APPENDIX E—TASK 8: RECOMMENDATIONS FOR MINIMUM CONTROL STATION HUMAN FACTORS CONSIDERATIONS

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EXECUTIVE SUMMARY

The objective of the work was to develop recommendations to support control station considerations for integrating unmanned aircraft systems (UAS) into the National Airspace System (NAS). The scope of the work was focused on the aviating tasks for fixed-wing UAS larger than 55 pounds and capable of using the existing NAS infrastructure in the following contexts.

To inform the effort, prior function allocation recommendations and a control station literature review composed of the Code of Federal Regulations (CFRs), incident and accident reviews, human factors UAS literature, and select fielded and research operational control stations were leveraged. These sources were used to create a database of potential information elements necessary for UAS operation in the NAS. Two taxonomies were created to categorize the information elements: one reflecting the level of availability of the information element, and one identifying the agent(s) with control over changing the information element. With respect to the display of information elements, the recommendations were developed using a five-level taxonomy including (1) the information element should be available and always displayed, (2) the information element should be available and displayed based on context, (3) the information element should be available and displayed by pilot request, (4) display of the information element is optional, and (5) the information element should be available from a source outside of the control station displays. With respect to control over the information element, the taxonomy included: (1) changes in the information element are controlled directly by the remote pilot in command (RPIC); (2) changes in the information element are influenced by an agent or force external to the UAS; (3) changes in the information element are influenced by a combination of RPIC actions and an external agent or force; and (4) the information element is unable to be changed by the RPIC or an external force or agent. The recommendations were reviewed by seven subject matter experts with a range of experience in various manned and unmanned operational roles but have not been objectively validated . The results of this independent research yielded one set of recommendations for control station considerations for minimum information elements for safe UAS operation in the NAS, as well as potential directions for future research.

1. INTRODUCTION

This document addresses Control Station Display Considerations for Aviate Tasks. The objective of the tasks was to identify recommendations for minimum information elements to support safe unmanned aircraft system (UAS) operation in an integrated National Airspace System (NAS). For information elements covering a broader scope (e.g., taxi, takeoff, landing, navigate, communicate, contingency, and handover tasks), we refer the reader to (Pankok & Bass, 2017).

The remainder of the document describes the assumptions that refine the context of the scope of the work (Section 2), the methodology employed (Section 3), analysis of the information elements (Section 4), recommendations for information requirements (Section 5), and potential directions for future work (Section 6).

2. SCOPE

The recommendations were developed under the following assumptions:

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

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

R1. RPICs comply with existing, adapted, and/or new operating rules or procedures as a prerequisite for NAS integration
R2. Civil UAS operating in the NAS must obtain an appropriate airworthiness certificate while public users retain their responsibility to determine airworthiness.
R3. All UAS file and fly an Instrument Flight Rules (IFR) flight plan.

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

Based on input from the FAA and discussions about the document scope, additional assumptions were considered. 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

To develop the recommendations, potential information elements were identified from various sources. A taxonomy was developed to refine the notion of "minimum" to categorize the information elements with respect to recommended availability. In addition, the information elements were analyzed with respect to control and feedback, and a second taxonomy was

developed to categorize information elements for this purpose. Recommendations were reviewed by a collection of subject matter experts (SMEs) with a range of manned and unmanned experiences. The details of the methodology are described in the following subsections.

3.1 INFORMATION SOURCES

Information elements from a variety of sources were identified and used to develop the recommendations for the minimum information requirements as well as control and feedback requirements for safe unmanned aircraft system (UAS) operation in the NAS. The sources and associated descriptions are listed in the following subsections.

3.1.1 Relevant Federal Regulations

Potentially relevant Federal regulations under Code 14 (14 CFR) were identified. Since the focus of the project is on identifying minimum information elements for UAS operation in the NAS, 14 CFR Parts 23 (general aviation regulations), 25 (transport category aircraft regulations), and 91 (regulations for all aircraft operating in the NAS) were identified as relevant. Part 107 (Small Unmanned Aircraft Regulations) was reviewed but it did not contain information relevant to the recommendations for minimum information elements (due to the fact that Part 107 is limited to visual line of sight (VLOS) operation, while the scope of the current work includes BVLOS operation).

3.1.2 Control Station Review

Five current and research operational control stations were reviewed in Pankok, Bass, and Smith (2017). The control stations were selected for their range of designs, features, and functionality spanning potential UAS operation in the NAS. Information presented to the RPIC was identified for each control station, as well as the format of the information to inform design recommendations.

3.1.3 UAS Control Station Literature Review

A review of the human factors research literature related to UAS control stations was conducted (Pankok, Bass, & Smith, 2017), including the development of a taxonomy related to UAS control station design. A portion of the taxonomy was dedicated to information presented to the RPIC; this information was included as a source in support of the development of the recommendations for the minimum information requirements. HF-STD-001B “Human Factors Design Standard” (Federal Aviation Administration, 2016) was reviewed, which includes general design guidelines for air traffic control displays and referenced where applicable. Note that HF-STD-001B is geared toward application for air traffic control rather than flight decks or UAS control station design; its relevance for UAS control station design is explained when referenced.

3.1.4 Function Allocation Recommendations

Minimum UAS human-automation function allocation recommendations were developed in related tasks (Pankok, Bass, Smith, Dolgov, & Walker, 2017; Pankok, Bass, Smith, & Walker, 2017; Pankok, Bass, Walker, & Smith, 2017). Included in these recommendations, where applicable, was information to be provided to the RPIC to safely operate the UAS under the

recommended automation level. These information elements are reported in Appendix E1, organized by a task analysis that was conducted to guide the function allocation recommendations.

3.2 TAXONOMIES FOR CATEGORIZING INFORMATION ELEMENTS

3.2.1 Information Element Availability

A taxonomy was developed to categorize each information element with respect to its recommended availability in the control station. The taxonomy and definitions for each level are provided in Table 1.

Table 1. Taxonomy characterizing information availability at the control station.

Recommendation of Information Availability	Description
Always Displayed	The information element is flight critical and must always be displayed to the RPIC. The information element cannot be hidden from the RPIC's field of view at any time.
Context Dependent	The information element is critical in some flight contexts and must be displayed to the RPIC, at minimum, during that context. The information element cannot be hidden from the RPIC's field of view during that context. Specific contexts for context dependent information elements are identified in Table 14.
Available at RPIC Request	The information element must be accessible to the RPIC in the control station. The information element need not be presented to the RPIC at all times.
Optional	The information element is not critical for safe operation, and thus represents a higher-than-minimum level of information. The information element has the potential to enhance RPIC and/or total system performance as well as to provide an additional layer of safety when available.
Available outside of Control Station displays	The information element can be obtained outside of the control station. Example methods of information acquisition include verbal communications with air traffic control, recorded information available on systems such as ATIS, and through documentation such as aeronautical charts.

3.2.2 Control and Feedback

Control and feedback related to the information elements identifies dependencies among the data elements and feedback that should be provided to the RPIC as a function of the changing values of the elements. The information elements can either be changeable by the RPIC or by an external agent or force (we refer to these information elements as *variable*) or unchangeable by any agent or force, internal or external to the UAS (we refer to these information elements as *constant*). Variable information items can be altered in one of three ways:

- information element is altered directly by the RPIC (i.e., a UAS control input),
- information element is altered by an agent or force external to the UAS (i.e. wind conditions), or
- information element is altered by a combination of RPIC actions and an agent or force external to the UAS.

