DOT/FAA/AR-xx/xx

Federal Aviation Administration
William J. Hughes Technical Center
Aviation Research Division
Atlantic City International Airport
New Jersey 08405

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A7 — UAS Human Factors Control Station Design Standards (Plus Function Allocation, Training, and Visual Observer)

Carl Pankok, Jr.
Ellen J. Bass
Philip J. Smith
John Bridewell
Igor Dolgov
Joel Walker
Ernest Anderson
Robert Concannon
Paul Cline
Amy Spencer

November 1, 2017

Final Report

U.S. Department of Transportation
Federal Aviation Administration

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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
A7 — UAS Human Factors Control Station Design Standards (Plus Function Allocation, Training, and Visual Observer)	November 2017
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Carl Pankok, Jr., Ellen J. Bass, Philip J. Smith, John Bridewell, Igor Dolgov, Joel Walker, Ernest Anderson, Robert Concannon, Paul Cline, 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

16. Abstract

The objective of the work was to develop recommendations for minimum unmanned aircraft system (UAS) control station standards and guidelines, and UAS pilot and visual observer (VO) training and certification guidelines. The recommendations focused on operation of fixed-wing unmanned aircraft larger than 55 pounds operated beyond visual line of sight in an integrated National Airspace System (NAS). The research approach included (1) a review of human-automation function allocation literature applicable to UAS control station design; (2) development of recommendations for minimum human-automation function allocation; (3) a review of planning literature relevant to UAS operation; (4) a review of UAS control station research literature, selected operational control stations, federal regulations, and incidents/accidents literature; (5) development of recommendations for minimum information requirements for safe UAS operation in the NAS, (6) development of recommended certification and training requirements for UAS pilots; and (7) development of recommended certification and training requirements for VOs. UAS pilot subject matter experts were leveraged throughout the project tasks, including as reviewers of the recommendations. The results of the work are expected to inform the development of regulations for UAS automation strategies, control station design, UAS pilot and crewmember training and certification, and VO training and certification.

17. Key Words	18. Distribution Statement
Certification Controls and Displays Design Guidelines Human-Automation Function Allocation Human Factors Information Requirements Training Unmanned Aircraft Systems Unmanned Aircraft System Control Station Visual Observer	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		

ACKNOWLEDGEMENTS

Acknowledgements for individual efforts are included within sections of the report. The authors would like to thank individuals who reviewed earlier versions of this document, including Stephen "Lux" Luxion. The authors acknowledge the subject matter experts who participated in the research: Amanda Brandt, Michael Sean Brown, Reuben Burch, Kurt Carraway, Joe Cerreta, Joseph Millette, Sean Moulton, Paul Snyder, and Gary Ullrich.

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EXECUTIVE SUMMARY

The purpose of this project was to develop recommendations for four synergistic areas necessary for the safe operation of unmanned aircraft systems (UAS) larger than 55 lb in the National Airspace System (NAS). These four areas include (1) minimum UAS control station standards and guidelines, (2) UAS operation and contingency planning, (3) remote pilot in command (RPIC) training and certification, and (4) visual observer (VO) training and certification. We anticipate the results of the work will inform the development of regulations for UAS operation in the NAS.

To develop recommendations for minimum human-automation function allocation strategies and minimum information requirements, the team conducted two literature reviews and a task analysis. A diverse group of UAS pilot subject matter experts (SMEs) reviewed all resulting recommendations. Results indicated that minimum automation strategies required for safe UAS operation in the NAS are comparable to those for manned operation in the NAS. One major difference between manned and unmanned operation is the need for an autonomous mode to account for lost command and control link situations. Based on these minimum human-automation function allocation strategies, the research team identified information elements that are necessary for safe operation in the NAS.

To develop recommendations for UAS planning, the team conducted a literature review on planning strategies. The review yielded topics that are unique to UAS operation that merit consideration. These topics include a focus on activities that may include roles beyond the pilot in command (such as what would be considered a flight dispatcher activity in commercial manned operation or those conducted by air traffic) and activities that occur before a flight takes off and during flight.

