

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

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## EXECUTIVE SUMMARY

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

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

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

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

## 1. INTRODUCTION

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

## 2. SCOPE AND ASSUMPTIONS

The recommendations were developed under the following scope:

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

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

- R1. RPICs comply with existing, adapted, and/or new operating rules or procedures as a prerequisite for NAS integration.
- R2. Civil UAS operating in the NAS must obtain an appropriate airworthiness certificate while public users retain their responsibility to determine airworthiness.
- R3. All UAS file and fly an IFR flight plan.
- R4. All UAS are equipped with ADS-B (Out) and transponder with altitude-encoding capability. This requirement is independent of the FAA's rule-making for ADS-B (Out).
- R5. UAS meet performance and equipage requirements for the environment in which they are operating and adhere to the relevant procedures.
- R6. Each UAS has a flight crew appropriate to fulfill the operators' responsibilities, and includes a RPIC. Each RPIC controls only one UA.

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

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

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

### 3. METHODOLOGY

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

#### 3.1 TASK ANALYSIS METHODOLOGY

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

### 3.2 FUNCTION ALLOCATION METHODOLOGY

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

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

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

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

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

### 3.3 SME FEEDBACK METHODOLOGY

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

Table 1. Subject matter expert professional experience.

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

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

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

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

#### 4. TASK ANALYSIS

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

##### 4.1 TAXI OUT

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

##### 4.2 TAKEOFF

- 1. Position aircraft for takeoff in the appropriate configuration**
2. Communicate with VO to ensure runway is clear for takeoff (Communicate)

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

#### 4.3 LANDING

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

#### 4.4 TAXI IN

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

### 5. FUNCTION ALLOCATION RUBRICS

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

## 5.1 PLANNING TASKS

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

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

## 5.2 MONITORING AND SITUATION ASSESSMENT TASKS

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

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

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

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

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

<b>Current UA State</b>	<b>Target/Expected State</b>	<b>Threshold for Safe Operation</b>
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 $\pm 200$ ft. from altitude clearance
Heading	Heading to next waypoint	N/A
Position	Planned route	N/A

### 5.3 CONTINUOUS CONTROL TASKS

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

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

### 5.4 DISCRETE CONTROL TASKS

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

slows to  $V_{FE}$ ); or (2) the RPIC (or automation) makes a discrete change and monitors a continuous process until a particular parameter is met.

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

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

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

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

<b>Strategy</b>	<b>Generate One Or More Action Options</b>	<b>Select an Action Option</b>	<b>Evaluate Selection</b>	<b>Execute Selection</b>
<i>a</i>	RPIC	RPIC	RPIC	RPIC
<i>b</i>	RPIC	RPIC	Automation	RPIC
<i>c</i>	Automation	RPIC	RPIC	RPIC

<i>d</i>	Automation (constrained by RPIC)	RPIC	RPIC	RPIC
<i>e</i>	Automation	RPIC	Automation	RPIC
<i>f</i>	Automation (constrained by RPIC)	RPIC	Automation	RPIC
<i>g</i>	Automation	Automation	RPIC	RPIC
<i>h</i>	Automation	Automation (constrained by RPIC)	RPIC	RPIC
<i>i</i>	Automation	Automation	Automation	RPIC
<i>j</i>	Automation	Automation (constrained by RPIC)	Automation	RPIC
<i>k</i>	Automation	Automation	Automation	Automation

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

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

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

### 6.1 TAXI OUT

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

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

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

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

SME comments: All SMEs agreed with the recommendation.

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

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

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

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

6.1.2 Ensure instruments, avionics, and navigation equipment are functioning properly and are ready for flight

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

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

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

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

- Comments from disagreements:

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

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

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

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

### 6.1.3 Perform brake check

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

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

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

SME comments: All SMEs agreed with the recommendation.

- “We used brake servo feedback as our initial and specific brake check, and then checked the dead man switch once the UA was moving to ensure the controls were working properly.”

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

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

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

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

#### 6.1.4 Control UA speed along taxi route

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

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

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

SME comments: All SMEs agreed with the recommendation.

