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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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Final Report

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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.

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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 standards and guidelines for taxi, takeoff, landing, navigation, communication, contingencies unique to unmanned operation, and handover tasks
- 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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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:

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})
Steering angle
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. Note also that the SME 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.
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, likely involving stopping the UA until visibility is regained.
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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APPENDIX B—TASK CS-2: FUNCTION ALLOCATION RECOMMENDATIONS FOR NAVIGATION, COMMUNICATION, CONTINGENCY, AND HANDOVER TASKS

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APPENDIX C—TASK CS-3: RECOMMENDATIONS FOR MINIMUM CONTROL STATION STANDARDS AND GUIDELINES FOR TAXI, TAKEOFF, LANDING, NAVIGATION, COMMUNICATION, AND CONTINGENCIES UNIQUE TO UNMANNED OPERATION, AND HANDOVER TASKS

Carl Pankok, Jr. and Ellen J. Bass

APPENDIX D—TASK CS-4: DEVELOPMENT OF STORYBOARDS TO SUPPORT COGNITIVE WALKTHROUGHS

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APPENDIX E—TASK CS-5: REFINEMENT AND EXTENSION OF WORKSTATION DESIGN REQUIREMENTS AND GUIDELINES BASED ON COGNITIVE WALKTHROUGHS

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