To develop recommendations for UAS pilot and crewmember training and certification, the team conducted a literature review focused on the subject. The literature revealed that UAS pilot training should leverage the current manned pilot training strategies, supplemented by topic areas that are unique to UAS operation. The researchers also suggested that a two-level certification scheme be used, including an entry-level "private" certification and a higher-level "commercial" certification.

To develop recommendations for VO training and certification strategies, the team used a three-phase approach based on Activity Theory. The three phases included interviewing SMEs, surveying UAS crewmembers and NAS stakeholders, and analyzing field recordings of UAS operations. Results revealed that VOs should be able to effectively track manned and unmanned aircraft in various lighting and meteorological conditions, scan airspace for intruder traffic, and inform the RPIC of potential near mid-air collisions. The survey of NAS stakeholders revealed conflicting opinions about whether VOs should be required to pass a formal classroom exam, but there was general agreement that a practical exam was unnecessary. The results also revealed the importance of considering a person's existing pilot certifications in designing an effective VO training program.

1. INTRODUCTION

This project report focuses on the development of recommendations for minimum unmanned aircraft systems (UAS) control station standards and guidelines, planning, UAS crewmember certification and training, and visual observer (VO) certification and training. This work applies to fixed-wing UAS greater than 55 pounds and capable of using the existing National Airspace System (NAS) infrastructure. It covers both line of sight (LOS) and beyond line of sight (BLOS) operations for unmanned aircraft (UA). It addresses these contexts with seven synergistic tasks:

- Function allocation literature review
- Function allocation strategy recommendations
- Planning literature review
- Control station literature review
- Recommendations for minimum control station human factors considerations
- UAS pilot and VO training and certification literature review
- VO certification and training criteria

1.1 BACKGROUND

1.1.1 Human-Automation Function Allocation

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 UAS uses, 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 that 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 necessary for certifying civil UAS automation systems.

1.1.2 Control Station Standards and Guidelines

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 and design guidelines. That is, the information needed by the pilot to perform those functions is determined and the strategies to display that information via the human-machine interface (HMI) are developed as a result of function allocation research. In developing minimum standards and design guidelines for UAS control stations, regulators should consider the human factors challenges associated with the control of UAS. UAS pilots receive information regarding the state and health of their aircraft solely through electronic displays, and 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 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 uniquely with unmanned aircraft operation, is critical to UAS safety, so information such as strength of data link connection becomes critical.

1.1.3 Planning

There is sparse literature on approaches to contingency planning for military applications of UAS, and the contingency planning literature for UAS operation in the NAS is even more limited. The majority of the existing contingency planning literature dealing with traditional aircraft in the NAS focuses on flight dispatchers, flight service providers, and traffic managers. The ultimate responsibility for contingency planning may fall to an individual UAS pilot who then flies the UAS, to a new position such as the UAS planning pilot who is distinct from the pilot in command, or to a non-pilot positions analogous to dispatchers and flight planners in current aircraft operations. Regardless, regulators will need research to help them define the necessary contingency planning and adaptive planning functions and to identify and evaluate alternative strategies for allocating those functions to people and automation.

1.1.4 UAS Pilot and Crewmember Training and Certification

There are currently no general industry training or certification standards for UAS pilots and UAS support personnel (e.g., sensor operators, ground support personnel, mission commanders, visual observers) to operate UAS larger than 55 lb in the NAS (note that 14 CFR Part 107 is applicable to UAS smaller than 55 lb). Individual organizations in industry and government have implemented their own training programs on an ad hoc basis. The UAS community has proposed a number of strategies for pilot training and certification, with many arguing that traditional practical test standards and stick-and-rudder skills no longer apply due to the current and potential UAS automation. Some argue that “video game” and computer experience is important, or that a UAS pilot needs skills and rules, as opposed to knowledge. Other cases are made that UAS pilots do not need a pilot certificate, or a case is made for a type rating specific to the system and/or the operation. There is a lack of research available to support unique UAS pilot or support personnel training and certification requirements for operation of UAS larger than 55 lb in the NAS.