- “I am not sure how much value a nose camera adds here. I need a speed indicator for manual control. Some airports have specific taxi speed limitations; a nose camera does not provide ample feedback to ensure compliance. Another point to consider with nose cameras

is that the FAA established a precedent by indicating that such devices do not meet sense and avoid criteria. While a nose camera enhances situation awareness, I'm not sure of the value associated with making it a minimum piece of equipment.”

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

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

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

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

#### 6.1.5 Control UA track along taxi route

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

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

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

Rationale: Assuming the control station delivers information on the UA position in relation to the taxiway and taxi route (e.g., via video feed of a forward-looking camera video or other method for providing the required position awareness and view of the environment ahead of the UA) and an indication of UA speed, and there is not substantial latency in the transfer of information between the UA and the control station, the RPIC should be able to manually control the UA track along its taxi route similar to taxi operation in manned operation. If a method for providing the required

position awareness and view of the environment ahead of the UA is used, the field of view of the camera video or other position awareness sensor has to be sufficient to support the view of the ground and area ahead of the UA so that the pilot can see information referenced by external agents and avoid obstacles.

SME comments: One SME disagreed with the recommendation.

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

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

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

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

#### 6.1.6 Monitor UA trajectory for obstacles

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

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

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

SME comments: All SMEs agreed with the recommendation.

- “I strongly concur with the use of a VO for providing clearance from both stationary and fixed obstacles during ground movement.”
- “The real challenge is to avoid any obstacle, whether built in (structures), aircraft traffic, ground equipment, or even animals. With the proper equipment and training, the UA can taxi with visibility as low as 600 ft., although 1200 to 600 exceptions are more common. In these conditions, the tower (and potentially the VO) cannot see the aircraft and the pilot

can only (poorly) see 600 ft. ahead. At 10 kt. taxi, this would give approximately 18 sec. to stop based on visual perception alone. Other situation awareness sensors can be used to increase this time and provide a greater degree of SA during taxi.”

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

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

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

#### 6.1.7 Configure UA for takeoff

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

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

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

SME comments: All SMEs agreed with the minimum recommendation.

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

just set the flaps at 30 or 45 degrees, it will set the flaps at 31.22222345 degrees to find the most accurate setting for the conditions provided.”

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

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

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

#### 6.1.8 Check for proper flight control surface movement

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

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

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

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

SME comments: All SMEs agreed with the recommendation.

- “I concur with the philosophy. Since the RPIC will not be able to visually confirm control surface movement, it may be good to do this with either the crew chief or VO prior to taxi. This is common with larger manned aircraft.”
- “I really would stay away from using specific methods/technologies. Cameras are probably how most will do this but if we put it here it will become the only way it can be done. There are also several aircraft on which you cannot see the control surfaces being moved during

the check. The only reference for the pilot is the feel/feedback through the control column or a control through display in the flight station.”

- “There are large UAS designs that do not let the pilot exercise movement of controls; they use a method prior to taxi to have all the controls show deflection.”
- Regarding potential higher levels of automation: “Why can’t there be sensors that indicate a problem with the control surfaces? I have flown a UA with this capability. This seems more reliable than a video camera. This is a good example of an area where the traditional manned method may not be as good as the potential afforded by automation.”

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

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

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

#### 6.1.9 Turn on required lights

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

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

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

SME comments: All SMEs agreed with the recommendation.

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

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

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

## 6.2 TAKEOFF

### 6.2.1 Position aircraft for takeoff in the appropriate configuration

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

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

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

SME comments: All SMEs agreed with the recommendation.

