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

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ACKNOWLEDGEMENTS

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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."

   o "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:

o "As stated earlier, the UA containing multiple links is not really a higher LOA; it is another scenario entirely"
o "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	Control

			Automation	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			

Task	RPIC	VO	Alerting Automation	Control Automation
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			

Task				
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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