1.1.5 Visual Observer Training and Certification

There is a lack of research for developing visual observer (VO) training and certification requirements. VOs are used in many current UAS operations to assist in protecting the UAS from other air traffic and hazards. Research is required that will help to establish clearly defined limitations for the use of VOs and to assist in the creation of procedures and training for their effective employment. There needs to be clearly defined rules for a variety of environmental conditions (e.g., clouds, fog, dust), lighting conditions (e.g., day, night, dusk), and type of operations. More clearly defined guidelines for the use of VOs will benefit rule makers in establishing and approving new UAS operations.

Although VOs have been a critical component of the vast majority of UAS operations in the United States, regulators have yet to codify detailed definitions of VO roles, responsibilities, and performance expectations. As stated in the UAS Operational Approval policy notice (publication N8900.227, FAA, 2013), VOs are expected to be responsible for: (1) helping UAS pilots keep the aircraft within visual line of sight (VLOS); (2) exercising see-and-avoid responsibilities by maintaining compliance with 14 CFR § 91.111, 91.113, 91.115; and (3) preventing the UAS from creating a collision hazard. To ensure that these functions can be performed adequately in the NAS, VOs must be able to scan the airspace effectively and to make accurate and reliable estimates of relative aircraft position, to assess the need for a potential avoidance maneuver, and to communicate that need to the UAS pilot in a timely manner. To date, VO training curricula and qualification criteria vary depending on type of aircraft, the operating environment, and background of the UAS operating organization.

1.2 PROJECT SCOPE

The research team developed recommendations under the following scope:

- 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 both within VLOS and 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 VO 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 (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 research recommendations do not include the impact of weather conditions such as cloud coverage, cloud height, icing, precipitation, convective weather, and visibility.
- 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. No fully autonomous operations 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. 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, the research team added the following assumptions. 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. A VO is used for takeoff and landing procedures because they are occurring at a non-towered airport.
A3. VFR flight is permitted only when the UA is within VLOS of a VO (necessary for takeoff and landing at non-towered airports).
A4. Each UA has a maximum crosswind component capability that limits the conditions under which it can depart or land.
A5. The airport has sufficient infrastructure (e.g., reliable power source, ATC communication) for operating the UAS.
A6. 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.

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 A7. Each appendix serves as a stand-alone document, with its own introduction, detailed description of the methodology, results, and recommendations (where applicable).

2. METHODOLOGY

This section overviews of the methodologies used to develop recommendations for minimum control station standards and guidelines, crewmember certification and training recommendations, and VO certification and training recommendations.

The research team conducted a review of generic human-automation function allocation strategies and UAS-specific strategies (Appendix A). The team developed a taxonomy and characterized the research literature using the taxonomy. A portion of the taxonomy focused on human-automation function allocation strategies, serving as a key precursor to the function allocation recommendations.

To develop UAS human-automation function allocation recommendations, the team conducted a task analysis to identify aviate tasks in the climb out, cruise, descent, and approach phases of flight. The team categorized each task identified in the task analysis using the human-automation function allocation taxonomy, with the goal of identifying minimum automation strategies required to operate the UAS in the NAS without decreasing the level of safety as compared to current NAS operations. UAS pilot subject matter experts (SMEs) reviewed the strategies. A more detailed description of the methodology is located in Appendix B.

The team adopted three approaches for the review of the relevance of contingency planning and adaptive planning to UAS operations (Appendix C). First, the team reviewed the broader literature on planning, especially as relevant to aviation. Second, domain experts (including two recently retired Global Hawk/Predator pilots, a business aviation pilot, a retired controller/traffic manager for DTW/D21, a retired controller/traffic manager for ZOB, two dispatchers, a certified VO for small UAS (sUAS), three pilots for sUAS, and three flight planners working for flight service providers) were interviewed to elicit their insights regarding similarities in planning for UAS operations and regarding unique issues relevant to UAS operations. Third, the team developed concrete scenarios, which were subsequently reviewed by these domain experts in order to ensure a more thorough, context-sensitive assessment of the planning issues relevant to UAS operations.

