APPENDIX B—FUNCTION ALLOCATION STRATEGY RECOMMENDATIONS

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

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TABLE OF CONTENTS

LIST OF TABLES

EXECUTIVE SUMMARY

A7 Task 6, *Function Allocation Strategy and Future Research Recommendations*, provides minimum human-automation function allocation recommendations for aviating tasks for large (i.e., greater than 55 lb), fixed-wing unmanned aircraft (UA) operating at a non-towered airport with a dedicated visual observer (VO), including transition to/from IFR when outside the VO's visual line of sight limit. Using a task analysis to guide the work, minimum function allocation recommendations for each task in the task analysis were developed.

The task analysis yielded a series of functions grouped by phase of flight, including climb out, cruise, descent, and approach. For each task, we identified a recommended functional requirement as well as a minimum automation recommendation (the minimum automation recommendation was more technology-specific than the functional recommendation, which is capability-centered). We also provided rationale for the recommendations, noteworthy subject matter expert (SME) comments, potential safety implications, and potential higher and/or lower levels of automation for the minimum function allocation recommendation. Finally, we also provided an autonomous mode function allocation recommendation in the event of lost control link.

The recommendations were refined via feedback from pilot SMEs. To ensure that the SMEs were engaged in thinking about the tasks in context, they were asked specifically about winds because they are an important consideration for most flights. SMEs considered (1) does the task necessitate a regulation? (2) Do you agree with the recommendation? and (3) if wind is a relevant concern for the task, what automation is necessary to compensate for any human factors implications associated with operating the aircraft remotely? All SME feedback was compiled and incorporated into the recommendations by the authors.

Generally, SME feedback indicated that the remote pilot in command is able, at minimum, to safely operate the UAS with low levels of control automation, such as control via joystick or hands-on-throttle-and-stick. This recommendation assumes, however, timely and accurate delivery of information to between the UAS control station and UA. There was disagreement among SMEs regarding alerting functionality, such as alerts indicating that the UA is approaching an airspeed that is too fast for safe operation or that the UA is in danger of climbing/descending through a cleared altitude. The recommendations provided are expected to be used in the development of minimum information requirements and control station design guidelines in the subsequent ASSURE A7 and A10 project tasks.

1. INTRODUCTION

Task 6 of the A7 project addresses function allocation strategies and future research recommendations for unmanned aircraft system (UAS) human-machine functions. This work is informed by an analysis of what function allocation strategies are possible, a literature review, associated assumptions, a task analysis for non-mission-specific UAS flight aviating activities, and input from subject matter experts (SMEs). Feedback from Remote Pilot in Command (RPIC) SMEs is identified. Gaps in the literature and scenario contexts with implications for function allocation requirements are documented as suggested areas for future research. This work is guided by the scope presented in the *Task Scope* Section. The methodology for generating function allocation recommendations follows, and the tasks considered appear in the *Task Analysis* Section. The *Function Allocation Rubrics* Section contains general function allocation rubrics, which guided our function allocation recommendations appearing in the *Function Allocation Recommendations: Aviate* Section. The final section of the document contains future research recommendations.

2. SCOPE AND ASSUMPTIONS

The scope for the Task 6 recommendations is constrained to aviating functions in the climb out, cruise, descent, and approach phases of flight for larger-than-small UAS operating in an integrated National Airspace System (NAS). Unless otherwise noted, the use of *large* or *larger-than-small* in the remainder of the document will refer to a UA that is greater than 55 lb.

The recommendations were developed under the following scope:

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

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

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

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

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

A1. The RPIC does not simultaneously control any payload onboard the UA (note that activities related to aerial work are outside of the scope).
A2. A visual observer (VO) is used for takeoff and landing procedures due to the fact that they are occurring at a non-towered airport.
A3. 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).
A4. Each UA has a maximum crosswind component capability that limits the conditions under which it can depart or land.
A5. The airport has sufficient infrastructure (e.g., reliable power source, ATC communication, etc.) for operating the UAS.
A6. While there may be UAS which use alternative methods for control, like differential engine output and rudder, this document assumes the use of traditional manned aircraft controls, including flaps.

3. METHODOLOGY

A task analysis was conducted based on the scope and a set of assumptions driving the recommendations. The tasks developed as part of the task analysis were grouped into three basic task categories, and generic function allocation strategies were developed for each task category, ranging from manual control to minimal automation support to fully automated operation (see *Function Allocation Rubrics* Section). These general function allocation strategies drove the function allocation recommendations. The work presented in the document was reviewed by A7 team members and by SMEs with the following UAS operational experience:

- Michael Sean Brown: Sean's piloting experience includes over 20 years with major commercial airlines. His commercial experience includes both Boeing (727, 737, 747, 7770) and Airbus (A320) aircraft. He also served for 12 years as United States Air Force Pilot/Loadmaster for the C-130 transport aircraft.
- Joseph Millette: Joe is the Senior External UAS Pilot/Lead Safety Analyst at the Physical Science Lab at New Mexico State University's UAS Test Site. He has documented over 900 hours on the Tigershark/Viking UAS as an external pilot and payload operator, as well as over 400 flight hours with the Aerostar UAS, including both day and night operations. He is rated as a Commercial Pilot with both multi-engine and IFR ratings.
- Sean Moulton: Sean holds certificates as an Instructor/Evaluator Pilot for the RQ-4 UAS (Global Hawk), C-130/T-38/T-1 and is a USAF Weapons Instructor Graduate. He is a FAA rated pilot rated for Commercial Instrument with Single and Multi-Engine aircraft. He is a consultant leading unmanned system projects for the USAF Research Laboratory.

3.1 TASK ANALYSIS METHODOLOGY

A key step in the function allocation process is the identification of tasks. To identify the tasks required to achieve the system goal (i.e., operate a UAS safely and efficiently), a task analysis was conducted considering the assumptions. The task analysis was conducted via the creation of potential operational scenarios and the identification of associated tasks, adaptation of manned aircraft procedures to envisioned UA operations when appropriate, and validation by SMEs.

3.2 FUNCTION ALLOCATION METHODOLOGY

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

In the second step of the function allocation process, we generated function allocation rubrics for each task category based on the function allocation taxonomy (reproduced in Appendix B2) from

A7 Task 3 “Function allocation literature review.” These rubrics are reported in the *Function Allocation Rubrics* Section.

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 were designed toward the least amount of automation as possible to maintain safety in normal operations. For each task, SMEs were presented with a recommended potential function allocation strategy and were asked to provide an explanation for why the recommendation is or is not the minimum level of automation 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. All SME responses were recorded.

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

3.3 SME FEEDBACK METHODOLOGY

A preliminary version of the current document, in editable Microsoft Word format, was sent to the SMEs for their feedback. They were asked to provide feedback on the document. In order to guide gaining the feedback as well as to ensure engagement in reviewing the recommendations, SMEs were asked to consider the following:

- Do you feel strongly that this task necessitates a regulation requiring allocation to automation?
- Do you agree with the recommendation for minimum automation?
- 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 participant were used to augment the authors’ 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.

4. TASK ANALYSIS

The aviating tasks in the task analysis are presented in black and bold. Other tasks, such as navigation and communication tasks, are colored in gray. In the parenthesis accompanying the non-aviating tasks is the categorization of the task.

4.1 CLIMB OUT

1. Identify top of climb (TOC) (Navigate)
2. Facilitate handover of separation responsibility from VO to ATC (before UAV is BVLOS) (Communicate)
3. Update ATC communication frequency, as necessary (Communicate)
4. **Manage horizontal flight path**
5. **Manage altitude, particularly for any level-off altitudes**
6. **Manage vertical speed**
7. **Manage airspeed (V_Y), including the 250 KIAS limit below 10,000 ft.**
8. **Set altimeter for transition altitude and transition level, if necessary**

4.2 CRUISE

1. **Level off and maintain cruising altitude**
2. **Configure aircraft for cruise**
3. Communicate with ATC, as necessary (Communicate)
4. Update ATC communication frequency, as necessary (Communicate)
5. **Manage horizontal flight path**
6. **Manage altitude**
7. **Manage vertical speed**
8. **Manage airspeed**

4.3 DESCENT

1. Obtain airport data (e.g., determine runway) (Navigate)
2. Communicate with ATC to obtain descent clearance (Communicate)
3. Update ATC communication frequency, as necessary (Communicate)
4. Plan descent (Navigate)
    a. Determine descent profile (Navigate)
    b. Determine TOD (Navigate)
5. **Execute descent**
    a. Configure aircraft for descent
    b. Set external lights appropriately
    c. Manage horizontal flight path
    d. Manage vertical flight path and altitude, particularly for any level-off altitude
    e. Manage vertical speed (for safe descent)
    f. Manage airspeed (for speed constraints and safety of the aircraft)
    g. Set altimeter to local altimeter setting at the transition level, if necessary
6. Announce landing on the runway via Common Traffic Advisory Frequency (CTAF) (Communicate)
7. Submit missed approach profile and procedure (Contingency)
8. Facilitate handoff from ATC to VO (Communicate)

4.4 APPROACH

1. Plan approach and landing (Navigate)
    a. Identify touchdown target on first third of the runway (Navigate)
    b. Determine approach profile (e.g., descent rate, thrust, angle of descent, etc.) (Navigate)
2. **Execute approach given approach profile**
    a. **Configure UA for approach**
    b. **Manage horizontal flight path**
    c. **Manage vertical flight path and altitude**
    d. **Manage vertical speed**
    e. **Manage airspeed**

5. FUNCTION ALLOCATION RUBRICS

For each of the general task categories, a rubric was created for identifying potential function allocation strategy recommendations. The following subsections present the categories, descriptions, and the potential allocations for each category. Within each subsection, the relationship with the function allocation strategies in Appendix B2 is explained.

5.1 MONITORING AND SITUATION ASSESSMENT

Monitoring tasks represent both periodic monitoring (e.g., regular scanning of UAS displays) as well as monitoring in response to an action or alert (e.g., monitoring airspeed after increasing thrust). Monitoring tasks encompass only the information acquisition and information analysis stages of information processing. No decisions are generated or made in these stages; the information gained from monitoring is used to make decisions for the control tasks in the decision and action selection and action implementation stages. Potential human-automation function allocations are listed below, including a label for each function allocation description in italic text:

(a) *State*: Automation provides current UA state; RPIC compares UA state to target state, expected state, and/or threshold for safe operation.
(b) *Filtered State*: Automation provides current UA state 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; 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; 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. 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. 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 1. UAS automation provides the current UA state in all potential allocations because the RPIC does not have the ability to perceive UA state data directly.

Table 1. Examples of current UA state, target/expected state, and threshold for safe operation referenced in the potential function allocation strategies for monitoring tasks.