Table 2 provides the rubric developed for recommendations based on control over the information elements, associated feedback on the value modified, and the subsequent effect on the UA. The terminology used in the *Type* column is identified in Section 4 to reference these recommended feedback options.

Table 2. Control and feedback taxonomy.

Type	Range	Control Agency	Feedback Recommended
RPIC	Variable	Information element is controlled directly by the RPIC.	• Feedback on input device • Subsequent effect on other information elements[1]
Other	Variable	Information element is influenced by an agent or force external to the UAS.	• External influence or force • Subsequent effect on other information elements[1]
Combination	Variable	Information element is influenced by a combination of RPIC actions and an agent or force external to the UAS.	• Feedback on the input device • External influence or force • Subsequent effect on other information elements[1]
Constant	Constant	Neither the RPIC nor any external agent or force can change the value of the information element.	• Value of the information element

[1]Other information elements altered by degree of control include flight parameters, route of flight, communications, and/or contingency plans.

Examples of the application of the taxonomy in Table 2 follow:

- *Pitch attitude* is variable and the target for its value can be changed directly by the RPIC. The RPIC should be able to view the commanded pitch attitude as well as the resultant changes in the affected variables based on the changes to the UA pitch, such as indicated airspeed (IAS), vertical speed, and indicated altitude.
- *Command/control link strength* is variable and influenced by an agent external to the UAS. The control station should contain the command/control (C2) link status as well as any associated contingency plans for lost C2 link.
- *Ground track* is variable and influenced by a combination of RPIC actions (e.g., UA commanded heading and IAS) and forces external to the UAS (e.g., wind direction and

wind speed). Therefore, the control station should contain information on the ground track, UA heading, UA IAS, wind direction, and wind speed.

- *UA maximum certified altitude* is a fixed value; it is unable to be altered. Information elements that do not change values may necessitate the RPIC to have knowledge of them from memory, from a source outside of the control station, or by retrieval from the control station.

3.3 PROCEDURE

The first step in developing recommendations was to identify relevant sources of potential information elements. Information elements were identified from the relevant sources and concatenated in a custom Microsoft Access database, providing a structure for the information elements, the sources from which they were derived, and design guidance associated with the information element (where applicable). Since terminology varied across the information sources, the information elements were reviewed and revised to ensure consistent terminology. SQL queries were developed to identify sources for each information element; these SQL queries are reported in Appendix E2.

A taxonomy (Table 1) was developed to convey the level of information availability recommended for safe UAS operation in the NAS. Another taxonomy (Table 2) was developed reflecting the control and feedback attributes of each information element. The information elements were categorized via both taxonomies to inform the recommendations.

SMEs with a range of manned and unmanned flight experience reviewed the recommendations and provided their feedback. SMEs were instructed to review the information elements and their associated levels of availability and provide feedback if the element and/or the availability did not represent a minimum requirement.

3.4 SUBJECT MATTER EXPERT QUALIFICATIONS

Seven SMEs reviewed the minimum information recommendations; their operational experience is contained in Table 3. Feedback was solicited from 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. 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. While the SME input was invaluable to this work, the feedback was subjective to their individual opinions and does not necessarily represent the majority view of other UAS professionals.

Table 3. Subject matter expert professional experience.

ID	Operational 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 (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	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.
5	UAS patent formation and design for pilot/cockpit technology deployment.
6	Led creation of the Global Hawk training program. Flight instructor and evaluator with vast international experience. Professor of flight operations courses at Kansas State University (KSU). Flight Operations Manager and Executive Director of KSU UAS Program. Contributed to the revision of the UAS degree curriculum at KSU.
7	Holds certificates as an Instructor/Evaluator Pilot for the RQ-4 UAS (Global Hawk), and as a Weapons Instructor Officer/Evaluator Pilot for the C-130/T-38/T-1. Rated for Commercial Instrument and Single and Multi-Engine. Formerly worked at Infoscitex as the UAS Research lead for the Air Force Research Lab and for Booz Allen Hamilton as the UAS Operation Lead for the Aeronautical Systems Center.

4. INFORMATION ELEMENT ANALYSIS

This section includes the information elements and their associated recommendations. Each entry includes the information element, the control and feedback attribute (labeled "Control Attribute"), and the information availability recommendation (labelled "Availability"). Section 4.1 presents information elements that span several contexts. In subsequent subsections, the elements are organized by flight regime. If a SME disagreed with the consensus, the SME's input is documented and any response/rebuttal follows the SME comment.

4.1 INFORMATION SPANNING MULTIPLE CONTEXTS

4.1.1 Aircraft Identification

The RPIC needs to know the aircraft identifier for radio communications, filing flight plans and other activities in all contexts. Aircraft type is necessary for the flight plan. The values for these information elements would be fixed for a UA. Table 4 contains our recommendations.

Table 4. Information elements and recommendations for aircraft identification information.

Information Element	Control Attribute	Availability Recommendation
Aircraft ID	Constant	Always Displayed
Aircraft type	Constant	Source Outside Control Station Displays

SME Comments—Regarding aircraft ID, one SME suggested that "This could be a placard or just a piece of tape, but it is usually in the flight station. It just does not need to be on the screen."

- Response/Rebuttal: The aircraft ID in a manned aircraft is visible during preflight (on the aircraft) and the manned aircraft pilot can interrogate it. However during the flight this is not possible for a manned aircraft. Interrogation is not possible for remote pilots even during preflight as they are not co-located with the aircraft.

Regarding aircraft type, one SME suggested it should be optional. "The system does not need to tell the RPIC the aircraft type/model. I should know the type/model, and it is in the manual."

- Response/Rebuttal: The recommendation does not require the aircraft type to be contained on the displays, but rather in an external medium (such as the manual).

4.1.2 Time

The RPIC needs to have accurate time information in all contexts. Regarding time of day: it is required per 14 CFR 91.205(d)(6). The values for time of day are not recommended to be modifiable by the RPIC. Table 5 contains our recommendations.

Table 5. Information elements and recommendations for time information.

Information Element	Control Attribute	Availability Recommendation
Time of day	Other	Always Displayed
Time of day (origin)	Other	Optional
Time of day (destination)	Other	Optional

SME Comments—One SME suggested adding more information: "I suggest adding 'sunrise' and 'sunset' as optional, since some aircraft will have day and night restrictions."

- Response/Rebuttal: These information elements were not added, as presentation of time of day can be used to determine whether it is day or night.

4.1.3 Flight Parameters

Most flight parameters are recommended to always be displayed. However, ground speed and true airspeed are recommended to be optionally available. Table 6 contains our recommendations.

Table 6. Information elements and recommendations for flight parameters.

Information Element	Control Attribute	Availability Recommendation
Altitude above ground level (absolute)	Combination	Always Displayed
Angle of attack	RPIC	Optional
Density altitude	Combination	Optional
Ground speed	Combination	Available at RPIC Request
Ground track	Combination	Optional
Indicated airspeed	RPIC	Always Displayed
Indicated altitude	Combination	Always Displayed
Latitude	Combination	Always Displayed
Longitude	Combination	Always Displayed
Magnetic heading	RPIC	Always Displayed
Pitch attitude	RPIC	Always Displayed
Rate of turn	RPIC	Optional
Roll attitude/bank angle	RPIC	Always Displayed
Slip/skid	RPIC	Always Displayed
True airspeed	Combination	Optional
True heading[1]	Combination	Optional
Vertical speed	Combination	Always Displayed
Yaw attitude	RPIC	Optional

[1]True heading should be "always displayed" if magnetic heading is not presented to the RPIC in the control station. The control station should clearly indicate whether the heading being presented to the RPIC is the true heading or the magnetic heading.