The team conducted a control station literature review of relevant research literature, federal regulations, operational and experimental control stations, and UAS incident and accident reports. Appendix D contains the literature review. The team leveraged the reviewed documents and control stations to generate a list of potential information elements for inclusion in an operational control station. The team developed a taxonomy to refine the notion of “minimum” to categorize the information elements with respect to recommended availability. In addition, the team analyzed the information elements with respect to control and feedback, and the team developed a second taxonomy to categorize information elements for this purpose. A collection of SMEs with a range of manned and unmanned experiences reviewed the recommendations, and the research team incorporated SME comments into the results. Appendix E contains a more detailed account of the methods.

The research team conducted a search for resources most likely to address training and certification of UAS crewmembers. While there is not a readily accessible list of resources for this area of research, the research team (consisting of academic faculty and SMEs) reviewed a significant number of relevant documents. The review summarized the available literature, provided recommendations based upon the review, and included a reference list of the applicable documents.

There is a dearth of literature regarding the training of VOs. Thus, the team executed a three-phase approach based on Activity Theory (AT), which involved interviewing SMEs, surveying UAS crewmembers and NAS stakeholders, and analyzing field recordings of UAS operations (Appendix G). AT is a meta-analytic research framework that considers an entire work/activity system (including teams, organizations, etc.) beyond just one actor or user (Kaptelinin & Nardi, 2006). It accounts for environment, history of the people, culture, role of the artifact(s)/technology, motivations, and complexity of real life activity (Kaptelinin & Nardi, 2006). Systemic-structural activity theory (SSAT), used in this research, represents a modern synthesis within activity theory that integrates its branches with findings and methods from human factors, ergonomics and cognitive psychology (Bedny & Karwowski, 2006; Bedny, 2014; Bedny, Karwowski, & Bedny, 2014). As depicted in Figure 1, a typical AT model includes the object (or objective, in this case: Safe UAS Operations in the NAS), subjects (in this case: UAS crew), mediating artifacts (in this case: UAS control stations and other technologies), rules (in this case: 14 CFR § 91.111, 91.113, 91.115 and 107), community (in this case: all other aircraft and other stakeholders), and division of labor (in this case: function allocation). The typical components of the AT diagram in Figure 1 are depicted in black and the specific components of the current research are labelled in green.

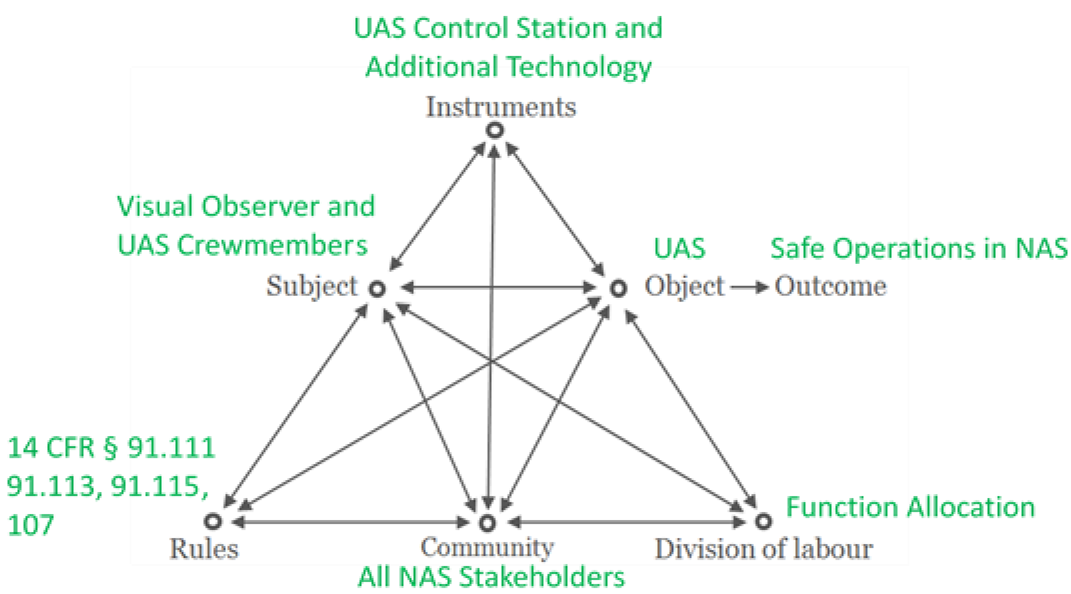

Figure 1. Activity Theory diagram of UAS operations in the NAS.