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

5.2 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, action selection, and action implementation stages of information processing. The agent that controls the UAS is continuously being informed by the agent performing the monitoring and/or planning tasks (note that the same human and/or automated agent could be performing all the functions). The potential allocations span from manual control of UA thrust and attitude to automated control of UA thrust and attitude to meet heading, speed, and altitude targets or to fly to waypoints uploaded to the UAS. Potential human-automation function allocations include:

(a) RPIC manipulates a UAS control input (thrust, roll, and/or pitch) to maintain target parameter (e.g., heading, vertical speed, airspeed). RPICs refer to this level of automation as *manual control*.
(b) RPIC controls a control input based on guidance provided by the automation. Guidance requires information analysis automation and decision and action selection automation. This type of automation is *flight guidance*.
(c) RPIC uploads target parameter (e.g., heading, airspeed, altitude, vertical speed); automation controls UA (surfaces and thrust) to maintain target. RPICs 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. RPICs 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.

5.3 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., put out flaps after the UA slows to V_{FE}); or (2) the RPIC (or automation) makes a discrete change and monitors a continuous process until a particular parameter is met.

Discrete control tasks occur in the decision and action selection and action implementation stages of information processing. 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, reported in Appendix B2.

Allocating the human RPIC and the automation to these roles, Table 2 reveals the potential function allocations for discrete control tasks. In addition to the function allocation strategies identified in Table 2, 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 2, the feedback strategy has been made explicit in the recommendations.

Table 2. Potential function allocations for UAS discrete control tasks.

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

6. FUNCTION ALLOCATION RECOMMENDATIONS: AVIATE

The subsections below contain recommendations for aviating tasks in the climb out, cruise, descent, and approach phases of flight. The recommendations are intended to be independent of the control interface (e.g., stick-and-throttle, joystick, glass cockpit interface, hand-held controller, etc.). In some allocations, the RPIC is assigned “manual control” of the UAS states such as bank angle, pitch, and thrust. Any reference to autonomous flight modes refers to instances in which the RPIC uploads parameters for determining a desired trajectory to the UAS (including waypoints, altitudes, speeds, and arrival times), and the UAS controls the appropriate surfaces, throttle, and/or systems to fly the uploaded route. The subsections are organized as follows:

- Functional requirement: recommendation for the capability that should be provided by the UAS.
- Minimum function allocation recommendation: Recommendation for minimum level of automation (LOA) for safe control during normal operations.

- Rationale for recommendation: Human factors perspective on the reasoning for the recommendation.
- SME comments: Feedback provided by SMEs on the recommendations.
- Potential safety implication(s): Implications for UAS and/or NAS safety related to the task and the LOA recommendation.
- Other potential LOAs: One or more higher or lower potential LOAs for the task.
- Autonomous mode function allocation recommendation: SME input suggested that large UAS should be equipped with autonomous capability due to the potential for lost link operations. Since the aircraft should have this capability for emergency situations, the autonomous mode should also be accessible to the RPIC. Therefore, we provide the LOA for each task for the autonomous mode, in addition to our recommendation for minimum LOA for safe control during normal operations.

6.1 CLIMB OUT

6.1.1 Manage Horizontal Flight Path

Functional requirement: The UAS should provide the RPIC with the ability to manage the horizontal flight path with a comparable degree of accuracy as required for manned aircraft operation (e.g., Advisory Circular 23.1311-1C Section 8.8). The UAS should also provide the RPIC with feedback on UA horizontal location.

Minimum function allocation recommendation: RPIC should be able to control UA trajectory to fly on the planned horizontal flight route without assistance from automation (continuous control function allocation strategy a, *manual control*).

Rationale: Aviating the aircraft is a top priority of the RPIC, and given the relative ease in conceptualization and visualization of the horizontal dimension, RPICs should be able to maintain the horizontal flight path manually. SME feedback indicates that the RPIC can manage the horizontal path of the UA via manual control inputs to the UAS, assuming that sufficient information is being delivered to the UA in a timely manner and there is not excessive latency for command and control.

SME comments: All SMEs agreed with the recommendation during this phase of flight.

- "The RPIC can operate the UAS flying in winds if (s)he is provided heading and track over ground. This is the way most aircraft have been flown for many years. There is not any automation required, it is just nicer and can reduce RPIC workload."
- "RPIC commands a 'heading' and the UA flies a track, which is the heading adjusted for winds. The course is a predetermined track between two waypoints (for the most part), so manually the pilot controls a heading to maintain a track to stay on the course."
- "Presentation of winds and significant changes in winds are critical to manual flight operations, a pilot should be proactive in manual flight with regard to winds and NOT reactive"
- Regarding the potential safety implications: "Cross-track error is part of a few different things that could cause a problem with the flight course, including overshooting waypoints, failure to account for drift or winds, incorrect waypoints, and/or wrong time at checkpoint."

- Regarding the autonomous mode recommendation: "Many systems have full automatic takeoff and landing (ATOL) capability."

Potential safety implication(s): Failure to maintain a proper horizontal flight path (e.g., large cross track error taking the UA outside of prescribed flight limits) could result in a collision with terrain, conflict with another aircraft or violate airspace requirements. Similarly, large latency either in delivery of position information to the control station, or delivery of commands to the UA, could result in the RPIC not being able make appropriate inputs.

Potential higher LOAs: (1) RPIC manually controls the horizontal path, and the control station calculates and presents to the RPIC the distance between the UA and the planned route. (2) RPIC manually controls the horizontal heading and is alerted when the UA's cross track error exceeds a threshold representing safe operation.

Autonomous mode function allocation recommendation: Automation controls the UA power and attitude to meet the planned horizontal flight path, providing real-time feedback on the horizontal trajectory (such as position, speed and heading). This reflects continuous control function allocation strategy a, *manual control*.

6.1.2 Manage Altitude, Particularly for Level-Off Altitudes

Functional requirement: The UAS should provide the RPIC with the ability to manage the UA altitude with a comparable degree of accuracy as required for manned aircraft operation (e.g., 14 CFR Part 43 Appendix E (b)(1)(ii)). The UAS should also provide the RPIC with feedback on UA altitude, and alert the RPIC if the UA is in danger of climbing through its cleared altitude. Automation should also provide an indication if the UA cannot achieve an altitude or maintain the minimum vertical profile required.

Minimum function allocation recommendation: The RPIC should be able to control UA power and attitude to meet an altitude target, and automation should alert the RPIC if the UA is in danger of climbing through the cleared level-off altitude. Automation should also inform the RPIC if the UA cannot reach an altitude or if the aircraft cannot maintain the minimum vertical profile required (continuous control function allocation strategy a, *manual control*; monitoring and situation assessment function allocation strategy g, *automated comparison and alert*).

Rationale: As a minimum requirement, automation should monitor the UA altitude and alert the RPIC if the UA becomes in danger of climbing through an altitude hold. Removing the pilot from the cockpit eliminates secondary cues (e.g., vestibular, kinesthetic) that the aircraft is leveling off. Furthermore, a primary mechanism of aircraft separation is altitude (as opposed to heading or speed; 14 CFR 91.159 and 14 CFR 91.179), increasing the criticality of flying the appropriate altitude compared to heading and airspeed.

SME comments: One SME disagreed with the recommendation during this phase of flight.

- Disagreement: "The RPIC should have the ability to climb and level the aircraft based on the altitude information displayed. There are many aircraft that do not have altitude alerting systems onboard. I recommend strategy (2) from the potential lower LOAs."
- "There should be an emphasis on altitude warnings for UAS operating in the NAS. So if I am operating a UAS and suddenly the UA has deviated from its cleared altitude by 100 feet, then I should get a mandatory warning, and the warning altitude should be available to me for quicker situational awareness. I think a two-level warning system might be most appropriate; for example, a caution at 50 ft deviation then a full warning at 100 ft."
- Regarding the autonomous mode recommendation: "Full automation can achieve this task with RPIC monitoring. This can reduce the workload of the RPIC. Manual override should be available for any autonomous flight in case of a failure."

Below are SME comments for managing altitude during other phases of flight.

- "I do not agree that we need automation to alert the RPIC. I would also say the system needs to provide the RPIC with the needed information, control, and feedback to level off at the desired altitude within a threshold number of feet. This value may need be adjusted for types of flight, but I would guess that +/- 200 ft. would be a typical number used."
- "The system needs to provide the RPIC with information, control, and feedback to be able to maintain the desired altitude within a defined threshold (probably +/- 200 ft.). This is similar to the altitude capture task for climb and descent, but the control and feedback can probably be at lower levels for maintaining altitude versus capture, which is more dynamic."
- Disagreement with the alerting functionality: "Pilots currently manage the vertical flight path via altimeter changes, vertical speed indicator, and external visual inputs."

Potential safety implication(s): The UA could climb through its cleared altitude and lose separation with another aircraft, potentially causing an incident or accident.

Potential lower LOAs: (1) RPIC manually controls the aircraft, and the UAS control station explicitly displays the difference between the UA's current altitude and its preselected altitude, but there is no alert. (2) RPIC manually controls the aircraft, and the UAS control station explicitly displays the UA's current altitude with no alerting functionality. (3) RPIC manually controls the aircraft and can sets limits that the automation will notify when violated.

Autonomous mode function allocation recommendation: Automation controls the UA power and attitude to meet the target altitude, providing real-time feedback on its status. This reflects continuous control function allocation strategy d. (RPIC should still be given indication if the automation cannot maintain altitude).

6.1.3 Manage Vertical Speed

Functional requirement: The UAS should provide the RPIC with the ability to manage UA vertical speed through control of aircraft thrust and attitude (pitch). The UAS should also provide the RPIC with feedback on UA vertical speed.

Minimum function allocation recommendation: The RPIC should be able to control UA thrust and attitude to control vertical speed without assistance from automation (continuous control function allocation strategy a, *manual control*).

Rationale: The RPIC's primary objective during climb is aviating the aircraft to a target altitude. Therefore, like our recommendation for managing altitude and airspeed, the pilot should be able to manually control the UA thrust and attitude to control vertical speed.

SME comments: One SME disagreed with the recommendation during this phase of flight.

- Disagreement: "The recommendation is slightly above minimum. I think the RPIC should also be able to control an angle and lift-to-drag ratio (L/D) maximum. Yes, both of those are a 'target speed' but different approaches and situations can desire these outcomes."
- One SME commented that having direct control over the vertical speed (i.e., uploading a vertical speed target to the UA) would be considered a higher-than-minimum recommendation: "I understand the rationale [for the original recommendation] but it is not required. As long as the UA can maintain greater than 500 fpm climb or descent, it meets ATC requirements. If the UA cannot maintain that level of climb or descent, it needs to be reported to ATC. Most aircraft do not have a means to set a vertical speed directly. The pilot does this by adjusting pitch angle, adjusting airspeed relative to thrust, or adjusting thrust relative to airspeed. I just want to make sure we don't say that a direct vertical speed control that allows for specific values to be entered is a minimum requirement."
- Regarding the autonomous mode recommendation: "Full automation can achieve this task with RPIC monitoring. This can reduce the workload of the RPIC. Manual override should be available for any autonomous flight in case of a failure."

Potential safety implication(s): An excessively large vertical speed increases the difficulty of meeting an altitude target, which could be problematic in terms of maintaining separation from other aircraft or climbing away from the ground (such as meeting noise abatement requirements). This is particularly the case when large latencies exist in transmitting information and commands between the control station and UA.