SME Comments—There was a lack of consensus with respect to SME input regarding ground speed, altitude above ground level, true heading, and magnetic heading.

- Regarding ground speed: One SME indicated it should be optional across all phases of flight.
    - Response/Rebuttal: There could be instances for which the RPIC needs to know the ground speed, such as during approach and landing or during taxi, where the RPIC does not have the out-the-window visual cues that give an indication of UA ground speed that a manned pilot has.
- Regarding altitude above ground level, one SME indicated it should be optional.
    - Response/Rebuttal: Terrain awareness is an important factor in aviation safety and controlled flight into terrain (CFIT) continues to be a safety concern for manned aircraft (Boeing Company, 2015; International Air Transportation Association, 2015); removing the pilot from the cockpit (along with information from out-the-window view) can exacerbate the issue. If AGL is not presented, the RPIC will

have to reference a static terrain map to calculate distance above ground. This is very different from manned operation, in which the RPIC can make a judgment on whether the aircraft is clear of terrain and obstacles by simply looking out the window during visual meteorological conditions. This reflects HF-STD-001B is meant for ATC design, but it is applicable here because Section 5.1.1.10 states that systems should avoid increasing demands for cognitive resources and Section 5.1.12.3 states that displays should provide information in a usable format (Federal Aviation Administration, 2016).

- Regarding true heading and magnetic heading, SME input ranged from always displayed to optional. One SME suggested that "Having either true heading or magnetic heading 'always displayed' is fine, but the control station would have to indicate which one it is so the RPIC would not have to search the control station displays further for that information." Another SME suggested that "Typical commands reference magnetic heading, so this should be 'Available at RPIC Request'."
    - Response/Rebuttal: The recommendation for true heading is "optional" with the caveat that true heading should be "always displayed" (and labeled clearly to ensure the RPIC knows it is true heading) if the control station does not present the RPIC with the magnetic heading.

4.1.4 Targets

Flight targets can support RPIC awareness of the state of the UA compared to the desired state, but are not considered a minimum information need as recommended in Table 7.

Table 7. Information elements and recommendations for targets.

Information Element	Control Attribute	Availability Recommendation		
		Takeoff	Aviate	Landing
Altitude target	RPIC	Optional	Optional	Optional
Heading target	RPIC	Optional	Optional	Optional
Indicated airspeed target	RPIC	Optional	Optional	Optional
Vertical speed target	RPIC	Optional	Optional	Optional
Roll attitude/bank angle target	RPIC	Optional	Optional	Optional
Pitch angle target	RPIC	Optional	Optional	Optional

4.1.5 Constraints and V-Speeds

Constraints should be available as appropriate for their context. For example, landing gear and flaps information may not be critical if they are not being used. Note that some constraints are dependent on the aircraft type; for example, we did not include minimum control speed (V_{MC}) since it assumes an aircraft with multiple powerplants. Table 8 contains our recommendations.

Table 8. Information elements and recommendations for constraints and V-speeds.

Information Element	Control Attribute	Availability Recommendation
Maximum altitude	Constant	Optional
Maximum flaps extended speed (V_{FE})	Constant	Always Displayed
Maximum landing gear extended speed (V_{LE})	Constant	Context Dependent
Maximum landing gear operating speed (V_{LO})	Constant	Always Displayed
Maximum operating limit speed (V_{MO})	Constant	Always Displayed
Maximum operating maneuvering speed (V_O)	Constant	Always Displayed
Maximum speed for normal operations (V_{NO})	Constant	Always Displayed
Never-exceed speed (V_{NE})	Constant	Always Displayed
Optimal climb rate	Combination	Optional
Optimal cruise speed	Combination	Optional
Optimal descent rate	Combination	Optional
Stall speed (V_S)	Constant	Always Displayed
Stall speed in landing configuration (V_{S0})	Constant	Always Displayed

4.1.6 UA Device Control

Device control can be specific to phase of flight but some devices are used across contexts. For example, wheel braking is not relevant when not on the ground. Flight mode annunciation is included to represent an indication of which flight mode(s) are engaged and disengaged at any time. Since the flight mode is specific to the aircraft type and its equipment, we do not list all possible flight modes but instead use this term for all related annunciations. Table 9 contains our recommendations.

Table 9. Information elements and recommendations for UA device control information.

Information Element	Control Attribute	Availability Recommendation
Throttle position	RPIC	Always Displayed
Thrust level	RPIC	Optional
Thrust reverser position	RPIC	Always Displayed
Flight surface positions	RPIC	Optional
Control device position[1]	RPIC	Always Displayed
Trim device position	RPIC	Always Displayed
Flight mode annunciation[2]	RPIC	Always Displayed

[1]Since this work is control device agnostic, this information element refers to the position of any control device contained in the control station, including but not limited to a yoke, pedals, joystick, or on-screen interface.

[2]The modes used by a manufacturer may differ but what modes are engaged and not engaged should be annunciated

SME Comments—There was disagreement among the SMEs for flight mode annunciation. One SME commented: "I suggest making this optional. Or, if you are referring to alerting, I suggest making this context-dependent."

- Response/Rebuttal: Mode awareness is a known safety issue for automated aircraft (Sarter & Woods, 1995). For aircraft that have multiple autopilot modes, it is critical that the mode is apparent to the RPIC. 14 CFR 25.1302(c) states that operationally-relevant behavior of the installed equipment must be (1) predictable and unambiguous, and (2) designed to enable the flightcrew to intervene in a manner appropriate to the task. In other words, operationally relevant system behavior should be predictable and unambiguous, enabling a qualified flightcrew to know what the system is doing and why (Yeh, Jo, Donovan, & Gabree, 2013).

4.1.7 Onboard Equipment

This section reflects recommendations for onboard equipment, settings, and status relevant across flight contexts. Table 10 contains our recommendations.

Table 10. Information elements and recommendations for onboard equipment.

Information Element	Control Attribute	Availability Recommendation
Altimeter setting	RPIC	Always Displayed
Aircraft external lights status	RPIC	Always Displayed
Transponder code[1]	RPIC	Always Displayed
Transponder status	Other	Always Displayed

[1]In this work, installation and maintenance are not addressed. There are many information elements associated with transponders such as the address and mode and they could change if a transponder is moved from one aircraft to another.

4.2 APPROACH AND LANDING

In addition to the information elements presented in Section 4.1, the recommendations below are for the approach and landing phases of flight. Table 11 contains our recommendations.

Table 11. Information elements and recommendations for approach and landing.

Information Element	Control Attribute	Availability Recommendation
Position relative to desired glidepath	Combination	Context Dependent
Position relative desired path over ground	Combination	Context Dependent

4.2.1 Terrain

It is recommended that terrain information be available when the UA is near the ground. While this information could be addressed outside of the control station displays, safety could be compromised as the RPIC lacks the robust out-the-window view that a traditional manned pilot has during visual meteorological conditions. Table 12 contains our recommendations.

Table 12. Information elements and recommendations for terrain information.