3. KEY POINTS

3.1 KEY POINTS FROM THE FUNCTION ALLOCATION WORK

The tables below summarize the function allocation recommendations for aviate tasks by indicating the recommended agent or agents (RPIC, VO, 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 a VO or control automation, as SME feedback suggested that the tasks could be performed safely by the RPIC and/or alerting automation. These tables are reproduced from the *Summary of the Recommendations* section in Appendix B.

3.1.1 Climb Out

Table 1. Overview of function allocation recommendations for aviate tasks during the climb out phase of flight.

Task	RPIC	VO	Alerting Automation	Control Automation
Manage horizontal flight path	X			
Manage altitude, particularly for any level-off altitudes	X		X	
Manage vertical speed	X			
Manage airspeed (V_Y), including the 250 KIAS limit below 10,000 ft.	X		X	
Set altimeter for transition altitude and transition level, if necessary	X			

3.1.2 Cruise

Table 2. Overview of function allocation recommendations for aviate tasks during the cruise phase of flight.

Task	RPIC	VO	Alerting Automation	Control Automation
Level off and maintain cruising altitude	X		X	
Configure aircraft for cruise	X			
Manage horizontal flight path	X			
Manage altitude	X			
Manage vertical speed	X			
Manage airspeed	X		X	

3.1.3 Descent

Table 3. Overview of function allocation recommendations for aviate tasks during the descent phase of flight.

Task	RPIC	VO	Alerting Automation	Control Automation
Configure aircraft for descent	X			
Set external lights appropriately	X			
Manage horizontal flight path	X			
Manage vertical flight path and altitude, particularly for any level-off altitude	X		X	
Manage vertical speed (for safe descent)	X			
Manage airspeed (for speed constraints and safety of the aircraft)	X		X	
Set altimeter to local altimeter setting at the transition level, if necessary	X			

3.1.4 Approach

Table 4. Overview of function allocation recommendations for aviate tasks during the approach phase of flight.

Task	RPIC	VO	Alerting Automation	Control Automation
Configure UA for approach	X			
Manage horizontal flight path	X			
Manage vertical flight path and altitude	X		X	
Manage vertical speed	X			
Manage airspeed	X		X	

3.2 KEY POINTS FROM THE PLANNING WORK

The list below contains key points regarding contingency planning and adaptive planning in UAS operations (Appendix C).

- To guide design decisions regarding minimum human factors requirements, the range of potential contingency operations needs to be specified. Such design decisions must, where possible, enable robust operations for anticipated contingency operations. They must also ensure sufficient flexible resources and human-centered designs to ensure resilient responses in the face of unanticipated scenarios.
- The NAS, as currently operated, is heavily reliant on a distributed work system design to ensure safety. The same underlying principles need to be applied to the integration of UAS into the NAS.

- Many of the most important scenarios relevant to contingency planning and adaptive planning fall outside of the scope of A7 such as convective weather and operations in more complex airspace and at airports with higher-density operations. UAS operations involving rotorcraft, especially in urban areas, are also very important. Future research should encompass this broader scope to determine how to safely integrate UAS into the NAS.

3.3 KEY POINTS FROM THE INFORMATION RECOMMENDATIONS WORK

Table 5 contains the information elements that the control station should have capability to display at all times, as recommended in Appendix E.

Table 5. Information elements that are recommended to be always displayed.