Potential higher LOAs: (1) UAS control station explicitly displays the difference between current vertical speed and target vertical speed. (2) UAS control station alerts the RPIC if vertical speed error reaches a threshold representing safe operation.

Autonomous mode function allocation recommendation: Automation controls the UA thrust and attitude to control vertical speed, providing real-time feedback on its status. This reflects continuous control function allocation strategy d.

6.1.4 Manage Airspeed

Functional requirement: The UAS should provide the RPIC with the ability to control the UA airspeed, as well as feedback on UA airspeed, and alert the RPIC when the UA approaches its stall speed or an over speeding condition.

Minimum function allocation recommendation: The RPIC should be able to control the airspeed without assistance from automation (e.g., V_Y). The UAS should alert the RPIC when UA airspeed approaches the stall speed or when it approaches over speeding (continuous control function allocation strategy a, *manual control*; monitoring and situation assessment function allocation strategy g, *automated comparison and alert*).

Rationale: Some manned aircraft are required to alert the pilot when the aircraft approaches its stall airspeed or when the aircraft approaches its maximum (structural limit or never exceed) speed; see 14 CFR 23.207(b) and 14 CFR 23.1303(e), respectively. In manned operations, when an aircraft approaches these speeds, the pilot is exposed to noises and vibrational cues that suggest the aircraft is traveling too fast or too slow; RPICs do not have exposure to these cues. Therefore, these alerts should also be required for the operation of UAS.

SME comments: One SME disagreed with the recommendation during this phase of flight.

- Disagreement: "I do believe [the alerting functionality] is a good idea, but manned aircraft are not required to provide this advisory feedback until the pilot gets close to stall, so it is difficult for me to say that it should be a minimum requirement."
    - "The pilot must be provided either obvious airframe type cues (e.g., buffeting) or a compelling alert (e.g., aural or stick shaker) with enough forwarding to provide correction prior to stall (there are FARs that provide the margins above stall for the warning)."
    - "[Rather than alerting, the control station should] provide adequate feedback to avoid stall (warning) and over speeding (speed display with adequate update rate). If feedback is not possible due to link latency, then autonomy could be utilized to enforce similar airspeed limits (i.e., RPIC sets an airspeed above stall (V_S + margin of safety) below which autonomy would take over to ensure the UA remains faster than the stall speed)."
- "You reference V_S and V_{MO}/M_{MO} which are for high performance aircraft 23.1303(e). Most aircraft use V_{NE} for maximum speed, but these rules are not the same across all aircraft types."
- "Automation should provide advisory notifications for when the RPIC selects unsafe airspeeds. For larger UAS, there is little reason the aircraft should exceed airspeed limits or stall."
- Regarding the autonomous mode recommendation: "Automation will adjust the power and attitude as required, but the RPIC should know how both of these are changing"

Below are SME comments for managing airspeed during other phases of flight.

- Disagreement: "'Alert' is an aviation buzz term. I would agree with stall speed warning since that is required for all aircraft either via fly quality cues or an overt system (e.g., horn, light, or stick shaker) but the over speed warning is only required for larger and more complete aircraft not general aviation. I wouldn't impose the over speed warning/alert as a requirement but would require the display to provide the information for the RPIC to determine this for himself/herself."

- "As the RPIC loses 'in the cockpit' cues, (s)he must be provided with other information. When a RPIC's body moves [in response to aircraft movements], it gives the RPIC 'trend' information that something is starting to change. So providing a layered information cueing system, example: as wind is changing, simply having a wind arrow change the text may not effectively keep the RPIC informed. So other cues may be needed, such as showing heading changes or course changes if corrections are not made."

Potential safety implication(s): Traveling above or below the cleared airspeed could lead to incidents or accidents with other aircraft. Operating the UA too close to the stall or maximum (structural limit or never exceed) airspeeds could lead to loss of aircraft control, resulting in collisions with terrain or other aircraft.

Potential lower LOAs: (1) RPIC controls the UAS manually and the control station explicitly displays the difference between the UA airspeed and both the stall and maximum (structural limit or never exceed) speeds. (2) RPIC controls the UAS manually and the control station displays only the UA airspeed.

Autonomous mode function allocation recommendation: Automation controls the thrust and UA attitude to meet the target airspeed; automation increases or decreases airspeed when airspeed approaches either the stall speed or the maximum (structural limit or never exceed) speed. The RPIC is also alerted when the UA approaches these speeds (continuous control function allocation strategy d).

6.1.5 Set Altimeter for Transition Altitude and Transition Level

Functional requirement: The UAS should provide the RPIC with the ability to monitor the UA altitude and set the altimeter at the transition altitude.

Minimum function allocation recommendation: The RPIC should be able to monitor the UA altitude and set the altimeter when the aircraft is passing through the transition altitude or transition level, such as 18,000 ft. during operations in the United States, without assistance from automation (discrete control function allocation strategy *a*).

Rationale: Since the RPIC is monitoring UA altitude as part of his/her regular scan pattern as the UA climbs to its cruising altitude, automation is not required to set the altimeter at the transition altitude.

SME comments: All SMEs agreed with the recommendation.

- "Agreed. I see that many UAS manufacturers forget the importance of this task."
- Regarding the autonomous mode recommendation: "I agree, there is no reason the UAS cannot complete this simple task in the background. I recommend the addition of the

system informing the pilot that the change has been made, not just for confirmation but also as a check and balance."

Potential safety implication(s): If the RPIC climbs through 18,000 ft. without setting the altimeter, (s)he risks operating the aircraft with the wrong altimeter setting (and flying at an incorrect flight level).

Potential higher LOAs: (1) UAS control station explicitly displays difference between UA altitude and 18,000 ft. (without any alerting), and the RPIC manually sets the altimeter. (2) UAS control station alerts the RPIC when the UA is approaching 18,000 ft. and the RPIC manually sets the altimeter when UA altitude achieves 18,000 ft.

Autonomous mode function allocation recommendation: Automation sets the altimeter when the UA achieves an altitude of 18,000 ft., and informs the RPIC that this has been completed (discrete control function allocation strategy *k*).

6.2 CRUISE

6.2.1 Level Off and Maintain Cruising Altitude

(Note: The recommendation for this task is similar to the climb out task *Manage Altitude, Particularly for Level-Off Altitudes*)

Functional requirement: The UAS should provide the RPIC with the ability to level off the UA and maintain cruise altitude with a comparable degree of accuracy as required for manned aircraft operation (e.g., 14 CFR Part 43 Appendix E (b)(1)(ii)). The UAS should also provide the RPIC with feedback on UA altitude, and provide an alert if the UA is in danger of climbing through the target altitude.

Minimum function allocation recommendation: The RPIC should be able to control UA thrust and attitude to meet an altitude target, and automation should alert the RPIC if the UA is in danger of climbing through the cleared level-off altitude (continuous control function allocation strategy a, *manual control*; monitoring and situation assessment function allocation strategy g, *automated comparison and alert*).

Rationale: As a minimum requirement, automation should monitor the UA altitude and alert the RPIC if the UA becomes in danger of climbing through an altitude hold. Removing the pilot from the cockpit eliminates secondary cues (e.g., vestibular, kinesthetic) that the aircraft is leveling off, potentially increasing the likelihood of an altitude bust. Furthermore, a primary mechanism of aircraft separation is altitude (as opposed to heading or speed; 14 CFR 91.159 and 14 CFR 91.179), increasing the criticality of flying the appropriate altitude compared to heading and airspeed.

SME comments: One SME disagreed with the recommendation during this phase of flight.

- Disagreement: "I do not agree that we need automation to alert the RPIC. I would also say the system needs to provide the RPIC with the needed information, control, and feedback to level off at the desired altitude within a threshold number of feet. This value may need be adjusted for types of flight, but I would guess that +/- 200 ft. would be a typical number used."

Below are SME comments for managing altitude during other phases of flight.

- "The RPIC should have the ability to climb and level the aircraft based on the altitude information displayed. There are many aircraft that do not have altitude alerting systems onboard. I recommend strategy (2) from the potential lower LOAs."
- "There should be an emphasis on altitude warnings for UAS operating in the NAS. So if I am operating a UAS and suddenly the UA has deviated from its cleared altitude by 100 feet, then I should get a mandatory warning, and the warning altitude should be available to me for quicker situational awareness. I think a two-level warning system might be most appropriate; for example, a caution at 50 ft deviation then a full warning at 100 ft."
- "The system needs to provide the RPIC with information, control, and feedback to be able to maintain the desired altitude within a defined threshold (probably +/- 200 ft.). This is similar to the altitude capture task for climb and descent, but the control and feedback can probably be at lower levels for maintaining altitude versus capture, which is more dynamic."
- Disagreement with the alerting functionality: "Pilots currently manage the vertical flight path via altimeter changes, vertical speed indicator, and external visual inputs."
- Regarding the autonomous mode recommendation: "Full automation can achieve this task with RPIC monitoring. This can reduce the workload of the RPIC. Manual override should be available for any autonomous flight in case of a failure."

<u>Potential safety implication(s)</u>: Climbing through the UA's cleared altitude or departing from a cruising altitude could result in an accident with another aircraft.

<u>Potential lower LOAs</u>: (1) RPIC manually controls the aircraft, and the UAS control station explicitly displays the difference between the UA's current altitude and its preselected altitude, but there is no alert. (2) RPIC manually controls the aircraft, and the UAS control station explicitly displays the UA's current altitude with no alerting functionality.

<u>Autonomous mode function allocation recommendation</u>: Automation controls the UA thrust and attitude to meet the target altitude, providing real-time feedback on its status. This reflects continuous control function allocation strategy d.

<u>6.2.2 Configure Aircraft for Cruise</u>

<u>Functional requirement</u>: The UAS should provide the RPIC the ability to configure the UA for cruise as well as feedback on the status/position of the relevant flight surfaces.

<u>Minimum function allocation recommendation</u>: The RPIC should be able to configure the UA for cruise without assistance from automation (discrete control function allocation strategy *a*).

Rationale: Since cruise is generally a lower-workload phase of flight, compared to other phases of flight, the RPIC should be able to manually manipulate the aircraft to put the UA into cruise configuration.

SME comments: All SMEs agreed with the recommendation.

Potential safety implication(s): Incorrect configuration could lead the aircraft to gradually drift to an incorrect altitude or flight level, potentially losing separation with another aircraft.

Potential higher LOA: Automation provides one or more recommendations for cruise configuration settings that maximize fuel efficiency or range efficiency.

Autonomous mode function allocation recommendation: Automation controls the UA thrust and trim to maintain the target altitude, providing real-time feedback on its status. This reflects discrete control function allocation strategy *d*.

6.2.3 Manage Horizontal Flight Path

(Note: The recommendation for this task is similar to the climb out task *Manage Horizontal Flight Path*)

Functional requirement: The UAS should provide the RPIC with the ability to manage the horizontal flight path with a comparable degree of accuracy as required for manned aircraft operation (e.g., Advisory Circular 23.1311-1C Section 8.8). The UAS should also provide the RPIC with feedback on UA horizontal location.