Information Element	Control Attribute	Availability Recommendation
Terrain/obstacle height	Other	Optional

SME Comments—One SME commented "This should be optional. Pilots do this in IFR all the time. I have shot many approaches where only the runway lights could be seen through the fog or I broke out at 200ft. I had to determine my height above ground from other information (chart, altimeter, location on approach, etc.). If there was a working radar altimeter, that was extra."

- Response/Rebuttal: Assuming the altitude AGL is displayed in the control station, the terrain/obstacle height should be optional.

5. RECOMMENDATIONS

The recommendations to support control station considerations for integrating UAS flying in the NAS can be summarized based on the characteristics of the information elements described in this report and summarized in Table 16.

Information elements that are recommended to always be displayed (Table 13) would yield recommendations like the following:

> It is recommended the control station have the capability to display <*information element*> at all times.

Table 13. Information elements that should be displayed at all times.

Information Element: Always Displayed
Aircraft external lights status
Aircraft ID
Altimeter setting
Altitude above ground level (absolute)
Control device position
Flight mode annunciation
Indicated airspeed
Indicated altitude
Latitude
Longitude
Magnetic heading
Maximum flaps extended speed (VFE)
Maximum landing gear operating speed (VLO)
Maximum operating limit speed (VMO)
Maximum operating maneuvering speed (VO)
Maximum speed for normal operations (VNO)
Never-exceed speed (VNE)
Pitch attitude

Roll attitude/bank angle
Slip/skid
Stall speed (VS)
Stall speed in landing configuration (VS0)
Throttle position
Thrust reverser position
Time of day
Transponder code
Transponder status
Trim device position
Vertical speed

Information elements that are recommended to be displayed during specific contexts (Table 14) would yield recommendations like the following:

> The control station is recommended to have the capability to always display <*information element*> when <*context*>.

Table 14. Information elements that are context dependent.

Information Element	Context
Maximum landing gear extended speed (V_{LE})	When in takeoff, final approach and landing phases
Position relative to desired path over ground	When in final approach and landing phases
Position relative to desired glidepath	When in final approach and landing phases

Information elements that are recommended to be displayed at the RPIC's request (Table 15) would yield recommendations like the following:

> The control station is recommended to have the capability to display <*information element*> at the pilot's request.

Table 15. Information elements that are available at RPIC request.

Information Element: RPIC Request
Ground speed

Information elements that are optional would not lead to specific recommendations but could lead to design guidance or suggestions.

Information elements that can be obtained outside of the control station displays would not lead to recommendations.

Information elements that can be controlled directly by the RPIC would yield two types of recommendations like the following:

> The control station is recommended to have the capability for the pilot to enter a value for <*information element*> for upload to the UA.
>
> The control station is recommended to have the capability for the pilot to view the commanded value for <*information element*>.

In addition, for every information element that can be controlled directly by the RPIC, the design recommendation is for the display to include the value of related information elements that change as a result. For example, if the RPIC changes the landing gear control position, the control station display is recommended to make the landing gear status visible to the RPIC. For information elements that are influenced by an agent or force external to the UAS, or those influenced in combination, the design recommendation is for the display to include the value of related information elements that change as a result.

A summary of the categorizations for all of the information elements is contained in Table 16.

Table 16. Summary of information element characteristics informing recommendations.

Recommended Availability	**Control Attribute**	**Information Element**
Optional	Combination	Density altitude Ground track Optimal climb rate Optimal cruise speed Optimal descent rate True airspeed True heading
Optional	Constant	Maximum altitude
Optional	Other	Terrain/obstacle height Time of day (destination) Time of day (origin)
Optional	RPIC	Altitude target Angle of attack Flight surface positions Heading target Indicated airspeed target Pitch angle target Rate of turn Roll attitude/bank angle target Thrust level Vertical speed target Yaw attitude
Context Dependent	Combination	Position relative to desired path over ground Position relative to desired glidepath

Context Dependent	Constant	Maximum landing gear extended speed (V_{LE})
Always Displayed	Combination	Altitude above ground level (absolute) Indicated altitude Latitude Longitude Vertical speed
Always Displayed	Constant	Aircraft ID Maximum flaps extended speed (V_{FE}) Maximum landing gear operating speed (V_{LO}) Maximum operating limit speed (V_{MO}) Maximum operating maneuvering speed (V_O) Maximum speed for normal operations (V_{NO}) Never-exceed speed (V_{NE}) Stall speed (V_S) Stall speed in landing configuration (V_{S0})
Always Displayed	Other	Time of day Transponder status
Always Displayed	RPIC	Aircraft external lights status Altimeter setting Control device position Flight mode annunciation Indicated airspeed Magnetic heading Pitch attitude Roll attitude/bank angle Slip/skid Throttle position Thrust reverser position Transponder code Trim device position
Available at RPIC Request	Combination	Ground speed
Source Outside of Control Station Displays	Constant	Aircraft type

6. FUTURE RESEARCH AREAS

The work presented in this document presents recommendations for minimum information content as well as control and feedback recommendations for UAS operation in the NAS. More work is required to validate the recommendations, including empirical testing and human-in-the-loop testing. This process should also be iterated with other relevant roles, such as for VOs and air traffic control.

A significant portion of the Certified Federal Regulations and operational control stations reviewed focused on system health and status information elements for manned and unmanned aircraft. Since these information elements are aircraft-specific, future work should identify additional information recommendations to ensure that the RPIC is continually informed of the status of the various systems required to operate the aircraft, including (but not limited to): powerplant, fuel system, electrical system, hydraulic system, pitot tube, and oil system.

Further work is required for other items that are aircraft-specific as well, such as indication of control modes, since there is a wide range of automation and modes that could be available to the RPIC dependent on the platform. Similarly, control devices are UAS-specific, so future work should investigate how the recommendations may differ across potential control devices. Navigation equipment is also platform-specific; future work should investigate how information needs differ as a function of onboard navigation equipment.

The current work focused on UAS operation in VMC, so future work should address how information needs differ for non-VMC conditions.

Future work should also assess information needs not accounted for in the scope of this work, including needs for unmanned rotorcraft or vertical takeoff and landing UA larger than 55 lb., or fixed-wing aircraft that are not capable of flying standard takeoff or landing procedures.

One of the most significant differences between operating manned and unmanned aircraft is the lack of an out-the-window view of the environment. Future work should investigate information that is acquired by manned pilots via the out-the-window view of the aircraft (such as airport configuration, terrain, and environmental conditions) and the best way to incorporate that information into a UAS control station.

Future work should also address the information needs for situations in which the RPIC has visual contact with the UA.

The current work addressed information needs assuming the RPIC communicates with the VO and ATC via voice radio communication. Information needs may differ for other communication mediums, such as direct voice contact or data communications.

7. REFERENCES

Boeing Company. (2015). *Statistical summary of commercial jet airplane accidents: Worldwide operations 1959-2015*. Retrieved from https://www.boeing.com/resources/boeingdotcom/company/about_bca/pdf/statsum.pdf

Federal Aviation Administration. (2012). *Integration of Unmanned Aircraft Systems into the National Airspace System: Concept of Operations*. Federal Aviation Administration Retrieved from https://www.suasnews.com/wp-content/uploads/2012/10/FAA-UAS-Conops-Version-2-0-1.pdf.