Information Element: Always Displayed
Aircraft external lights status
Aircraft ID
Altimeter setting
Altitude above ground level (absolute)
Control device position
Flight mode annunciation
Indicated airspeed
Indicated altitude
Latitude
Longitude
Magnetic heading
Maximum flaps extended speed (VFE)
Maximum landing gear operating speed (VLO)
Maximum operating limit speed (VMO)
Maximum operating maneuvering speed (VO)
Maximum speed for normal operations (VNO)
Never-exceed speed (VNE)
Pitch attitude
Roll attitude/bank angle
Slip/skid
Stall speed (VS)
Stall speed in landing configuration (VS0)
Throttle position
Thrust reverser position
Time of day
Transponder code
Transponder status
Trim device position
Vertical speed

3.4 KEY POINTS FROM THE UAS PILOT CERTIFICATION AND TRAINING WORK

Key points from the crewmember training and certification literature review include:

- UAS pilot training should leverage the long-established history of manned pilot training, including aeronautical knowledge subjects and flight experience exemplified by PTS/ACS and FAR Part 61.
- Portions of Part 61 that apply to UAS operations should be incorporated into UAS training. Elements unique to UAS operation should constitute additional training topics.
- Regarding certification, our review recommended two levels of certification; private and commercial. Private certification would be considered entry-level certification and permit UAS operations in circumstances of least risk. Commercial certification would authorize operations for compensation or hire in all classes of airspace and under instrument meteorological conditions beyond visual line of sight.
- There were no recommendations for visual observer certification based upon this literature review.

3.5 KEY POINTS FROM THE VO CERTIFICATION AND TRAINING WORK

In Phase 1 of the VO work (Appendix G), SMEs and various UAS crewmembers reported that proficiency with the following VO skills is critical for safe UAS operations in the NAS:

- Tracking unmanned and manned aircraft in various lighting and meteorological conditions
    - Must be able to maintain VLOS
    - Must be able to re-engage visual contact after loss and/or distraction
- Scanning airspace for approaching air traffic
    - Must be able to shift visual depth of field
- Informing pilot of impending near mid-air collision (NMAC) or some other danger with enough time for the pilot to take appropriate action
    - Must maintain cockpit discipline
    - Must use appropriate verbiage when communicating with the pilot
    - Must be able to use global bearings and local landmarks to identify positions of UAS and other air traffic
    - Must be able to estimate aircraft flight paths, altitudes, and closure rates in order to determine the likelihood of an NMAC
    - Must be able to determine and communicate correct course of action and a safe deviation from the flight path to avoid a potential NMAC

The findings based on the UAS flight test operation field recordings of Phase 2 confirmed the findings from Phase 1. Specifically, VOs relied on a combination of visual perception, communication, and team coordination skills to assist pilots in effectively accomplishing see-and-avoid duties during UAS operations. In the current scenario, the pilots offloaded excessive workload in three ways: (1) pilots offloaded takeoff and landing flight dynamics were offloaded to the external pilot (and tow vehicle driver), (2) pilots offloaded see-and-avoid duties to VOs, and (3) pilots offloaded some communication tasks to the mission commander. The mission commander monitored cooperative air traffic communications and only relayed mission critical information to the pilot. In a crew configuration where any of the noted personnel are not present, the task of the UAS pilot becomes that much more difficult.

In the survey conducted in Phase 3, NAS stakeholders acknowledged the added risk of operating a UAS larger than 55 lb, but there was a lack of consensus regarding whether training and/or certification needs to be mandated. NAS stakeholders were approximately evenly split on whether VOs should receive formal classroom/online and hands-on training. While survey participants favored requiring VOs to pass a formal classroom/online exam, the trend was not significant. More participants were against a formal practical exam than favored it. When examining the reasons for why participants felt that training and examination were necessary, participants noted the usefulness of classroom training in understanding NAS regulations and manned/unmanned aircraft operations, as well as increased risk due to platform size.

Due to the complexity and human factors involved in UAS operations, future rulemaking should take into account persons' existing certificates. Licensed pilots have already mastered all of the essential skills needed to carry out VO duties. Furthermore, licensed pilots have already been trained and certified in their knowledge of rules and regulations pertaining to operations in the NAS. Moreover, manned and unmanned aircraft pilots have a multitude of hours performing see-and-avoid duties, are well versed in aviation verbiage, and are trained in maintaining a proper cockpit discipline. Thus, licensed manned/unmanned aircraft pilots should not require any additional training or certification to act as VOs in UAS operations, regardless of platform weight. On the other hand, the added risk involved in operations of UAS greater than 55lb suggests that previously unlicensed persons who would like to serve as VOs can rely on existing print/online materials for training and should be certified with a process similar to what the FAA is currently using for Part 107 licensure.