Minimum function allocation recommendation: RPIC should be able to control UA attitude to fly on the planned horizontal flight route without assistance from automation (continuous control function allocation strategy a, *manual control*).

Rationale: Aviating the aircraft is a top priority of the RPIC, and given the relatively lower workload compared to other phases of flight, RPICs should be able to manage the horizontal flight path manually.

SME comments: All SMEs agreed with the recommendation during this phase of flight. Below are SME comments for managing the horizontal flight plan during other phases of flight.

- "The RPIC can operate the UAS flying in winds if (s)he is provided heading and track over ground. This is the way most aircraft have been flown for many years. There is not any automation required, it is just nicer and can reduce RPIC workload."
- "RPIC commands a 'heading' and the UA flies a track, which is the heading adjusted for winds. The course is a predetermined track between two waypoints (for the most part), so manually the pilot controls a heading to maintain a track to stay on the course."
- "Presentation of winds and significant changes in winds are critical to manual flight operations, a pilot should be proactive in manual flight with regard to winds and NOT reactive"

- Regarding the potential safety implications: “Cross-track error is part of a few different things that could cause a problem with the flight course, including overshooting waypoints, failure to account for drift or winds, incorrect waypoints, and/or wrong time at checkpoint.”
- Regarding the autonomous mode recommendation: “Many systems have full automatic takeoff and landing (ATOL) capability.”

Potential safety implication(s): Large cross track error could result in a collision with terrain or other aircraft. Similarly, large latency either in delivery of position information to the control station, or delivery of commands to the UA, could result in large cross track error.

Potential higher LOAs: (1) RPIC manually controls the horizontal path, and the control station explicitly displays the distance between the UA and the planned route. (2) RPIC manually controls the horizontal path and is alerted when the UA’s cross track error exceeds a threshold representing safe operation. (3) Present cross track information and comparison to cross track limits.

Autonomous mode function allocation recommendation: Automation controls the UA thrust and attitude to meet the planned horizontal flight path, providing real-time feedback on the horizontal position and heading. This reflects continuous control function allocation strategy d.

6.2.4 Manage Altitude

(Note: The recommendation for this task is similar to the cruise task *Manage Horizontal Flight Path*)

Functional requirement: The UAS should provide the RPIC with the ability to manage the UA altitude with a comparable degree of accuracy as required for manned aircraft operation (e.g., 14 CFR Part 43 Appendix E (b)(1)(ii)). The UAS should also provide the RPIC with feedback on UA altitude.

Minimum function allocation recommendation: RPIC should be able to control UA thrust and attitude to meet a target altitude without assistance from automation (continuous control function allocation strategy a, *manual control*).

Rationale: Aviating the aircraft is a top priority of the RPIC, and given the relatively lower workload compared to other phases of flight, RPICs should be able to manage the UA altitude manually.

SME comments: All SMEs agreed with the recommendation during this phase of flight.

- “This section and the next could be stated as the system needs to provide the RPIC with information, control, and feedback to be able to maintain the desired altitude within a defined threshold (probably +/- 200 ft.). This is similar to the altitude capture task for climb and descent, but the control and feedback can probably be at lower levels for maintaining altitude versus capture, which is more dynamic.”

Below are SME comments for managing altitude during other phases of flight.

- "The RPIC should have the ability to climb and level the aircraft based on the altitude information displayed. There are many aircraft that do not have altitude alerting systems onboard. I recommend strategy (2) from the potential lower LOAs."
- "There should be an emphasis on altitude warnings for UAS operating in the NAS. So if I am operating a UAS and suddenly the UA has deviated from its cleared altitude by 100 feet, then I should get a mandatory warning, and the warning altitude should be available to me for quicker situational awareness. I think a two-level warning system might be most appropriate; for example, a caution at 50 ft deviation then a full warning at 100 ft."
- "I do not agree that we need automation to alert the RPIC. I would also say the system needs to provide the RPIC with the needed information, control, and feedback to level off at the desired altitude within a threshold number of feet. This value may need be adjusted for types of flight, but I would guess that +/- 200 ft. would be a typical number used."
- "Pilots currently manage the vertical flight path via altimeter changes, vertical speed indicator, and external visual inputs."
- Regarding the autonomous mode recommendation: "Full automation can achieve this task with RPIC monitoring. This can reduce the workload of the RPIC. Manual override should be available for any autonomous flight in case of a failure."

Potential safety implication(s): The airspace is structured such that altitude is a primary means of separating aircraft. Therefore, large altitude errors could result in a loss of separation with other aircraft. Furthermore, large latencies could delay the transmission of UA state to the control station (creating error in displayed information) or commands from the control station to the UA, resulting in a delayed maneuver and/or potential loss of separation with other aircraft.

Potential higher LOAs: (1) RPIC manually controls UA thrust and attitude, and the control station explicitly displays the difference between UA altitude and cruise altitude. (2) RPIC manually controls UA thrust and attitude, and is alerted when the UA's altitude error crosses a threshold representing safe operation.

Autonomous mode function allocation recommendation: Automation controls the UA thrust and attitude to meet the target cruise altitude, providing real-time feedback on the UA altitude. This reflects continuous control function allocation strategy d.

6.2.5 Manage Vertical Speed

(Note: The recommendation for this task is similar to the climb out task *Manage Vertical Speed*)

Functional requirement: The UAS should provide the RPIC with the ability to manage UA vertical speed through control of aircraft thrust and attitude (pitch). The UAS should also provide the RPIC with feedback on UA vertical speed.

Minimum function allocation recommendation: The RPIC should be able to control UA thrust and attitude to control vertical speed without assistance from automation (continuous control function allocation strategy a, *manual control*).

Rationale: In the vertical dimension, the RPIC's primary objective during cruise is maintaining the target cruise altitude. Therefore, similar to our recommendation for managing altitude and airspeed in the cruise phase of flight, the pilot should be able to manually control the UA thrust and attitude to meet a vertical speed target (which will be zero for much of the cruise phase of flight).

SME comments: All SMEs agreed with the recommendation during this phase of flight. Below are SME comments for managing vertical speed during other phases of flight.

- Disagreement: "The recommendation is slightly above minimum. I think the RPIC should also be able to control an angle and lift-to-drag ratio (L/D) maximum. Yes, both of those are a 'target speed' but different approaches and situations can desire these outcomes."
- One SME commented that having direct control over the vertical speed (i.e., uploading a vertical speed target to the UA) would be considered a higher-than-minimum recommendation: "I understand the rationale [for the original recommendation] but it is not required. As long as the UA can maintain greater than 500 fpm climb or descent, it meets ATC requirements. If the UA cannot maintain that level of climb or descent, it needs to be reported to ATC. Most aircraft do not have a means to set a vertical speed directly. The pilot does this by adjusting pitch angle, adjusting airspeed relative to thrust, or adjusting thrust relative to airspeed. I just want to make sure we don't say that a direct vertical speed control that allows for specific values to be entered is a minimum requirement."
- Regarding the autonomous mode recommendation: "Full automation can achieve this task with RPIC monitoring. This can reduce the workload of the RPIC. Manual override should be available for any autonomous flight in case of a failure."

Potential safety implication(s): The airspace is structured such that altitude is the primary means of separating aircraft, i.e., aircraft fly at different altitudes based on their direction of travel. Therefore, large altitude errors could result in a loss of separation with another aircraft. Furthermore, large latencies could delay the transmission of UA state to the control station or commands from the control station to the UA, resulting in a delayed maneuver and/or potential loss of separation.

Potential higher LOA: UAS control station alerts the RPIC if vertical speed error reaches a threshold representing safe operation.

Autonomous mode function allocation recommendation: Automation controls the UA thrust and attitude to meet the target vertical speed, providing real-time feedback on its status. This reflects continuous control function allocation strategy d.

6.2.6 Manage Airspeed

(Note: The recommendation for this task is similar to the climb out task *Manage Airspeed*)

Functional requirement: The UAS should provide the RPIC with the ability to control the UA airspeed, as well as feedback on UA airspeed, and alert the RPIC when the UA approaches its stall speed or an over speeding condition.

<u>Minimum function allocation recommendation</u>: The RPIC should be able to control the UA thrust and attitude to meet an airspeed target without assistance from automation. The UAS should alert the RPIC when UA airspeed approaches the stall speed or when it approaches the maximum (structural limit or never exceed) airspeed (continuous control function allocation strategy a, *manual control*; monitoring and situation assessment function allocation strategy g, *automated comparison and alert*).

<u>Rationale</u>: Some manned aircraft are required to alert the pilot when the aircraft approaches its stall airspeed or when the aircraft approaches its maximum (structural limit or never exceed) speed; see 14 CFR 23.207(b) and 14 CFR 23.1303(e), respectively. In manned operations, when an aircraft approaches these speeds, the pilot is exposed to noises and vibrational cues that suggest the aircraft is traveling too fast or too slow; RPICs do not have exposure to these cues. Therefore, these alerts should also be required for the operation of UAS.

<u>SME comments</u>: One SME disagreed with the recommendation during this phase of flight. Below are SME comments for managing airspeed during other phases of flight.

- Disagreement: "I do believe [the alerting functionality] is a good idea, but manned aircraft are not required to provide this advisory feedback until the pilot gets close to stall, so it is difficult for me to say that it should be a minimum requirement."
  - "The pilot must be provided either obvious airframe type cues (e.g., buffeting) or a compelling alert (e.g., aural or stick shaker) with enough forwarding to provide correction prior to stall (there are FARs that provide the margins above stall for the warning)."
  - "[Rather than alerting, the control station should] provide adequate feedback to avoid stall (warning) and over speeding (speed display with adequate update rate). If feedback is not possible due to link latency, then autonomy could be utilized to enforce similar airspeed limits (i.e., RPIC sets an airspeed above stall (V_S + margin of safety) below which autonomy would take over to ensure the UA remains faster than the stall speed)."
- "You reference V_S and V_{MO}/M_{MO} which are for high performance aircraft 23.1303(e). Most aircraft use V_{NE} for maximum speed, but these rules are not the same across all aircraft types."
- "Automation should provide advisory notifications for when the RPIC selects unsafe airspeeds. For larger UAS, there is little reason the aircraft should exceed airspeed limits or stall."
- Regarding the autonomous mode recommendation: "Automation will adjust the power and attitude as required, but the RPIC should know how both of these are changing."
- Disagreement: "'Alert' is an aviation buzz term. I would agree with stall speed warning since that is required for all aircraft either via fly quality cues or an overt system (e.g., horn, light, or stick shaker) but the over speed warning is only required for larger and more complete aircraft not general aviation. I wouldn't impose the over speed warning/alert as a requirement but would require the display to provide the information for the RPIC to determine this for himself/herself."
- "As the RPIC loses 'in the cockpit' cues, (s)he must be provided with other information. When a RPIC's body moves [in response to aircraft movements], it gives the RPIC 'trend'

information that something is starting to change. So providing a layered information cueing system, example: as wind is changing, simply having a wind arrow change the text may not effectively keep the RPIC informed. So other cues may be needed, such as showing heading changes or course changes if corrections are not made."