Federal Aviation Administration. (2013). *Integration of Civil Unmanned Aircraft Systems (UAS) in the National Airspace System (NAS) Roadmap*. Retrieved from https://www.faa.gov/uas/media/uas_roadmap_2013.pdf

Federal Aviation Administration. (2014). *Aeronautical Information Manual*. Retrieved from https://www.faa.gov/air_traffic/publications/media/aim_basic_4-03-14.pdf

Federal Aviation Administration. (2016). HF-STD-001B.

International Air Transportation Association. (2015). *Controlled flight into terrain accident analysis report*. Retrieved from https://www.iata.org/whatwedo/safety/Documents/CFIT-Report-1st-Ed-2015.pdf

Pankok, C., & Bass, E. J. (2017). Project A10: Human Factors Considerations of UAS Procedures and Control Stations: Recommendations for Minimum Control Station Human Factors Considerations.

Pankok, C., Bass, E. J., & Smith, P. J. (2017). Project A7: UAS Human Factors Control Station Design Standards (Plus Function Allocation, Training, Visual Observer): Control Station Literature Review.

Pankok, C., Bass, E. J., Smith, P. J., Dolgov, I., & Walker, J. (2017). Project A7: UAS Human Factors Control Station Design Standards (Plus Function Allocation, Training, Visual Observer): Function Allocation Strategy and Future Research Recommendations.

Pankok, C., Bass, E. J., Smith, P. J., & Walker, J. (2017). Project A10: Human Factors Considerations of UAS Procedures and Control Stations: Function Allocation Recommendations for Taxi, Takeoff, and Landing.

Pankok, C., Bass, E. J., Walker, J., & Smith, P. J. (2017). Project A10: Human Factors Considerations of UAS Procedures and Control Stations: Function Allocation Recommendations for Navigation, Communication, and Contingency.

Sarter, N. B., & Woods, D. D. (1995). How in the world did we ever get into that mode? Mode error and awareness in supervisory control. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 37*(1), 5-19.

Yeh, M., Jo, Y. J., Donovan, C., & Gabree, S. (2013). *Human Factors Considerations in the Design and Evaluation of Flight Deck Displays and Controls*. Washington, D.C.: United States Department of Transportation.

8. APPENDIX E1: INFORMATION ELEMENTS DERIVED FROM FUNCTION ALLOCATION RECOMMENDATIONS

The tables in this appendix present the information elements derived from the Projects A7 and A10 function allocation recommendations. All information elements are organized by task, which resulted from a task analysis conducted as part of the work.

A7 TASK 6: AVIATE

Task	Information Content	Category
Manipulate required aircraft lights	Aircraft external lights status	Aviate
Manage horizontal flight path	Latitude	Aviate
Manage horizontal flight path	Longitude	Aviate
Manage horizontal flight path	Position relative to desired flight route	Aviate
Manage horizontal flight path	Magnetic heading	Aviate
Manage horizontal flight path	True heading	Aviate
Manage altitude	Indicated altitude	Aviate
Manage altitude	Indicated altitude target	Aviate
Manage altitude	Maximum altitude	Aviate
Manage vertical speed	Vertical speed	Aviate
Manage airspeed	Indicated airspeed	Aviate
Manage airspeed	Indicated airspeed target	Aviate
Manage airspeed	Optimal climb speed	Aviate
Manage airspeed	Optimal cruise speed	Aviate
Manage airspeed	Optimal descent speed	Aviate
Manage airspeed	Stall speed (V_S)	Aviate
Manage airspeed	Stall speed in landing configuration (V_{S0})	Aviate
Manage airspeed	Maximum speed for normal operations (V_{NO})	Aviate
Manage airspeed	Never-exceed speed (V_{NE})	Aviate
Set altimeter for transition level/altitude	Indicated altitude	Aviate
Set altimeter for transition level/altitude	Altimeter setting	Aviate
Configure aircraft for appropriate phase of flight	Flight surface positions	Aviate

A10 TASK CS-1: TAXI, TAKEOFF, AND LANDING

Task	Information Content	Category
Obtain taxi route	Active flight plan	Taxi
Obtain taxi route	Airport configuration	Taxi
Perform brake check	Wheel brake position	Taxi
Perform brake check	Ground speed	Taxi

Control aircraft speed along taxi route	Ground speed	Taxi
Control aircraft speed along taxi route	Wheel brake position	Taxi
Control aircraft speed along taxi route	Thrust level	Taxi
Control aircraft track along taxi route	Position relative to desired taxi route	Taxi
Control aircraft track along taxi route	Position relative to taxiway centerline	Taxi
Monitor aircraft trajectory for obstacles	Obstacle(s) along taxi route	Taxi
Configure aircraft for appropriate phase of flight	Flight surface positions	Taxi
Check for proper flight control surface movement	Flight surface positions	Taxi
Manipulate required aircraft lights	Aircraft external lights status	Taxi
Position aircraft for takeoff in appropriate configuration	Position relative to runway centerline	Takeoff
Smoothly advance power to takeoff (full) thrust	Throttle position	Takeoff
Smoothly advance power to takeoff (full) thrust	Wheel brake position	Takeoff
Observe aircraft indicators operating normally	Aircraft engine indication(s)	Takeoff
Observe aircraft indicators operating normally	Aircraft performance indication(s)	Takeoff
Maintain runway centerline	Position relative to runway centerline	Takeoff
Maintain runway centerline	Magnetic heading	Takeoff
Maintain runway centerline	True heading	Takeoff
Monitor aircraft airspeed in relation to scheduled takeoff speeds	Indicated airspeed	Takeoff
Monitor aircraft airspeed in relation to scheduled takeoff speeds	Takeoff decision speed (V1)	Takeoff
Monitor aircraft airspeed in relation to scheduled takeoff speeds	Takeoff safety speed (V2)	Takeoff
Monitor aircraft airspeed in relation to scheduled takeoff speeds	Rotation speed (VR)	Takeoff
Lift off/rotate	Throttle position	Takeoff
Lift off/rotate	Pitch attitude	Takeoff
Lift off/rotate	Pitch angle target	Takeoff
Check for positive rate of climb	Vertical speed	Takeoff
Check for positive rate of climb	Indicated altitude	Takeoff
Monitor airspeed in comparison to configuration-based airspeed limits	Indicated airspeed	Takeoff
Monitor airspeed in comparison to configuration-based airspeed limits	Optimal climb speed	Takeoff

Monitor airspeed in comparison to configuration-based airspeed limits	Maximum flap operating speed (VFO)	Takeoff
Monitor airspeed in comparison to configuration-based airspeed limits	Maximum flaps extended speed (VFE)	Takeoff
Monitor airspeed in comparison to configuration-based airspeed limits	Maximum landing gear operating speed (VLO)	Takeoff
Monitor airspeed in comparison to configuration-based airspeed limits	Maximum landing gear extended speed (VLE)	Takeoff
Landing decision	Altitude above ground level (absolute)	Landing
Landing decision	Indicated airspeed	Landing
Landing decision	Position relative to desired path over ground	Landing
Reduce power to thrust required for landing	Throttle position	Landing
Ensure aircraft is in safe location for landing	Position relative to runway centerline	Landing
Perform landing/touchdown	Throttle position	Landing
Perform landing/touchdown	Pitch attitude	Landing
Perform landing/touchdown	Pitch angle target	Landing
Slow aircraft to taxi speed	Ground speed	Landing
Determine runway turn-off	Taxi route	Landing
Determine runway turn-off	Position relative to desired taxi route	Landing
Determine runway turn-off	Airport configuration	Landing
Turn aircraft off runway	Position relative to desired taxi route	Landing