- “Requiring engagement of the brakes on the runway assumes the UA must center and stop on the runway prior to applying takeoff power. Although a common practice, I do not think applying the brakes for this task should be a requirement. For example, a RPIC may position the UA from the hold short line, obtain the runway centerline and apply takeoff power without braking or stopping on the active runway.”
- “Performing this task does not always require visual cues. I have performed takeoffs using only instruments with only the next runway light visible. While an extreme, there are takeoffs where it is based more on instruments for heading, and visual cues for the location laterally (relative to runway centerline) on the runway.”
- Regarding the autonomous mode recommendation:
  - “In a highly-automated system, the UA would have the airfield data available, including runway headings. Typically, there will be waypoints on the runway to show centerline deviation.”
  - “If the mission plan is already loaded is based on the take-off runway, the RPIC does not upload the runway heading to the UAS. The aircraft is using GPS coordinates to taxi out to the centerline and align with runway heading. Even if the UAS is being taxied manually, the RPIC would not upload a runway heading to the UAS.”

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

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

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

## 6.2.2 Takeoff roll

### 6.2.2.1 Smoothly advance power to takeoff (full) thrust

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

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

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

SME comments: All SMEs agreed with the recommendation.

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

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

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

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

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

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

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

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

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

SME comments: All SMEs agreed with the recommendation.

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

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

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

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

### 6.2.2.3 Maintain runway centerline

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

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

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

SME comments: All SMEs agreed with the recommendation.

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

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

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

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

### 6.2.3 Monitor UA airspeed in relation to scheduled takeoff speeds

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

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

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

SME comments: All SMEs agreed with the recommendation.

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

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

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

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

#### 6.2.4 Lift off/rotate

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

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

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

SME comments: All SMEs agreed with the recommendation.

- “The recommendation can be interpreted to imply that the VO should announce when the UA is airborne. During this critical phase of flight, I would do this only by exception; the RPIC should have indications of the aircraft being airborne, such as a positive indication

on the VSI and an increase in altitude—both common to manned pilot IFR departure procedures.”

- “Rotating a UA could be as simple as the RPIC rotating to a known pitch setting based on the weight and configuration for that aircraft.”
- “The autonomous mode takes into account temperature, air density, weight and selects the perfect rotate speed to climb away at. Some aircraft start in a “hiked” position and don’t require a rotation as it lifts off based on the angle of attack it is at during the takeoff roll.”

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

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

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

## 6.2.5 Initial climb

### 6.2.5.1 Check for positive rate of climb

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

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

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

SME comments: All SMEs agreed with the recommendation.

- “This does not need to be performed with a Vertical Speed Indicator (VSI); it can just be the altimeter reading starts to increase.”

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

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

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

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

#### 6.2.5.2 Configure UA for climb out

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

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

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

SME comments: All SMEs agreed with the recommendation.

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

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

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

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

## 6.3 LANDING

### 6.3.1 Configure UA for landing

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

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

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

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

SME comments: All SMEs agreed with the recommendation.

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

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

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

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

### 6.3.2 Landing decision

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

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

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

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

SME comments: All SMEs agreed with the recommendation.

- “I concur with the assertion that the landing phase of flight is the most difficult. I believe there is research that confirms the majority of UAS accidents involving pilot error occur during landing. While manual landings should be feasible, this is probably the most critical phase of flight where automation can enhance safe operations.”

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

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

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

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

### 6.3.3 Reduce power to thrust required for landing

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

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

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

SME comments: All SMEs agreed with the recommendation.

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

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

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

#### 6.3.4 Ensure UA is in a safe location for landing

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

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

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

SME comments: All SMEs agreed with the recommendation.

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

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

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

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

### 6.3.5 Perform landing/touchdown

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

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

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

SME comments: All SMEs agreed with the recommendation.

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

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

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

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

### 6.3.6 Maintain runway centerline

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

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

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

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

SME comments: All SMEs agreed with the recommendation.

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

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

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

### 6.3.7 Slow UA to taxi speed

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

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

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

SME comments: All SMEs agreed with the recommendation.

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

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

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

### 6.3.8 Determine runway turn-off

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

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

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

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

SME comments: All SMEs agreed with the recommendation.

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

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

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

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

#### 6.3.9 Turn UA off runway

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

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

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

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

SME comments: All SMEs agreed with the recommendation.

- “A 360-degree virtual reality camera could be used to promote a higher level of situation awareness. This would add a higher level of safety to allow the pilot added information regarding runway turnoff.”