Potential safety implication(s): Traveling above or below the cleared airspeed could lead to incidents or accidents with other aircraft. Operating the UA too close to the stall or maximum (structural limit or never exceed) airspeeds could lead to loss of aircraft control, resulting in collisions with terrain or other aircraft.

Potential lower LOAs: (1) RPIC controls the UAS manually and the control station explicitly displays the difference between the UA airspeed and both the stall and maximum (structural limit or never exceed) speeds. (2) RPIC controls the UAS manually and the control station displays only the UA airspeed.

Autonomous mode function allocation recommendation: Automation controls the thrust and UA attitude to meet the target airspeed; automation increases or decreases airspeed when airspeed approaches either the stall speed or the maximum (structural limit or never exceed) speed. The RPIC is also alerted when the UA approaches these speeds (continuous control function allocation strategy d).

6.3 DESCENT

6.3.1 Configure Aircraft for Descent

(Note: The recommendation for this task is similar to the cruise task *Configure Aircraft for Cruise*)

Functional requirement: The UAS should provide the RPIC with the ability to configure the aircraft for descent as well as the status/position of relevant flight surfaces.

Minimum function allocation recommendation: RPIC should be able to adjust flight control surfaces and/or thrust to configure the UA for descent without assistance from automation (discrete control function allocation strategy *a*).

Rationale: Manned aircraft PICs can manually configure the aircraft for descent, and there is little implication for conducting this task remotely compared to being in the aircraft cockpit (except for the potential for latency). Therefore, as in manned aircraft, the RPIC should be able to configure the aircraft for a given descent profile.

SME comments: All SMEs agreed with the recommendation.

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

Potential higher LOA: Automation provides one or more recommendations for descent configuration settings to achieve the descent objective of efficiently descending to the destination airport.

Autonomous mode function allocation recommendation: Automation configures the aircraft to meet the descent profile and alerts the RPIC, reflecting discrete control function allocation strategy *f*.

6.3.2 Set External Lights Appropriately

(Note: This task was added to the task analysis after the report was sent to the SMEs, but it was addressed in the A10 CS-1 document. This recommendation is based on the similar A10 tasks)

Functional requirement: The UAS should provide the RPIC with the ability to manipulate UA external lighting as well as feedback on whether the lights are on or off.

Minimum function allocation recommendation: RPIC should be able to manipulate UA external lighting without assistance from automation (discrete control function allocation strategy *a*).

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

SME comments: All A10 SMEs agreed with the recommendation.

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

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

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

6.3.3 Manage Horizontal Flight Path

(Note: The recommendation for this task is similar to the climb out task *Manage Horizontal Flight Path*)

Functional requirement: The UAS should provide the RPIC with the ability to manage the horizontal flight path with a comparable degree of accuracy as required for manned aircraft operation (e.g., Advisory Circular 23.1311-1C Section 8.8). The UAS should also provide the RPIC with feedback on the UA horizontal location.

<u>Minimum function allocation recommendation</u>: RPIC should be able to control UA attitude to fly on the planned horizontal flight route without assistance from automation (continuous control function allocation strategy a, *manual control*).

<u>Rationale</u>: Aviating the aircraft is a top priority of the RPIC, and given the relative ease in conceptualization and visualization of the horizontal dimension, RPICs should be able to manage the horizontal flight path manually. Feedback from two SMEs indicates that the RPIC can manage the horizontal path of the UA via manual control inputs to the UAS. This assumes that sufficient information is being delivered to the UA in a timely manner and there is not excessive latency for command and control.

<u>SME comments</u>: All SMEs agreed with the recommendation during this phase of flight. Below are SME comments for managing the horizontal flight plan during other phases of flight.

- "The RPIC can operate the UAS flying in winds if (s)he is provided heading and track over ground. This is the way most aircraft have been flown for many years. There is not any automation required, it is just nicer and can reduce RPIC workload."
- "RPIC commands a 'heading' and the UA flies a track, which is the heading adjusted for winds. The course is a predetermined track between two waypoints (for the most part), so manually the pilot controls a heading to maintain a track to stay on the course."
- "Presentation of winds and significant changes in winds are critical to manual flight operations, a pilot should be proactive in manual flight with regard to winds and NOT reactive"
- Regarding the potential safety implications: "Cross-track error is part of a few different things that could cause a problem with the flight course, including overshooting waypoints, failure to account for drift or winds, incorrect waypoints, and/or wrong time at checkpoint."
- Regarding the autonomous mode recommendation: "Many systems have full automatic takeoff and landing (ATOL) capability."

<u>Potential safety implication(s)</u>: Large cross track error could result in a collision with terrain or other aircraft. Similarly, large latency either in delivery of position information to the control station, or delivery of commands to the UA, could result in large cross track error.

<u>Potential higher LOAs</u>: (1) RPIC manually controls the horizontal path, and the control station calculates and presents to the RPIC the distance between the UA and the planned route. (2) RPIC manually controls the horizontal path and is alerted when the UA's cross track error crosses a threshold representing safe operation. (3) UAS can provide max descent, enroute descent and RPIC specified descent.

<u>Autonomous mode function allocation recommendation</u>: Automation controls the UA thrust and attitude to meet the planned horizontal flight path, providing real-time feedback on the horizontal position and heading. This reflects continuous control function allocation strategy d.

<u>6.3.4 Manage Vertical Flight Path and Altitude</u>

(Note: The recommendation for this task is similar to the climb out task *Manage Altitude, Particularly for Level-Off Altitudes*)

__Functional requirement__**: The UAS should provide the RPIC the ability to manage the vertical flight path with a comparable degree of accuracy as required for manned aircraft operation (e.g., 14 CFR Part 43 Appendix E (b)(1)(ii)). The UAS should also provide the RPIC with feedback on UA altitude, and alert the RPIC is the UA is in danger of descending through the target level-off altitude.**

__Minimum function allocation recommendation__**: The RPIC should be able to control UA thrust and attitude to meet an altitude target, and automation should alert the RPIC if the UA is in danger of descending through the cleared level-off altitude (continuous control function allocation strategy a, *manual control*; monitoring and situation assessment function allocation strategy g, *automated comparison and alert*).**

__Rationale__: As a minimum requirement, automation should monitor the UA altitude and alert the RPIC if the UA becomes in danger of descending through an altitude hold. Removing the pilot from the cockpit eliminates secondary cues (e.g., vestibular, kinesthetic) that the aircraft is leveling off, potentially increasing the likelihood of an altitude bust. Furthermore, a primary mechanism of aircraft separation is altitude (as opposed to heading or speed; 14 CFR 91.159 and 14 CFR 91.179), increasing the criticality of flying the appropriate altitude compared to heading and airspeed.

__SME comments__: One SME disagreed with the recommendation during this phase of flight. Below are SME comments for managing altitude during other phases of flight.

- Disagreement: “The RPIC should have the ability to climb and level the aircraft based on the altitude information displayed. There are many aircraft that do not have altitude alerting systems onboard. I recommend strategy (2) from the potential lower LOAs.”
- “There should be an emphasis on altitude warnings for UAS operating in the NAS. So if I am operating a UAS and suddenly the UA has deviated from its cleared altitude by 100 feet, then I should get a mandatory warning, and the warning altitude should be available to me for quicker situational awareness. I think a two-level warning system might be most appropriate; for example, a caution at 50 ft deviation then a full warning at 100 ft.”
- Disagreement: “I do not agree that we need automation to alert the RPIC. I would also say the system needs to provide the RPIC with the needed information, control, and feedback to level off at the desired altitude within a threshold number of feet. This value may need be adjusted for types of flight, but I would guess that +/- 200 ft. would be a typical number used.”
- “The system needs to provide the RPIC with information, control, and feedback to be able to maintain the desired altitude within a defined threshold (probably +/- 200 ft.). This is similar to the altitude capture task for climb and descent, but the control and feedback can probably be at lower levels for maintaining altitude versus capture, which is more dynamic.”
- Disagreement with the alerting functionality: “Pilots currently manage the vertical flight path via altimeter changes, vertical speed indicator, and external visual inputs.”
- Regarding the autonomous mode recommendation: “Full automation can achieve this task with RPIC monitoring. This can reduce the workload of the RPIC. Manual override should be available for any autonomous flight in case of a failure.”

Potential safety implication(s): The higher level of workload associated with operating the aircraft in descent (compared to cruise) could lead to the UA descending through its cleared altitude and losing separation with another aircraft, potentially causing an accident. In addition, it may be difficult to manage UA energy in descent, particularly under high wind conditions, where it may be more difficult to meet an altitude restriction at a particular fix.

Potential lower LOAs: (1) RPIC manually controls the aircraft, and the UAS control station explicitly displays the difference between the UA's current altitude and its preselected altitude, but there is no alert. (2) RPIC manually controls the aircraft, and the UAS control station explicitly displays the UA's current altitude with no alerting functionality.

Autonomous mode function allocation recommendation: Automation controls the UA thrust and attitude to meet the target altitude, providing real-time feedback on its status. This reflects continuous control function allocation strategy d.

6.3.5 Manage Vertical Speed

(Note: The recommendation for this task is similar to the climb out task *Manage Vertical Speed*)

Functional requirement: The UAS should provide the RPIC with the ability to manage UA vertical speed through control of aircraft thrust at attitude (pitch). The UAS should also provide the RPIC with feedback on UA vertical speed.

Minimum function allocation recommendation: The RPIC should be able to control UA thrust and attitude to control vertical speed without assistance from automation (continuous control function allocation strategy a, *manual control*).

Rationale: The RPIC's primary objective during descent is aviating the aircraft to a target altitude and location to begin approach. Therefore, like our recommendation for managing altitude and airspeed, the pilot should be able to manually control the UA thrust and attitude to meet a vertical speed target.

SME comments: One SME disagreed with the recommendation during this phase of flight. Below are SME comments for managing vertical speed during other phases of flight.

- Disagreement: "The recommendation is slightly above minimum. I think the RPIC should also be able to control an angle and lift-to-drag ratio (L/D) maximum. Yes, both of those are a 'target speed' but different approaches and situations can desire these outcomes."
- One SME commented that having direct control over the vertical speed (i.e., uploading a vertical speed target to the UA) would be considered a higher-than-minimum recommendation: "I understand the rationale [for the original recommendation] but it is not required. As long as the UA can maintain greater than 500 fpm climb or descent, it meets ATC requirements. If the UA cannot maintain that level of climb or descent, it needs to be reported to ATC. Most aircraft do not have a means to set a vertical speed directly. The pilot does this by adjusting pitch angle, adjusting airspeed relative to thrust, or adjusting thrust relative to airspeed. I just want to make sure we don't say that a direct

vertical speed control that allows for specific values to be entered is a minimum requirement."

- Regarding the autonomous mode recommendation: "Full automation can achieve this task with RPIC monitoring. This can reduce the workload of the RPIC. Manual override should be available for any autonomous flight in case of a failure."

Potential safety implication(s): An excessively large vertical speed increases the difficulty of meeting an altitude target, which could be problematic in terms of maintaining separation from other aircraft. This is particularly the case when large latencies exist in transmitting information and commands between the control station and UA.