A10 TASK CS-2: NAVIGATE, COMMUNICATE, CONTINGENCY, AND HANDOVER

Task	Information Content	Category
Verify top of climb	Top of climb	Navigate
Communicate with external agents	Communication channel	Communicate
Communicate with external agents	Communication frequency	Communicate
Communicate with external agents	Active communication radio	Communicate
Obtain airport data	Wind direction	Navigate
Obtain airport data	Wind speed	Navigate
Obtain airport data	Runway status	Navigate
Obtain airport data	Precipitation	Navigate
Determine descent profile	Wind direction	Navigate
Determine descent profile	Wind speed	Navigate
Determine descent profile	Weather conditions	Navigate
Determine descent profile	Optimal descent rate	Navigate
Determine descent profile	Airspace conditions	Navigate

Determine descent profile	Terrain/obstacle height	Navigate
Determine top of descent	Wind direction	Navigate
Determine top of descent	Wind speed	Navigate
Determine top of descent	Weather conditions	Navigate
Determine top of descent	Optimal descent rate	Navigate
Determine top of descent	Indicated altitude	Navigate
Determine top of descent	Position relative to desired path over ground	Navigate
Determine top of descent	Indicated airspeed	Navigate
Identify touchdown target on first third of runway	Charts/terminal procedures	Landing
Identify touchdown target on first third of runway	Position relative to desired path over ground	Landing
Determine approach profile	Charts/terminal procedures	Landing
Determine approach profile	Wind direction	Landing
Determine approach profile	Wind speed	Landing
Determine approach profile	Weather conditions	Landing
Determine approach profile	Optimal descent rate	Landing
Determine approach profile	Airspace conditions	Landing
Determine approach profile	Terrain/obstacle height	Landing
Tune applicable navigation avionics	Position relative to desired flight route	Navigate
Tune applicable navigation avionics	Selected navigation aid	Navigate
Monitor aircraft position along route	Latitude	Navigate
Monitor aircraft position along route	Longitude	Navigate
Monitor aircraft position along route	Position relative to desired flight route	Navigate
Command aircraft heading	Latitude	Navigate
Command aircraft heading	Longitude	Navigate
Command aircraft heading	Magnetic heading	Navigate
Command aircraft heading	True heading	Navigate
Command aircraft heading	Heading target/clearance	Navigate
Monitor aircraft altitude along route	Indicated altitude	Navigate
Monitor aircraft altitude along route	Altitude target/clearance	Navigate
Implement route change(s)	Chosen route alternative	Navigate
Pre-flight systems management and checks	System status	Manage Systems
Pre-flight systems management and checks	System safe operating range	Manage Systems
Monitor system health and status	System status	Manage Systems
Monitor system health and status	System safe operating range	Manage Systems
Perform system health and status intervention	Procedure	Manage Systems
Lost command and/or control link	Command/control downlink signal strength	Contingency

Lost command and/or control link	Command/control uplink signal strength	Contingency
Lost command and/or control link	Command/control link strength safe operating range/location	Contingency
Lost command and/or control link	Lost command/control link elapsed time	Contingency
Lost command and/or control link	Procedure	Contingency
Degraded aircraft position reporting	Aircraft position reporting system status	Contingency
Degraded aircraft position reporting	Procedure	Contingency
Loss of contingency flight plan automation	Contingency flight planning automation system status	Contingency
Loss of contingency flight plan automation	Procedure	Contingency
Visual observer failure	Communication frequency	Contingency
Visual observer failure	Procedure	Contingency
Positive transfer of control from transferring CS to receiving CS occurs	Command/control uplink connection status	Handover
Positive transfer of control from transferring CS to receiving CS occurs	Command/control downlink connection status	Handover

9. APPENDIX E2: STRUCTURED QUERY LANGUAGE QUERIES

This appendix contains SQL queries used to retrieve all the information elements that were consolidated from the various sources into the Microsoft Access Database.

FEDERAL AVIATION REGULATIONS

```
(SELECT DISTINCT Part_23_Regulation AS Regulations
FROM cfr_tbl
WHERE Information_Content LIKE '*' & [Information Element] & '*')
UNION
(SELECT DISTINCT Part_25_Regulation
FROM cfr_tbl
WHERE Information_Content LIKE '*' & [Information Element] & '*')
UNION (SELECT DISTINCT Part_91_Regulation
FROM cfr_tbl
WHERE Information_Content LIKE '*' & [Information Element] & '*');
```

OPERATIONAL CONTROL STATION REVIEW

```
SELECT DISTINCT operational_cs_tbl.Source
FROM operational_cs_tbl
WHERE Information_Content Like '*' & [Information Element] & '*';
```

LITERATURE REVIEW

```
SELECT Authors & " (" & Pub_Year & ") " & Title
FROM (SELECT DISTINCT Authors, Pub_Year, Title
        FROM cs_lit_tbl
        WHERE Information_Content LIKE '*' & [Information Element] & '*');
```

FUNCTION ALLOCATION RECOMMENDATIONS

```
SELECT DISTINCT Source
FROM fa_rec_tbl
WHERE Information_Content LIKE '*' & [Information Element] & '*';
```

APPLICABILITY

SELECT DISTINCT Applicability
FROM cfr_tbl
WHERE Information_Content LIKE '*' & [Information Element] & '*';

FAR DESIGN GUIDANCE

SELECT DISTINCT Design_Guidance
FROM cfr_tbl
WHERE Information_Content LIKE '*' & [Information Element] & '*';

OPERATIONAL CONTROL STATION DESIGN GUIDANCE

SELECT DISTINCT Design_Guidance
FROM operational_cs_tbl
WHERE Information_Content LIKE '*' & [Information Element] & '*';

10. APPENDIX E3: INFORMATION ELEMENT SOURCES

This appendix contains tables that provide all of the sources containing the information source (which is in bold above the table). The tables provide sources of the information element, applicability if necessary, and design recommendations.

Active communication radio

Relevant Certified Federal Regulation(s): • 14 CFR 91.135(b) • 14 CFR 91.205(d)(2)
Function Allocation Recommendation Tasks: • Communicate with external agents

Active contingency plan(s)

Operational Control Stations: • Advanced Cockpit Ground Control Station
Function Allocation Recommendation Tasks: • Determine necessary route change(s)
Design Recommendation: Formats in operational control stations: • Text • Text in a grid

Active flight plan

Operational Control Stations: • X-Gen Control Station

Air temperature (static or outside)

Relevant Certified Federal Regulation(s): • 14 CFR 23.1303(d) • 14 CFR 23.1305(b)(1) • 14 CFR 25.1303(a)(1) • 14 CFR 25.1305(b)(1)
Applicability: • For reciprocating engine-powered airplanes • Minimum required flight and navigation instrument for reciprocating engine-powered airplanes of more than 6,000 pounds maximum weight and turbine engine powered airplanes

Aircraft external lights status

Relevant Certified Federal Regulation(s): • 14 CFR 25.1383(c)
Operational Control Stations: • Advanced Cockpit Ground Control Station
Function Allocation Recommendation Tasks: • Manipulate required aircraft lights
Design Recommendation: Formats in operational control stations: • Color-coded indicator

Aircraft ID

Operational Control Stations: • Advanced Cockpit Ground Control Station • SenseFly eMotion Control Station
Literature: • F. Friedman-Berg, J. Rein and N. Racine (2014) Minimum visual information requirements for detect and avoid in unmanned aircraft systems • R. Arteaga, R. Kotcher, M. Cavalin and M. Dandachy (2016) Application of an ADS-B Sense and Avoid Algorithm
Design Recommendation: Formats in operational control stations: • Text

Aircraft position reporting system status

Function Allocation Recommendation Tasks: • Degraded aircraft position reporting

Aircraft type

Literature:

- Federal Aviation Administration (2017). Aeronautical Information Manual.