4. FUTURE WORK

The work presented in this document relates to UAS control station human-automation function allocation and the design guidance represents early stages in the development of recommendations for minimum control station regulations. Development of minimum function allocation strategies and recommendations for information requirements leveraged inputs including literature, exemplar control stations, and SME review. 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 storyboarding and cognitive walkthroughs beyond those conducted by Smith et al. (2017a) and Smith et al. (2017b).

Future work should evaluate the methods used to identify recommendations for minimum information requirements for UAS control stations. Regarding the sources used to identify the information elements, future work should include a more thorough review of operational and experimental control stations. This evaluation would also benefit from review by SMEs with a broader range of skills and experience and mock-ups of control station interfaces.

As the scope is expanded beyond that defined for Project A7 to include more complex and congested airport and airspace operations, cognitive walkthroughs are 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.

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 recommendations for information requirements can be applied to other topic areas relevant to UAS operation for which the system design process is in its infancy. Project A7 addresses recommendations for aviate tasks. Future work should apply the Project A7 methodology to the following phases of flight not covered by the Project A7 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 (Pankok & Bass, 2017; Pankok, Bass, Walker, & Smith, 2017), such as aircraft component failure or malfunction.

Pilots conduct their work in a real-time environment with other traffic, weather, and environmental factors. 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 A7 work was on operation of a fixed-wing UA larger than 55 lb that can fly standard airport patterns and comply with ATC clearances. Future work should investigate recommendations for minimum function allocation strategies and information requirements 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
- UAs incapable of complying with ATC clearances.

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 A7 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.

Regarding contingency planning and adaptive planning, many of the most important scenarios fall outside of the scope of Project A7. Future research should consider scenarios involving convective weather and operations in more complex airspace and at airports with higher density operations. UAS operations involving rotorcraft, especially in urban areas, are also very important. Future expansion to encompass this broader scope is clearly one of the next steps necessary to determine how to safely and efficiently integrate UAS into the NAS.

Areas of future work regarding UAS pilot training and certification review are below.

- Future efforts should explore whether some form of self-study or FAA approved student pilot program would be the most appropriate to develop the needed aeronautical knowledge, aeronautical experience, and flight proficiency to fly UAS.
- Future research could center upon what ratio of simulator and flight experience is necessary depending on aircraft classification, control system, mission, etc.
- Additional research should pursue details of what should be included as part of flight checks, if flight checks are to be administered.
- Future research should specifically examine the differences among the crewmembers necessary to safely operate a UAS (e.g., RPIC, launch/recovery personnel, and VO) and requirements between the components and the corresponding training and certification requirements.

Future work examining the role of visual observers in UAS operations should investigate the value that VOs and mission commanders (MCs) bring to UAS operation of various sizes. While BVLOS operations are desirable in the imminent future, such flights may require VOs at the time of takeoff and landing, particularly near airports. Thus, there are numerous current and future scenarios in which pilots would need to offload see-and-avoid and/or communications responsibilities to another crewmember, like a VO or MC. As illustrated in Figure 2, UAS pilots typically communicate over multiple channels and may often need to relinquish see-and-avoid duties to VOs because of environmental or technological constraints. SSAT will be used to investigate function allocation and model crewmember interactions, with interest in illuminating how changes in workload associated with see-and-avoid and/or communications tasks effect UAS crewmembers' performance, in solo and team operations.