Potential higher LOAs: (1) UAS control station explicitly displays the difference between current vertical speed and target vertical speed. (2) UAS control station alerts the RPIC if vertical speed error reaches a threshold representing safe operation. (3) UAS control station will show future state of airspeed after pilot sets thrust and attitude.

Autonomous mode function allocation recommendation: Automation controls the UA thrust and attitude to meet the target vertical speed, providing real-time feedback on its status. This reflects continuous control function allocation strategy d.

6.3.6 Manage Airspeed

(Note: The recommendation for this task is similar to the climb out task *Manage Airspeed*)

Functional requirement: The UAS should provide the RPIC with the ability to control the UA airspeed, as well as feedback on UA airspeed, and alert the RPIC when the UA approaches its stall speed or an over speeding condition.

Minimum function allocation recommendation: The RPIC should be able to control the UA thrust and attitude to meet an airspeed target without assistance from automation. The UAS should alert the RPIC when UA airspeed approaches the stall speed or when it approaches the maximum (structural limit or never exceed) airspeed (continuous control function allocation strategy a, *manual control*; monitoring and situation assessment function allocation strategy g, *automated comparison and alert*).

Rationale: Manned aircraft are required to alert the pilot when the aircraft approaches its stall airspeed or when the aircraft approaches its maximum (structural limit or never exceed) speed; see 14 CFR 23.207(b) and 14 CFR 23.1303(e), respectively. In manned operations, when an aircraft approaches these speeds, the pilot is exposed to noises and vibrational cues that suggest the aircraft is traveling too fast or too slow; RPICs do not have exposure to these cues. Therefore, these alerts should also be required for the operation of UAS.

SME comments: One SME disagreed with the recommendation during this phase of flight. Below are SME comments for managing airspeed during other phases of flight.

- Disagreement: "I do believe [the alerting functionality] is a good idea, but manned aircraft are not required to provide this advisory feedback until the pilot gets close to stall, so it is difficult for me to say that it should be a minimum requirement."
    - "The pilot must be provided either obvious airframe type cues (e.g., buffeting) or a compelling alert (e.g., aural or stick shaker) with enough forwarding to provide correction prior to stall (there are FARs that provide the margins above stall for the warning)."
    - "[Rather than alerting, the control station should] provide adequate feedback to avoid stall (warning) and over speeding (speed display with adequate update rate). If feedback is not possible due to link latency, then autonomy could be utilized to enforce similar airspeed limits (i.e., RPIC sets an airspeed above stall (V_S + margin of safety) below which autonomy would take over to ensure the UA remains faster than the stall speed)."
- "You reference V_S and V_{MO}/M_{MO} which are for high performance aircraft 23.1303(e). Most aircraft use V_{NE} for maximum speed, but these rules are not the same across all aircraft types."
- "Automation should provide advisory notifications for when the RPIC selects unsafe airspeeds. For larger UAS, there is little reason the aircraft should exceed airspeed limits or stall."
- Regarding the autonomous mode recommendation: "Automation will adjust the power and attitude as required, but the RPIC should know how both of these are changing."
- Disagreement: "'Alert' is an aviation buzz term. I would agree with stall speed warning since that is required for all aircraft either via fly quality cues or an overt system (e.g., horn, light, or stick shaker) but the over speed warning is only required for larger and more complete aircraft not general aviation. I wouldn't impose the over speed warning/alert as a requirement but would require the display to provide the information for the RPIC to determine this for himself/herself."
- "As the RPIC loses 'in the cockpit' cues, (s)he must be provided with other information. When a RPIC's body moves [in response to aircraft movements], it gives the RPIC 'trend' information that something is starting to change. So providing a layered information cueing system, example: as wind is changing, simply having a wind arrow change the text may not effectively keep the RPIC informed. So other cues may be needed, such as showing heading changes or course changes if corrections are not made."

<u>Potential safety implication(s)</u>: Energy management is extremely important during descent, so airspeeds that are too fast or too slow could result in inability to land on the desired runway as planned. Traveling above or below the cleared airspeed could lead to incidents or accidents with other aircraft. Operating the UA too close to the stall or maximum (structural limit or never exceed) airspeeds could lead to loss of aircraft control, resulting in collisions with terrain or other aircraft.

<u>Potential lower LOAs</u>: (1) RPIC controls the UAS manually and the control station explicitly displays the difference between the UA airspeed and both the stall and maximum (structural limit or never exceed) speeds. (2) RPIC controls the UAS manually and the control station displays only the UA airspeed.

Autonomous mode function allocation recommendation: Automation controls the thrust and UA attitude to meet the target airspeed; automation increases or decreases airspeed when airspeed approaches either the stall speed or the maximum (structural limit or never exceed) speed. The RPIC is also alerted when the UA approaches these speeds (continuous control function allocation strategy d).

6.3.7 Set Altimeter to Local Altimeter Setting at the Transition Level

(Note: The recommendation for this task is similar to the climb out task *Set Altimeter for Transition Altitude and Transition Level*)

Functional requirement: The UAS should provide the RPIC with the ability to monitor the UA flight level and set the altimeter at the transition level.

Minimum function allocation recommendation: The RPIC should be able to monitor the UA altitude and set the altimeter when the aircraft reaches the transition level without assistance from automation (discrete control function allocation strategy *a*).

Rationale: Since the RPIC is monitoring UA altitude as part of his/her regular scan pattern as the UA climbs to its cruising altitude, automation is not required to set the altimeter when the aircraft reaches FL180.

SME comments: All SMEs agreed with the recommendation. Below are SME comments for setting the altimeter during other phases of flight.

- "Agreed. I see that many UAS manufacturers forget the importance of this task."
- Regarding the autonomous mode recommendation: "I agree, there is no reason the UAS cannot complete this simple task in the background. I recommend the addition of the system informing the pilot that the change has been made, not just for confirmation but also as a check and balance."

Potential safety implication(s): If the RPIC descends through FL180 without setting the altimeter, (s)he risks operating the aircraft with the wrong altimeter setting. Similarly, if the control station loses its command and control link, there will need to be on-board automation to set the altimeter, so that the UA flying its contingency route will be flying at the proper flight level.

Potential higher LOAs: (1) UAS control station explicitly displays difference between UA flight level and FL180 (without any alerting), and the RPIC manually sets the altimeter. (2) UAS control station alerts the RPIC when the UA is approaching FL180 and the RPIC manually sets the altimeter when UA altitude achieves FL180.

Autonomous mode function allocation recommendation: Automation sets the altimeter when the UA achieves FL180, and informs the RPIC that this has been completed (discrete control function allocation strategy *k*).

6.4 APPROACH

6.4.1 Configure UA for Approach

Functional requirement: The UAS should provide the RPIC with the ability to configure the UA for approach as well as the status/position of relevant flight surfaces.

Minimum function allocation recommendation: RPIC should be able to configure the UA as necessary to control UA speed and altitude on approach (discrete control function allocation strategy *a*).

Rationale: Continual feedback of the status/position of the relevant flight surfaces (e.g., flaps) should be provided so that the RPIC can ensure that the airspeed is not too fast for the current or desired configuration. Since this task is not substantially different for RPICs compared to manned aircraft pilots, a low level of control automation is required for a RPIC to manipulate the flaps during approach.

SME comments: All SMEs agreed with the recommendation.

Potential safety implication(s): Since there are speed restrictions associated with certain configurations and flap settings, the RPIC needs to be continually informed of the configuration and flap position. Otherwise, structural damage could result, potentially making it more difficult to aviate and/or land the UA.

Potential higher LOA: The RPIC manually configures the UA for approach, and automation alerts the RPIC if the airspeed is at or near the structural limit of the flap setting.

Autonomous mode function allocation recommendation: Automation manipulates the flaps and the control station provides continual feedback on the flap position, reflecting discrete control function allocation strategy *f*.

6.4.2 Manage Horizontal Flight Path

(Note: The recommendation for this task is similar to the descent task *Manage Horizontal Flight Path*)

Functional requirement: The UAS should provide the RPIC with the ability to manage the horizontal flight path with a comparable degree of accuracy as required for manned aircraft operation (e.g., Advisory Circular 23.1311-1C Section 8.8). The UAS should also provide the RPIC with feedback on the UA horizontal location.

Minimum function allocation recommendation: RPIC should be able to control UA attitude to fly on the planned horizontal flight route without assistance from automation (continuous control function allocation strategy a, *manual control*).

Rationale: Aviating the aircraft is a top priority of the RPIC, and given the relative ease in conceptualization and visualization of the horizontal dimension, RPICs should be able to manage the horizontal flight path manually. Feedback from two SMEs indicates that the RPIC can manage the horizontal path of the UA via manual control inputs to the UAS. This assumes that sufficient information is being delivered to the UA in a timely manner and there is not excessive latency for command and control. This is particularly critical for approach, where wind conditions can force the UA off the planned approach route, and crabbing into the wind could position an onboard camera such that the runway is not in view of the camera.

SME comments: All SMEs agreed with the recommendation during this phase of flight. Below are SME comments for managing the horizontal flight plan during other phases of flight.

- "The RPIC can operate the UAS flying in winds if (s)he is provided heading and track over ground. This is the way most aircraft have been flown for many years. There is not any automation required, it is just nicer and can reduce RPIC workload."
- "RPIC commands a 'heading' and the UA flies a track, which is the heading adjusted for winds. The course is a predetermined track between two waypoints (for the most part), so manually the pilot controls a heading to maintain a track to stay on the course."
- "Presentation of winds and significant changes in winds are critical to manual flight operations, a pilot should be proactive in manual flight with regard to winds and NOT reactive"
- Regarding the potential safety implications: "Cross-track error is part of a few different things that could cause a problem with the flight course, including overshooting waypoints, failure to account for drift or winds, incorrect waypoints, and/or wrong time at checkpoint."
- Regarding the autonomous mode recommendation: "Many systems have full automatic takeoff and landing (ATOL) capability."

Potential safety implication(s): Large cross track error could result in a collision with terrain or other aircraft. Similarly, large latency either in delivery of position information to the control station, or delivery of commands to the UA, could result in large cross track error. It is possible for the UA to miss the runway to the left or right if the cross-track error is large enough.

Potential higher LOAs: (1) RPIC manually controls the horizontal path, and the control station calculates and presents to the RPIC the distance between the UA and the planned route or runway centerline. (2) RPIC manually controls the horizontal path and is alerted when the UA's cross track error exceeds a threshold representing safe operation.

Autonomous mode function allocation recommendation: Automation controls the UA thrust and attitude to meet the planned horizontal flight path, providing real-time feedback on the horizontal position and heading. This reflects continuous control function allocation strategy d.

6.4.3 Manage Vertical Flight Path and Altitude

(Note: The recommendation for this task is similar to the descent task *Manage Vertical Flight Path and Altitude*)

Functional requirement: The UAS should provide the RPIC the ability to manage the vertical flight path with a comparable degree of accuracy as required for manned aircraft operation (e.g., 14 CFR Part 43 Appendix E (b)(1)(ii)). The UAS should also provide the

RPIC with feedback on the UA altitude, and alert the RPIC is the UA is in danger of descending through the target level-off altitude.