- “If the autonomous mode is relying on GPS coordinates from mission plan, the UA is limited to the exits the aircraft can take, and if the UA misses the exits in landing roll, it often will need to be towed off the runway.”

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

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

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

## 6.4 TAXI IN

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

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

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

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

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

SME comments: All SMEs agreed with the recommendation.

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

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

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

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

#### 6.4.2 Configure UA for taxi

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

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

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

SME comments: All SMEs agreed with the minimum recommendation.

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

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

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

#### 6.4.3 Control UA speed along taxi route

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

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

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

SME comments: All SMEs agreed with the recommendation.

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

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

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

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

#### 6.4.4 Control UA track along taxi route

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

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

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

SME comments: One SME disagreed with the recommendation.

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

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

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

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

#### 6.4.5 Monitor UA trajectory for obstacles

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

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

Rationale: Since the RPIC may not have visual line of sight with the airport surface and/or UA, data on obstacles along the UA trajectory could be delivered via two-way communication with the

VO or via camera video or other method for gaining a forward view of the environment ahead of the UA. The use of camera or other position awareness sensor is dependent on the video quality, environmental conditions, and the potential for latency in the signal.

SME comments: All SMEs agreed with the recommendation.

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

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

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

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

## 7. SUMMARY OF THE RECOMMENDATIONS

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

### 7.1 TAXI OUT

<b>Task</b>	<b>RPIC</b>	<b>VO</b>	<b>Alerting Automation</b>	<b>Control Automation</b>
Obtain taxi route, including destination	X			
Ensure instruments, avionics, and navigation equipment are functioning properly and are ready for flight	X			
Perform brake check	X			
Control UA speed along taxi route	X			
Control UA track along taxi route	X			

Monitor UA trajectory for obstacles		X		
Configure UA for takeoff	X			
Check for proper flight control surface movement		X		
Turn on required lights	X			

7.2 TAKEOFF

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

7.3 LANDING

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

7.4 TAXI IN

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

## 8. REFERENCES

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## 9. APPENDIX A1: OVERVIEW OF SME COMMENTS

A majority of SME comments addressed the following:

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

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

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

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

really makes sense. I also agree with the comments about adding deicing considerations into the process.

Again, I'm not saying anything someone hasn't already said in a much more eloquent way but the feedback so far certainly makes sense to a non-pilot.

My biggest comment is that I feel we need to keep the recommendations general to the function and not specify to a method or technology. The example that I saw the most was the use of video. While I agree that this is a method that is commonly used, it is not the only way to fulfill these functions. I understand that people like video and feel it is easy to install but there are other issues with requiring specific technological solutions. If I want to use a different method I can't because the minimum requirement stipulates video. If I want to operate and I can't get a link that has enough bandwidth to provide video I can't fly. This might not be an issue for a local operation but UAS do fly remotely. I have done operations where we didn't have video and were still able to complete the task safely. Video is nice and I would want it if possible but I don't think we should make it or other specific solutions requirements. I tried to write my recommendations in terms of what function was required or what tools/data the pilot might need to complete the function in a more basic way.

Some comments are directed toward using standardized terms. I'd also encourage using RPIC now since it's an FAA term in 14CFR Part 107. I personally feel there is a bit too much emphasis placed on the nose camera. Don't get me wrong, it's a great tool for SA, but I think in some cases it's over emphasized.

I agree with the minimums presented in the documentation. The situational awareness sections, with today's technologies regarding VR and 360 cameras, there is no reason that this functionality cannot be added to >55 lb UAS. This can allow the pilot/operator to have more visibility of the environment the UAS is operating in (such as an airport). In addition, more UAS are gaining the ability of auto takeoff and landing (ATOL). This can allow the UAS to complete these phases of flight (Take-off and landing) safer and more consistently. The pilot/operator is there to monitor and take over in any emergency situations. With that said, a complete manual piloted UAS or RPA, should fall under similar FARs as manned aircraft. (in my opinion).