Airport configuration

Function Allocation Recommendation Tasks:

- Obtain taxi route
- Determine runway turn-off

Airspace boundaries

Literature:

- Federal Aviation Administration (2017). Aeronautical Information Manual.

Alternate airport

Operational Control Stations:

- Advanced Cockpit Ground Control Station
- Piccolo Command Center
- Procerus Virtual Cockpit
- SenseFly eMotion Control Station

Literature:

- B. Donmez, H. Graham and M. Cummings (2008) Assessing the Impact of Haptic Peripheral Displays for UAV Operators
- B. Donmez, M. L. Cummings and H. D. Graham (2009) Auditory decision aiding in supervisory control of multiple unmanned aerial vehicles
- C. Fuchs, C. Borst, G. C. de Croon, M. R. van Paassen and M. Mulder (2014) An ecological approach to the supervisory control of UAV swarms
- C. Kenny, R. J. Shively and K. Jordan (2014) Unmanned Aircraft System (UAS) Delegation of Separation in NextGen Airspace
- C. Santiago and E. R. Mueller (2015) Pilot Evaluation of a UAS Detect-and-Avoid System's Effectiveness in Remaining Well Clear
- G. L. Calhoun, C. A. Miller, T. C. Hughes and M. H. Draper (2014) UAS sense and avoid system interface design and evaluation
- G. L. Calhoun, M. Draper, C. Miller, H. Ruff, C. Breeden and J. Hamell (2013) Adaptable automation interface for multi-unmanned aerial systems control: Preliminary usability evaluation
- H. Graham and M. Cummings (2007) Assessing the Impact of Auditory Peripheral Displays for UAV Operators

- J. Haber and J. Chung (2016) Assessment of UAV Operator Workload in A Reconfigurable Multi-Touch Ground Control Station Environment
- K. Monk, R. J. Shively, L. Fern and R. C. Rorie (2015) Effects of Display Location and Information Level on UAS Pilot Assessments of a Detect and Avoid System
- K. W. Williams (2012) An Investigation of Sensory Information, Levels of Automation, and Piloting Experience on Unmanned Aircraft Pilot Performance
- L. Damilano, G. Guglieri, F. Quagliotti and I. Sale (2012) FMS for unmanned aerial systems: HMI issues and new interface solutions
- L. Fern and J. Shively (2011) Designing airspace displays to support rapid immersion for UAS handoffs
- L. Fern, C. A. Kenny, R. J. Shively and W. Johnson (2012) UAS integration into the NAS: an examination of baseline compliance in the current airspace system
- L. Fern, R. C. Rorie, J. S. Pack, R. J. Shively and M. H. Draper (2015) An evaluation of Detect and Avoid (DAA) displays for unmanned aircraft systems: The effect of information level and display location on pilot performance
- M. B. Cook, H. S. Smallman, F. C. Lacson and D. I. Manes (2009) Design and validation of a synthetic task environment to study dynamic unmanned aerial vehicle re-planning
- M. B. Cook, H. S. Smallman, F. C. Lacson and D. I. Manes (2010) Situation displays for dynamic UAV replanning: Intuitions and performance for display formats
- M. F. L. De Vries, G. J. M. Koeners, F. D. Roefs, H. T. A. Van Ginkel and E. Theunissen (2006) Operator support for time-critical situations: Design and evaluation
- M. H. Draper, J. S. Pack, S. J. Darrah, S. N. Moulton and G. L. Calhoun (2014) Human-Machine Interface development for common airborne sense and avoid program
- R. C. Rorie and L. Fern (2014) UAS measured response the effect of GCS control mode interfaces on pilot ability to comply with ATC clearances
- R. C. Rorie and L. Fern (2015) The impact of integrated maneuver guidance information on UAS pilots performing the Detect and Avoid task
- R. C. Rorie, L. Fern and J. Shively (2016) The Impact of Suggestive Maneuver Guidance on UAS Pilot Performing the Detect and Avoid Function
- S. Watza, E. Mueller and C. Santiago (2016) Piloted Well Clear Performance Evaluation of Detect and Avoid Systems with Suggestive Guidance
- X. Yuan, J. M. Histon and S. Waslander (2014) Survey of Operators' Information Requirements on Individually Operated Unmanned Aircraft Systems

Function Allocation Recommendation Tasks:

- Loss of contingency flight plan automation
- Monitor aircraft position along route

Design Recommendation:
Formats in operational control stations:
- Line format (solid, dashed, or translucent)
- Lines connecting waypoints
- Ownship symbol relative to route
- Route overlaid on map
- Text in a grid
- Text

Altimeter Setting

Function Allocation Recommendation Tasks:
- Set altimeter for transition level/altitude

Altitude above ground level (absolute)

Function Allocation Recommendation Tasks:
- Landing decision

Altitude target

Operational Control Stations:
- Advanced Cockpit Ground Control Station
- Piccolo Command Center
- Procerus Virtual Cockpit
- SenseFly eMotion Control Station
- X-Gen Control Station

Function Allocation Recommendation Tasks:
- Monitor aircraft altitude along route

Design Recommendation:
Formats in operational control stations:
- Text
- Text and bug
- Text in pop-up window

Angle of attack

Operational Control Stations:
- Advanced Cockpit Ground Control Station
- X-Gen Control Station

Design Recommendation:
Formats in operational control stations:
- Text
- Text and AOA tape

ATC clearance

Literature:
- Federal Aviation Administration (2017). Aeronautical Information Manual.

ATC contact information
This information element was suggested by a subject matter expert.

Atmospheric pressure

Operational Control Stations:
- Advanced Cockpit Ground Control Station
- X-Gen Control Station

Design Recommendation:
Formats in operational control stations:
- Color-coded text and color-coded gauge
- Text
- Text and color-coded scale

Charts/terminal procedures

Function Allocation Recommendation Tasks:
- Determine approach profile

Cloud cover/height

Literature:
- Federal Aviation Administration (2017). Aeronautical Information Manual.