Minimum function allocation recommendation**: The RPIC should be able to control UA thrust and attitude to descend to the runway, and automation should alert the RPIC if the UA is descending too quickly to the runway (continuous control function allocation strategy a, *manual control*; monitoring and situation assessment function allocation strategy g, *automated comparison and alert*).**

Rationale: As a minimum requirement, automation should monitor the UA altitude and alert the RPIC if the UA is descending too quickly to the runway. Latencies in receiving the UA altitude as well as in command and control of the UA can make it difficult to conduct an approach, where the margin of error for descending to a runway is much smaller than for climbing to a target altitude or flying a planned route in cruise. Furthermore, it may be difficult to ascertain altitude and rate of descent from a fixed forward-view camera, making it difficult to interpret the status of the UA in relation to the runway. These human factors issues are exacerbated in wind conditions, which force quick decision and control manipulations (relative to climb or cruise phases of flight) to keep the aircraft on the path of the runway. Since the RPIC is not exposed to the auditory, vestibular, and kinesthetic cues associated with landing in wind conditions, the latency in delivering this information to the control station could make it impossible to manually manage the vertical flight path.

SME comments: One SME disagreed with the recommendation during this phase of flight.

- Disagreement with the alerting functionality: "Pilots currently manage the vertical flight path via altimeter changes, vertical speed indicator, and external visual inputs."

Below are SME comments for managing altitude during other phases of flight.

- Disagreement: "The RPIC should have the ability to climb and level the aircraft based on the altitude information displayed. There are many aircraft that do not have altitude alerting systems onboard. I recommend strategy (2) from the potential lower LOAs."
- "There should be an emphasis on altitude warnings for UAS operating in the NAS. So if I am operating a UAS and suddenly the UA has deviated from its cleared altitude by 100 feet, then I should get a mandatory warning, and the warning altitude should be available to me for quicker situational awareness. I think a two-level warning system might be most appropriate; for example, a caution at 50 ft deviation then a full warning at 100 ft."
- Disagreement: "I do not agree that we need automation to alert the RPIC. I would also say the system needs to provide the RPIC with the needed information, control, and feedback to level off at the desired altitude within a threshold number of feet. This value may need be adjusted for types of flight, but I would guess that +/- 200 ft. would be a typical number used."
- "The system needs to provide the RPIC with information, control, and feedback to be able to maintain the desired altitude within a defined threshold (probably +/- 200 ft.). This is similar to the altitude capture task for climb and descent, but the control and feedback can probably be at lower levels for maintaining altitude versus capture, which is more dynamic."

- Disagreement with the alerting functionality: "Pilots currently manage the vertical flight path via altimeter changes, vertical speed indicator, and external visual inputs."
- Regarding the autonomous mode recommendation: "Full automation can achieve this task with RPIC monitoring. This can reduce the workload of the RPIC. Manual override should be available for any autonomous flight in case of a failure."

Potential safety implication(s): The higher level of workload associated with operating the aircraft in descent (compared to cruise) could lead to the UA climbing through its cleared altitude and losing separation with another aircraft, potentially causing an accident.

Potential lower LOAs: (1) RPIC manually controls the aircraft, and the UAS control station explicitly displays the difference between the UA's current altitude and its preselected altitude, but there is no alert. (2) RPIC manually controls the aircraft, and the UAS control station explicitly displays the UA's current altitude with no alerting functionality.

Autonomous mode function allocation recommendation: Automation controls the UA thrust and attitude to meet the target altitude, providing real-time feedback on its status. This reflects continuous control function allocation strategy d.

6.4.4 Manage Vertical Speed

(Note: The recommendation for this task is similar to the descent task *Manage Vertical Speed*)

Functional requirement: The UAS should provide the RPIC with the ability to manage UA vertical speed through control of aircraft thrust and attitude (pitch). The UAS should also provide the RPIC with feedback on the UA vertical speed.

Minimum function allocation recommendation: The RPIC should be able to control UA thrust and attitude to meet the vertical speed required for safe operation (continuous control function allocation strategy a, *manual control*).

Rationale: The RPIC's primary objective during approach is aviating the aircraft to the destination runway. Therefore, like our recommendation for managing altitude and airspeed, the pilot should be able to manually control the UA thrust and attitude to meet a vertical speed target.

SME comments: All SMEs agreed with the recommendation during this phase of flight. Below are SME comments for managing vertical speed during other phases of flight.

- Disagreement: "The recommendation is slightly above minimum. I think the RPIC should also be able to control an angle and lift-to-drag ratio (L/D) maximum. Yes, both of those are a 'target speed' but different approaches and situations can desire these outcomes."
- One SME commented that having direct control over the vertical speed (i.e., uploading a vertical speed target to the UA) would be considered a higher-than-minimum recommendation: "I understand the rationale [for the original recommendation] but it is not required. As long as the UA can maintain greater than 500 fpm climb or descent, it meets ATC requirements. If the UA cannot maintain that level of climb or descent, it needs to be reported to ATC. Most aircraft do not have a means to set a vertical speed directly.

The pilot does this by adjusting pitch angle, adjusting airspeed relative to thrust, or adjusting thrust relative to airspeed. I just want to make sure we don't say that a direct vertical speed control that allows for specific values to be entered is a minimum requirement."

- Regarding the autonomous mode recommendation: "Full automation can achieve this task with RPIC monitoring. This can reduce the workload of the RPIC. Manual override should be available for any autonomous flight in case of a failure."

Potential safety implication(s): An excessively large vertical speed increases the difficulty of safe landing. This is particularly the case when large latencies exist in transmitting information and commands between the control station and UA.

Potential higher LOAs: (1) UAS control station explicitly displays the difference between current vertical speed and target vertical speed. (2) UAS control station alerts the RPIC if vertical speed error reaches a threshold representing safe operation

Autonomous mode function allocation recommendation: Automation controls the UA thrust and attitude to meet the target vertical speed, providing real-time feedback on its status. This reflects continuous control function allocation strategy d.

6.4.5 Manage Airspeed

(Note: The recommendation for this task is similar to the descent task *Manage Airspeed*)

Functional requirement: The UAS should provide the RPIC with the ability to control the UA airspeed, as well as feedback on the UA airspeed, and alert the RPIC when the UA approaches its stall speed or an over speeding condition.

Minimum function allocation recommendation: The RPIC should be able to control the UA thrust and attitude to meet an airspeed target (e.g., V_{REF}). The UAS should alert the RPIC when UA airspeed approaches the stall speed or when it approaches the maximum (structural limit or never exceed) airspeed (continuous control function allocation strategy a, *manual control*; monitoring and situation assessment function allocation strategy g, *automated comparison and alert*).

Rationale: Manned aircraft are required to alert the pilot when the aircraft approaches its stall airspeed or when the aircraft approaches its maximum (structural limit or never exceed) speed; see 14 CFR 23.207(b) and 14 CFR 23.1303(e), respectively. In manned operations, when an aircraft approaches these speeds, the pilot is exposed to noises and vibrational cues that suggest the aircraft is traveling too fast or too slow; RPICs do not have exposure to these cues. Therefore, these alerts should also be required for the operation of UAS.

SME comments: One SME disagreed with the recommendation during this phase of flight.

- Disagreement: "'Alert' is an aviation buzz term. I would agree with stall speed warning since that is required for all aircraft either via fly quality cues or an overt system (e.g., horn, light, or stick shaker) but the over speed warning is only required for larger and more complete aircraft not general aviation. I wouldn't impose the over speed warning/alert as a requirement but would require the display to provide the information for the RPIC to determine this for himself/herself."

- "As the RPIC loses 'in the cockpit' cues, (s)he must be provided with other information. When a RPIC's body moves [in response to aircraft movements], it gives the RPIC 'trend' information that something is starting to change. So providing a layered information cueing system, example: as wind is changing, simply having a wind arrow change the text may not effectively keep the RPIC informed. So other cues may be needed, such as showing heading changes or course changes if corrections are not made."

Below are SME comments for managing airspeed during other phases of flight.

- Disagreement: "I do believe [the alerting functionality] is a good idea, but manned aircraft are not required to provide this advisory feedback until the pilot gets close to stall, so it is difficult for me to say that it should be a minimum requirement."
    - "The pilot must be provided either obvious airframe type cues (e.g., buffeting) or a compelling alert (e.g., aural or stick shaker) with enough forwarding to provide correction prior to stall (there are FARs that provide the margins above stall for the warning)."
    - "[Rather than alerting, the control station should] provide adequate feedback to avoid stall (warning) and over speeding (speed display with adequate update rate). If feedback is not possible due to link latency, then autonomy could be utilized to enforce similar airspeed limits (i.e., RPIC sets an airspeed above stall (V_S + margin of safety) below which autonomy would take over to ensure the UA remains faster than the stall speed)."
- "You reference V_S and V_{MO}/M_{MO} which are for high performance aircraft 23.1303(e). Most aircraft use V_{NE} for maximum speed, but these rules are not the same across all aircraft types."
- "Automation should provide advisory notifications for when the RPIC selects unsafe airspeeds. For larger UAS, there is little reason the aircraft should exceed airspeed limits or stall."
- Regarding the autonomous mode recommendation: "Automation will adjust the power and attitude as required, but the RPIC should know how both of these are changing."

Potential safety implication(s): Energy management is extremely important during approach, so airspeeds that are too fast or too slow could result in inability to land on the desired runway as planned. Traveling above or below the cleared airspeed could lead to incidents or accidents with other aircraft, or result in the inability to safely land the UA on the runway. Operating the UA too close to the stall or maximum (structural limit or never exceed) airspeeds could lead to loss of aircraft control, resulting in collisions with terrain or other aircraft.

Potential lower LOAs: (1) RPIC controls the UAS manually and the control station explicitly displays the difference between the UA airspeed and both the stall and maximum (structural limit or never exceed) speeds. (2) RPIC controls the UAS manually and the control station displays only the UA airspeed.

Autonomous mode function allocation recommendation: Automation controls the thrust and UA attitude to meet the target airspeed; automation increases or decreases airspeed when airspeed approaches either the stall speed or the maximum (structural limit or never exceed) speed. The RPIC is also alerted when the UA approaches these speeds (continuous control function allocation strategy d).

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(s) to which the task is allocated in the recommendations. Note that no tasks are allocated to a visual observer (VO) or control automation, as SME feedback suggested that the tasks could be performed safely by the RPIC and/or alerting automation.

7.1 CLIMB OUT

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

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

7.2 CRUISE

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

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

7.3 DESCENT

Table 5. Overview of function allocation recommendations for aviate tasks during the descent phase of flight.

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

7.4 APPROACH

Table 6. Overview of function allocation recommendations for aviate tasks during the approach phase of flight.

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

8. RECOMMENDATIONS FOR FUTURE RESEARCH

Areas for future research for the safe integration of UAS into the NAS are addressed in this section. Based on direction from the FAA, this work did not consider all phases of flight and all types of tasks:

- Function allocation recommendations for ground-based and airborne detect and avoid (DAA) systems
- Human-automation function allocation strategies for pre-flight planning
- Human-automation function allocation strategies for communication with VO and/or ATC
- Human-automation function allocation strategies for navigation

With respect to contingency operations, there could be many types (if applicable) not already mentioned such as an aircraft without transponder, a bird strike, brake problems, crew incapacitation, hydraulic problems, in-flight fire, landing gear problems, and power problems (engine or electrical).

