recommendations:

Recommendation 5a. The VO must be placed so as to have full visibility of the airport surface as well as departure and arrival airspace. Since changes in runway configuration are a routine practice, such placement of the VO must take this into consideration.

Recommendation 5b. Since the VO (as a non-FAA function) is not likely to be located in the ATC Tower and since many of the airports involved do not have airline ramp towers, the possibility of another aircraft or vehicle blocking the line of sight must be considered a possibility. Procedures need to be defined to guide VO and RPIC responses when this happens, likely involving stopping the UA until visibility is regained. Note that CS-2 recommends that contingency planning be performed for "VO failure", which could include VO loss of visual contact with the UA. The minimum function allocation recommendation states that this process can be done without automation (i.e., it could be simply a procedural solution), which is in agreement with Recommendation 5.

3.1.6 Category 6. Requirements for Alternate Airports

The SMEs provided the following inputs relevant to this category.

Input 6a: "Due to liability issues and the potential level of distraction, I question how realistic it is for an ATC controller to be a VO on a UAS crew." (The scenario assumed that a requirement for filing a particular alternate airport would be the presence of a VO, and that one way to achieve this would be to train ATC Tower controllers as VOs for such cases in order to have a sufficient number of acceptable alternate airports.)

Input 6b. "The ACT controller may not have the time/ certification to perform duties as a VO."

Input 6c. "The schedule could change because of weather or in-flight emergencies."

Based on these data, we make the following recommendation.

Recommendation 6. Requiring the flight operator to staff a VO at the filed alternate airport would be a significant additional cost. Having ATC Tower controllers certified as VOs would be one approach to deal with this (recognizing that this has a training cost). Having a VO staffed by flight operators as a whole at "certified" alternate airports might be another (with a different set of attendant costs.) The recommendation is that requirements be established to ensure that there is a VO available at a filed alternate airport without specifying the required method to achieve this. Note that this topic is not covered by the function allocation or control station information requirements work.

3.1.7 Category 7. Information Requirements for RPIC

The SMEs provided the following input relevant to this category.

Input 7a. "The maps given do not show terrain elevation, but should be a GS requirement."

Based on these data, we make the following recommendation.

Recommendation 7. Given the scope of A10, information regarding planned or current altitude above terrain should be required. Note that CS-3 recommends that terrain/obstacle height is optional, but that is because CS-3 recommends requiring UA altitude above ground level (AGL) to be displayed at all times in the control station. RPICs do not have the out-the-window visual cues to judge aircraft height above terrain that manned pilots have, so they require some information in the control station that conveys UA clearance over terrain. Altitude AGL is a variable that can be quickly processed by the RPIC to mitigate the risk of CFIT.

3.1.8 Category 8. Access to Camera Views

The SMEs provided the following inputs relevant to this category.

Input 8a. “Nose camera: It offers some mitigation and enhances SA, but it can also create a false sense of security if that's the closes thing to sense and avoid. There could be conflicts not on the camera. Even if flying at a high AoA, there could be co-altitude hazards that the camera may not detect. It can definitely help if there are objects in front of the UA's taxi/flight paths.”

Input 8b. “This would increase situational awareness provided this capability doesn’t degrade. It may degrade because of equipment failure, weather, of obscurations between the camera and UA (i.e. birds form a next in front of the camera). Additionally, the camera equipment should have a night operational capability (i.e. FLIR).”

Input 8c. “A forward-looking camera may not have a field of view equivalent to a manned pilot in the cockpit; whereas the manned pilot can turn his/her head to improve the situational awareness or widen the field of view.”

Input 8d. “A better variation for a minimum requirement to this scenario would be to have a 360 degree field of view to determine the location of other traffic. This field of view may not necessarily be optical as an ADSB in may also provide information. Still, VOs will be required for aircraft without transponders also operating within the area.”

Input 8e. “With a forward POV camera the RPIC will not have improved situational awareness during surface operations.”

Input 8f. “With a multi-directional POV camera, the RPIC may be capable of independent operations during surface operations.”

Input 8g. “With fixed cameras showing the airport surface (ramp, taxiway and runways), the RPIC will have improved situational awareness.”

Input 8h. “Airport cameras can help with SA and can help the RPIC identify hazards during taxi, takeoff, and landing. But they can also be distracting to monitor. As I picture this, I'm thinking of something like a security officer would have in a mall. Lots of cameras to monitor, each potentially distracting, and each one adds to complexity in terms of understanding the location of that camera to discern potential ramifications on UA operations. Unless there's a way for the system to only show feeds for areas in the vicinity of the UA, I don't think I like this idea.”