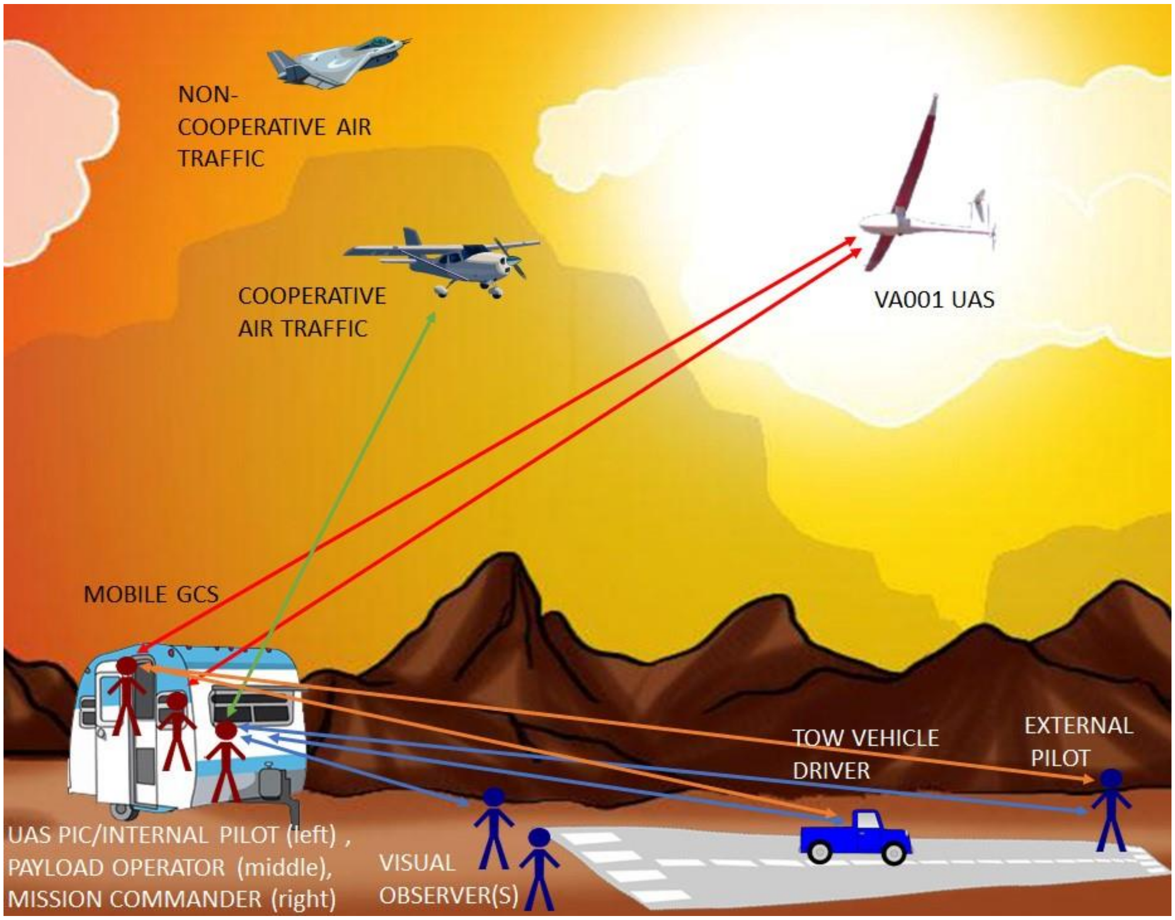

Figure 2. Diagram of crew and communication networks used during UAS operations when the PIC is in an enclosure and needs to rely on VO(s) to accomplish see-and-avoid duties. Colors represent different communication channels.

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APPENDIX A—FUNCTION ALLOCATION LITERATURE REVIEW

Carl Pankok, Jr. and Ellen J. Bass

APPENDIX B—FUNCTION ALLOCATION STRATEGY RECOMMENDATIONS

Carl Pankok, Jr., Ellen J. Bass, Philip J. Smith, Igor Dolgov, and Joel Walker

APPENDIX C—PLANNING LITERATURE REVIEW

Philip J. Smith and Amy Spencer

APPENDIX D—CONTROL STATION LITERATURE REVIEW

Carl Pankok, Jr., Ellen J. Bass, and Philip J. Smith

APPENDIX E—RECOMMENDATIONS OF MINIMUM CONTROL STATION HUMAN FACTORS CONSIDERATIONS

Carl Pankok, Jr. and Ellen J. Bass

APPENDIX F—UAS PILOT AND VISUAL OBSERVER TRAINING AND CERTIFICATION LITERATURE REVIEW

John Bridewell, Ernest Anderson, Robert Concannon, and Paul Cline

APPENDIX G—VISUAL OBSERVER CERTIFICATION AND TRAINING CRITERIA

Igor Dolgov