There are a range of contexts (and combinations of the contexts) on function allocation recommendations that need to be addressed in future work:

- Rotorcraft or VTOL aircraft
- Different aircraft characteristics (including modes of control)
- Inability to fly standard airport patterns
- Takeoff that does not require a runway (e.g., catapult or launcher)
- Landing that does not require a runway (e.g., net or sky hook)
- RPIC located outdoors with visual sight lines of the runway
- Takeoff and landing without VOs
- Takeoff and landing at towered vs. non-towered airports
- Takeoff and landing at a high density vs. low density airports
- Operation in high density vs. low density airspace
- VFR vs. IFR flights in different phases of flight

In addition, the range of scenarios considered for UAS operations should be expanded. Some scenarios that were discussed in the development of this work included the following:

- Rotorcraft at non-towered airport with RPIC off site
- Fixed wing aircraft at low volume towered airport with RPIC on site
- Rotorcraft at low volume towered airport with RPIC on site
- Fixed wing aircraft at high volume towered airport with RPIC on site
- Rotorcraft at high volume towered airport with RPIC on site

Finally, although we assume the use of VOs for takeoff and landing, SME comments have suggested that there may be cases in which VOs may not be necessary at low-density towered or non-towered airports. As one RPIC indicated, "As camera, automation, and workstation technologies mature, the UAS will be able to meet a minimum level of safety without the use of VOs." Therefore, future work should investigate and identify situations for which VOs are necessary.

It would be useful to consider whether new or different recommendations would be developed for these scenarios.

Future work should consider whether the recommendations are dependent on the airspace class traversed.

There are a set of aircraft states that may be difficult to discern and input from a VO might be necessary. As mentioned one state that may require automation due to time criticality is the takeoff itself. Thus, future work should consider what level of automation support is required for the RPIC to know that the takeoff was successful.

In the research presented here, we do not explicitly specify a control interface for our recommendations (the recommendations are intended to be independent of specific control interface guidance). Future work should assess any interaction between our function allocation recommendations and differing control interfaces.

We do not explicitly specify a communication medium for our recommendations. Differing function allocation strategies could have differing implications on communication mediums (e.g., data link communications require visual processing resources, while radio communication requires auditory processing resources). Future work should assess any interaction between levels of automation and the communication medium.

Specific communication phraseology was not a part of the A7 scope. Procedures and phraseology for RPIC communication with ATC, VO, CTAF, UNICOM, etc. in various contexts would reduce potential miscommunication. In addition, planning, procedures, and phraseology for communications including handing off separation responsibility between VO and ATC should be addressed in future work.

The environmental context in which the UAS operates can impact safety. For example, terrain and winds could impact UAS operations in different situations. Future research should consider:

- UAS terrain awareness/avoidance automation and the contexts in which RPICs may require terrain information.
- RPIC performance with varying automation strategies supporting taking off and landing with crosswinds

The ability for the RPIC to manage systems is critical to safety. SME feedback revealed that RPICs are more concerned about energy management during descent and landing. Levels of automation for energy management should be addressed in future work.

9. REFERENCES

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10. APPENDIX B1: ASSUMPTIONS FOR COMMUNICATION FUNCTIONS AND VO

Communication:

1. RPICs have the same communication access to ATC, CTAF, and Automatic Terminal Information Service (ATIS), etc. as manned aircraft.
2. The VO does not have a direct communication line with ATC; the VO is able to monitor ATC communication, but all communication with ATC must be coordinated through the RPIC. This assumption is based on observations of present-day VO procedures and communication.
    a. The transfer-of-separation-responsibility point for climb out is agreed upon prior to takeoff and the transfer-of-separation-responsibility point for approach is agreed upon prior to approach. The transfer of control point must be within the VO's VLOS.
3. During approach to a non-towered airport, the RPIC should make all standard traffic pattern calls, including entering downwind, turning base, and established on final approach, as applicable.

Visual Observers:

1. The VO cannot monitor multiple UAVs simultaneously.
2. The VO should have distance visual acuity of 20/20 or better (with or without corrective lenses), normal color vision, and normal hearing acuity.
3. VOs should be positioned in areas with an unobstructed view of the airport surface and sky, taking into account the position of the sun, glare from reflections off buildings or other objects, and signs or other large obstructions.
4. The VO should have the capability to monitor applicable local CTAF, departure, approach, and tower frequencies.
5. The VO should be aware of the location of flight corridors relative to his/her position
6. The VO should be within the RPIC's audible range or, otherwise, have the capability to communicate via radio.

11. APPENDIX B2: FUNCTION ALLOCATION TAXONOMY

Information Acquisition Automation

Table 7 summarizes the information acquisition automation taxonomy. Information acquisition automation addresses sensing/presentation of data where no calculations or other forms of data manipulation are performed. On one end of the spectrum is no automation where all sensing is handled by a human such as when a visual observer may acquire information about the environment with no assistance. The category of "assisted" refers to the case where some technology collects and potentially enhances the sensing such as with night vision goggles. Processed data presentation includes the situation where automation may acquire and process the sensed data for display. It also includes remote sensing. Mixed initiative data presentation includes situations where the human can control some portion of the data presentation including what data are included (such as with filtering). Because information acquisition can address a single data stream or may include data from more than one source, the taxonomy considers both the single and multiple information source cases.

Table 7. Taxonomy for information acquisition automation.

Number of Sources	Level of Automation	Description
Single Information Source	None	Human perceives information from one data source with no assistance from the automation
	Assisted	Device enhances the signal from one data source
	Processed Data Presentation	Automation presents signal processed data from one data source to the human
	Mixed Initiative Data Presentation	Automation presents signal processed data from one data source to the human, subject to constraints specified by the human
Multiple Information Sources	None	Human perceives information from multiple data sources with no assistance from the automation
	Assisted	Device enhances the signal from multiple data sources
	Processed Data Presentation	Automation presents signal processed data from multiple data sources to the human
	Mixed Initiative Data Presentation	Automation presents signal processed data from multiple data sources to the human, subject to constraints specified by the human

Information Analysis Automation

Information analysis automation can assist humans in making assessments by processing the acquired information. The assessment may be of some current or future state. Information analysis automation can function in many ways, such as: (1) converting raw data into an easier-to-understand form; (2) comparing sensor data to databases or models to aid in the assessment; (3)

using statistical and pattern recognition techniques to highlight trends; and (4) assembling multiple sources of information into a single assessment (Bass & Pritchett, 2008). To make an assessment, a human and/or the automation may need to compare a value to a reference. The reference value itself may be fixed or situation-specific and may be under control of the human, the automation or both. Information analysis automation is often a component of an alerting system that can integrate multiple sources of information to make an assessment of the potential hazard (Bass, Ernst-Fortin, Small, & Hogans Jr, 2004; Dingus et al., 1997; Pritchett, 2001; Seagull & Sanderson, 2001).

Table 8 summarizes the information analysis automation taxonomy. It separates the analysis into the assessment of a value and the determination of the reference value to use for comparison.

Table 8. Taxonomy of information analysis automation.

Level of Automation	Description
None	No automation
Mixed Initiative Reference Generation	The human makes the assessment; the automation makes the comparison to the reference but the human can constrain the reference
Automated Reference Generation	The human makes the assessment; the automation makes the comparison to the reference
Automated Situation Assessment	The automation makes the assessment; the human makes the comparison to the reference
Automated Situation Assessment and Reference Generation	The automation makes the assessment; the automation makes the comparison to the reference
Automated Situation Assessment and Reference Generation with Alerting	The automation makes the assessment; the automation makes the comparison to the reference and generates an alert
Automated Situation Assessment and Mixed Initiative Reference Generation	The automation makes the assessment; the automation makes the comparison to the reference but the human can constrain the reference
Automated Situation Assessment and Mixed Initiative Reference Generation with Alerting	The automation makes the assessment; the automation makes the comparison to the reference and generates an alert but the human can constrain the reference
Mixed Initiative Situation Assessment	The automation makes the assessment but the human can constrain the solution; the human makes the comparison to the reference
Mixed Initiative Situation Assessment and Automated Reference Generation	The automation makes the assessment but the human can constrain the solution; the automation makes the comparison to the reference
Mixed Initiative Situation Assessment and Automated Reference Generation with Alerting	The automation makes the assessment but the human can constrain the solution; the automation makes the comparison to the reference and generates an alert

Mixed Initiative Situation Assessment and Reference Generation	The automation makes the assessment but the human can constrain the solution; the automation makes the comparison to the reference but the human can constrain the reference
Mixed Initiative Situation Assessment and Reference Generation with Alerting	The automation makes the assessment but the human can constrain the solution; the automation makes the comparison to the reference and generates an alert but the human can constrain the reference

Decision and Action Selection Automation

Decision and action selection automation addresses generating and selecting among a set of action alternatives. For function allocation we use a modified version of the Sheridan and Verplank (1978) taxonomy where the mixed initiative interaction is explicit. Table 9 summarizes the decision and action selection automation.

Table 9. Taxonomy of decision and action selection automation.

Level of Automation	**Description**
None	Human generates potential decision/action options and chooses an option
Assisted Option Generation	Human generates potential decision/action options subject to constraints set by the automation
Automated Option Generation	Automation generates potential decision/action options; human chooses an option
Filtered Option Generation	Automation generates a subset of the potential decision/action options; human chooses an option
Automated Option Ordering	Automation generates potential decision/action options and ranks them; human chooses an option
Mixed Initiative Option Generation	Automation generates potential decision/action options subject to constraints set by the human; human chooses an option
Management by Consent	Automation generates potential decision/action options and chooses an option; RPIC accepts or rejects option
Management by Exception	Automation generates potential decision/action options and chooses an option; human has a time window to reject option before it is selected
Mixed Initiative Decision Selection	Automation generates potential decision/action options subject to constraints set by the human; automation chooses an option
Fully Automated Decision Selection	Automation generates potential decision/action options and chooses an option without human involvement

Action Implementation Automation

The action implementation stage of processing includes which agent implements the action (human vs. automation), as well as the level of feedback provided by the automation to a human if the automation implements the action. Table 10 summarizes the action implementation automation.

Table 10. Taxonomy of action implementation automation.

Level of Automation	**Description**
None	Human implements action
Compulsory Feedback	Automation implements action and necessarily informs human
Feedback by Request	Automation implements action and informs the human if requested by the RPIC
Feedback by Design	Automation implements action and informs the human only if it decides to inform the human
No Feedback	Automation implements action and does not inform the human

12. APPENDIX B3: FUNCTION ALLOCATION RUBRICS

Communication

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 allocations are listed in Table 11. 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 11. Function Allocation Recommendations Strategies for Communication.

Label	**Determine appropriate time to communicate** (Information Analysis Automation)	**Generate message** (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

Planning

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

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