Input8i. "Better real-time video transmission from the UA, perhaps going so far as to allow a 360 degree view."

Based on these data, we make the following recommendation.

> **Recommendation 8.** While views from cameras might be useful in some situations, within the scope of A10, there was no strong argument to require them as minimum human factors requirements. Note that SME feedback in CS-1 and CS-2 indicated that cameras are not necessary to safely operate a UA in the NAS, as long as information is being delivered to the control station with minimal delay and a high degree of accuracy. For example, SME comments from CS-1 include: "I disagree with the assumption about [requiring] the nose camera. I have operated UAS that do not need this to be able to fly safely. The FAA has not allowed cameras as a safe separation method either. I could use VO or millimeter wavelength radar to do something similar. I would recommend that we remove the assumption." Similarly, another SME commented as input to the preparation of CS-1: "I personally feel there is a bit too much emphasis placed on the nose camera. Don't get me wrong, it's a great tool for SA, but I think in some cases it's over emphasized." On the other hand, a third SME commented: "With today's technologies regarding VR and 360-degree cameras, there is no reason that this functionality cannot be added to UAS larger than 55 lb. This can allow the pilot/operator to have more visibility of the environment the UAS is operating in (such as an airport)." Note the emphasis of the third SME's comments was not on requiring a camera, but the fact that camera technology is relatively inexpensive and unsophisticated compared to the technology on a UAS larger than 55 lb so that there is little reason to exclude a camera.

3.1.9 Category 9. ADSB Equipage

The SMEs provided the following input relevant to this category.

Input 9a. "ADSB out may not provide the RPIC/OAC with the situation awareness necessary to manually operate the UA to avoid other aircraft. Recommend an ADSB in/Out capable transponder."

Based on these data, we make the following recommendation.

> **Recommendation 9.** For an IFR flight landing and departing in Class G and Class D airspace, there will be aircraft that do not have ADSB/Out and furthermore do not have a transponder and radio. ADSB will not provide information regarding the presence of these aircraft. The recommendations for requirements for a Visual Observer to support taxi, arrival and departure operations along with required interaction with ATC to fly IFR once airborne, as documented in the report for CS-1, provide adequate minimum standards for taxi, departure and arrival operations without requiring ADSB/In.
>
> For enroute operations where all aircraft will be flying IFR, procedures to fly under positive control by ATC while enroute could benefit from ADSB/In, but within the scope of A10 it

is not required. Note that the FAA UAS Integration into the NAS Roadmap states the UAS will be required to have ADSB/Out to operate in the NAS. Beyond stating this as an assumption, CS-1 through CS-3 do not address any other requirements for ADSB capability.

For enroute operations in Class D and G airspace there could be manned aircraft that are not equipped with ADSB/Out and are even without a transponder and radio. Standards/procedures for response when an unequipped manned aircraft is on a trajectory that is in conflict with a UA need to be defined. However, detect and avoid was not addressed in CS-1 through CS-3 as it was not in scope.

3.1.10 Category 10. Training of Manned Pilots

The SMEs provided the following input relevant to this category.

Input 10a. “Manned Pilots not accustomed to looking carefully enough to visually locate smaller, more agile aircraft.”

Based on these data, we make the following recommendation.

Recommendation 10. This consideration needs to be added to the training of pilots for manned aircraft.

3.2 INPUTS WITH RELEVANCE TO NON-HUMAN FACTORS REQUIREMENTS AND A SCOPE BROADER THAN A10

Note that some of these recommendations are outside the scope of A10 but apply to expansions beyond that scope.

The SMEs provided the following inputs (each followed by a note indicating potential considerations associated with that input. Recommendations are not provided because these inputs are outside of the scope of A10.

Input: “Frequency deconfliction must be accounted for.” (Note, however, that to the extent that this isn’t achieved, procedures need to be defined.)

Input: “UAs must be programmed so that in a lost signal situation, it would avoid infrastructure on their way to the specified loiter point. This path would not be part of the filed flight plan. Other aircraft in the area would need to be alert to this possibility. Does the NOTAM cover this possibility from all angles?” (Note that if the RPIC or the supporting flight operator has responsibility to do this for each flight, then this has human factors implications in terms of information requirements.)

Input: "Need to overlay as much information as possible onto a single visual source. For example, the inability to overlay (or remove) weather or other aircraft information on the same screen where the flight control/path is being monitored/manipulated has been mentioned repeatedly as an issue. When the information is presented on separate displays or in separate windows on the same display, this creates too much work for the pilot especially if they have a more complex control system (and increasingly complex if peddles are involved which usually seems to indicate a more dated system)." (Note: Within the scope of A10, much of this information is assumed to be accessed external to the GS.)

Input: "ATC sometimes will talk in terms of land marks, (i.e. report when abeam the water tower). RPIC may not have this marked on available maps." (Relevant to ATC training?)

Input: "Automating the checklists and other aspects in flight that remove cognitive load or that simply having an understanding of when the pilot can get overloaded is important to acknowledge in the minimums." (This input is more relevant for other more complex airspace and airport operations.)

Input: "Assumption of a roadway inspection of 1000 feet may not be accurate. Many UAS with EO/IR sensors are capable of performing this inspection from 4000-6000 ft. above ground level (AGL). This potentially adds risk as many other aircraft may be operating at this altitude compared to 1000' AGL. Also, depending on the topography, at 1,000' AGL the electronic line-of-sight may be obscured causing the UA to implement its lost link logic." (This may have implications for the technology used to support these operations.)

Input: Sample Scenario –

"Intermittent command and control (C2) link malfunction:

- Tiger 33 is flying into Wilmington Airport (KILN) [5 NM from Wizard for GPS 22R approach].
- RPIC is manually flying the approach.
    - RPIC is manipulating stick control and throttle.
    - Tiger 33 has an auto rudder system and is not required for flight.
- C2 display page is to the right side of the ground station.
    - It is NOT located with the primary flight display (PFD) which the pilot is focusing on during the approach.
- Maintenance malfunction – the C2 link to Tiger 33 has become intermittent.
    - Ground station indication for C2 link is on a non-integrated display.
    - C2 link is outside the primary PFD field of view (FOV) the RPIC utilizes for the approach and landing.
- RPIC attempts to turn aircraft to final.
    - PFD does not indicate a turn.
    - RPIC attempts the turn a second time again and the aircraft does turn.
    - RPIC scans the ground station displays and does not see any problem indications.

- RPIC attempts to level off the aircraft on the final approach.
  - PFD does not indicate a nose pitch up to capture the required altitude.
  - RPIC attempt to level the aircraft a second time and the aircraft does not respond.
  - RPIC scans the ground station displays and sees a C2 link ‘yellow’ light.
  - While examining the C2 link ‘yellow’ light, the light extinguishes.
  - RPIC returns to the PFD in the ground station, now the aircraft is descending below the targeted altitude.

- Since the C2 link indications are outside the PFD FOV the following could be an issue:
  - Delayed notification of C2 issues.
  - Pilot induced oscillations (PIO):
    - Potentially missed altitude assignments.
    - Heading misalignment.
  - Incorrect diagnosis of a flight control malfunction.”

3.3 STORYBOARD IMPROVEMENTS

The SMEs also noted two improvements that could be made to the three storyboards that were presented as part of this knowledge elicitation exercise.

Input: “There was no basic assumption about two-way radio capabilities. Although not required for Class G airspace, I recommend two-way radio capability as a minimum requirement/assumption.” (This was inadvertently left out of the assumptions indicated in the storyboards and should be added.)

Input: “Is there a point in 18,000 ft.? It doesn't seem practical for the length of ferry.” (The intention was to get the participants in the cognitive walkthrough to think about RPIC/ATC interactions at higher altitudes. This topic merits further investigation.)

In summary, above we have presented the results (“Inputs” and “Sample Scenarios”) generated by this knowledge elicitation exercise and, based on these data as well as the data considered as part of CS-1 through CS-3, have presented recommendations.

4. CONCLUSIONS

This exercise involved:

- The development of storyboards illustrating normative performance under nominal conditions (CS-4).
- Using these storyboards to conduct a knowledge elicitation exercise using cognitive walkthroughs in which SMEs were asked to walk through the storyboards, to consider alternative versions of these scenarios where a near miss, incident or accident could occur, and to suggest changes in the relevant human factors minimal requirements that could have prevented the occurrence of these hypothetical scenarios or scenario branches.

- Using these data to develop recommendations.
- Contrasting these recommendations with those developed thus far by CS-1, CS-2, and CS-3 without the benefit of these data.

In many cases, the data from the cognitive walkthroughs provided additional validation for the recommendations developed in CS-1 through CS-3. And in other cases, the resultant data indicated additional recommendations to add to those documented as part of CS-1 through CS-3. However, in one case, the presentation of the specific contexts provided by the storyboards triggered input from the SMEs that was not consistent with the recommendations in CS-3. These consistencies and inconsistencies with CS-1 through CS-3 are specifically noted in the results section.