Command sent status

Operational Control Stations:

- Advanced Cockpit Ground Control Station
- Piccolo Command Center
- Procerus Virtual Cockpit
- SenseFly eMotion Control Station
- X-Gen Control Station

Literature:

- A. C. Trujillo, R. W. Ghatas, R. Mcadaragh, D. W. Burdette, J. R. Comstock, L. E. Hempley and H. Fan (2015) Small Unmanned Aircraft Systems Integration into the National Airspace System Visual-Line-of-Sight Human-in-the-Loop Experiment
- B. Donmez, H. Graham and M. Cummings (2008) Assessing the Impact of Haptic Peripheral Displays for UAV Operators
- C. Fuchs, C. Borst, G. C. de Croon, M. R. van Paassen and M. Mulder (2014) An ecological approach to the supervisory control of UAV swarms
- C. Kenny, R. J. Shively and K. Jordan (2014) Unmanned Aircraft System (UAS) Delegation of Separation in NextGen Airspace
- C. Santiago and E. R. Mueller (2015) Pilot Evaluation of a UAS Detect-and-Avoid System's Effectiveness in Remaining Well Clear
- F. Friedman-Berg, J. Rein and N. Racine (2014) Minimum visual information requirements for detect and avoid in unmanned aircraft systems
- G. R. Arrabito, G. Ho, Y. Li, W. Giang, C. M. Burns, M. Hou and P. Pace (2013) Multimodal Displays for Enhancing Performance in a Supervisory Monitoring Task Reaction Time to Detect Critical Events
- H. Graham and M. Cummings (2007) Assessing the Impact of Auditory Peripheral Displays for UAV Operators
- J. D. Stevenson, S. O'Young and L. Rolland (2015) Assessment of alternative manual control methods for small unmanned aerial vehicles
- J. Haber and J. Chung (2016) Assessment of UAV Operator Workload in A Reconfigurable Multi-Touch Ground Control Station Environment
- J. S. Pack, M. H. Draper, S. J. Darrah, M. P. Squire and A. Cooks (2015) Exploring Performance Differences Between UAS Sense-and-Avoid Displays
- K. Monk, R. J. Shively, L. Fern and R. C. Rorie (2015) Effects of Display Location and Information Level on UAS Pilot Assessments of a Detect and Avoid System
- L. Fern, C. A. Kenny, R. J. Shively and W. Johnson (2012) UAS integration into the NAS: an examination of baseline compliance in the current airspace system
- L. Fern, R. C. Rorie, J. S. Pack, R. J. Shively and M. H. Draper (2015) An evaluation of Detect and Avoid (DAA) displays for unmanned aircraft systems: The effect of information level and display location on pilot performance
- M. F. L. De Vries, G. J. M. Koeners, F. D. Roefs, H. T. A. Van Ginkel and E. Theunissen (2006) Operator support for time-critical situations: Design and evaluation
- R. C. Rorie and L. Fern (2014) UAS measured response the effect of GCS control mode interfaces on pilot ability to comply with ATC clearances
- R. C. Rorie and L. Fern (2015) The impact of integrated maneuver guidance information on UAS pilots performing the Detect and Avoid task

Command/control downlink connection status

Function Allocation Recommendation Tasks:

- Positive transfer of control from transferring CS to receiving CS occurs

Command/control downlink signal strength

Function Allocation Recommendation Tasks:

- Lost command and/or control link

Command/control link frequency

Operational Control Stations:

- Advanced Cockpit Ground Control Station

Literature:

- A. Hobbs and B. Lyall (2015). Human factors guidelines for unmanned aircraft system ground control stations

Command/control link strength safe operating range

Function Allocation Recommendation Tasks:

- Lost command and/or control link

Command/control uplink connection status

Function Allocation Recommendation Tasks:

- Positive transfer of control from transferring CS to receiving CS occurs

Command/control uplink signal strength

Function Allocation Recommendation Tasks:

- Lost command and/or control link

Communication channel (ATC)

Operational Control Stations:

- Advanced Cockpit Ground Control Station

Function Allocation Recommendation Tasks: • Communicate with external agents
Design Recommendation: Formats in operational control stations: • Text

Communication channel (CS)

Operational Control Stations: • Advanced Cockpit Ground Control Station
Function Allocation Recommendation Tasks: • Communicate with external agents
Design Recommendation: Formats in operational control stations: • Text

Communication channel (VO)

Operational Control Stations: • Advanced Cockpit Ground Control Station
Function Allocation Recommendation Tasks: • Communicate with external agents
Design Recommendation: Formats in operational control stations: • Text

Communication frequency (ATC)

Operational Control Stations: • Advanced Cockpit Ground Control Station
Function Allocation Recommendation Tasks: • Communicate with external agents • Visual observer failure
Design Recommendation: Formats in operational control stations: • Text

Communication frequency (CS)

Operational Control Stations: • Advanced Cockpit Ground Control Station
Function Allocation Recommendation Tasks: • Communicate with external agents • Visual observer failure
Design Recommendation: Formats in operational control stations: • Text

Communication frequency (VO)

Operational Control Stations: • Advanced Cockpit Ground Control Station
Function Allocation Recommendation Tasks: • Communicate with external agents • Visual observer failure
Design Recommendation: Formats in operational control stations: • Text

Communication radio signal strength (ATC)

Operational Control Stations: • Advanced Cockpit Ground Control Station
Design Recommendation: Formats in operational control stations: • Text

Communication radio signal strength (CS)

Operational Control Stations: • Advanced Cockpit Ground Control Station

Design Recommendation: Formats in operational control stations: • Text

Communication radio signal strength (VO)

Operational Control Stations: • Advanced Cockpit Ground Control Station
Design Recommendation: Formats in operational control stations: • Text

Contingency flight planning automation system status

Function Allocation Recommendation Tasks: • Loss of contingency flight plan automation

Control device position

Operational Control Stations: • Advanced Cockpit Ground Control Station • X-Gen Control Station
Literature: • A. C. Trujillo, R. W. Ghatas, R. Mcadaragh, D. W. Burdette, J. R. Comstock, L. E. Hempley and H. Fan (2015) Small Unmanned Aircraft Systems Integration into the National Airspace System Visual-Line-of-Sight Human-in-the-Loop Experiment • C. Kenny, R. J. Shively and K. Jordan (2014) Unmanned Aircraft System (UAS) Delegation of Separation in NextGen Airspace • C. Santiago and E. R. Mueller (2015) Pilot Evaluation of a UAS Detect-and-Avoid System's Effectiveness in Remaining Well Clear • F. Friedman-Berg, J. Rein and N. Racine (2014) Minimum visual information requirements for detect and avoid in unmanned aircraft systems • J. D. Stevenson, S. O'Young and L. Rolland (2015) Assessment of alternative manual control methods for small unmanned aerial vehicles • J. S. Pack, M. H. Draper, S. J. Darrah, M. P. Squire and A. Cooks (2015) Exploring Performance Differences Between UAS Sense-and-Avoid Displays • K. Monk, R. J. Shively, L. Fern and R. C. Rorie (2015) Effects of Display Location and Information Level on UAS Pilot Assessments of a Detect and Avoid System

- L. Fern, C. A. Kenny, R. J. Shively and W. Johnson (2012) UAS integration into the NAS: an examination of baseline compliance in the current airspace system
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- R. C. Rorie and L. Fern (2014) UAS measured response the effect of GCS control mode interfaces on pilot ability to comply with ATC clearances
- R. C. Rorie and L. Fern (2015) The impact of integrated maneuver guidance information on UAS pilots performing the Detect and Avoid task

Density altitude

Operational Control Stations:

- Advanced Cockpit Ground Control Station

Design Recommendation:

Formats in operational control stations:

- Text

Departure time

Operational Control Stations:

- Advanced Cockpit Ground Control Station
- Piccolo Command Center
- Procerus Virtual Cockpit
- SenseFly eMotion Control Station

Literature:

- B. Donmez, H. Graham and M. Cummings (2008) Assessing the Impact of Haptic Peripheral Displays for UAV Operators
- B. Donmez, M. L. Cummings and H. D. Graham (2009) Auditory decision aiding in supervisory control of multiple unmanned aerial vehicles
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- H. Graham and M. Cummings (2007) Assessing the Impact of Auditory Peripheral Displays for UAV Operators
- J. Haber and J. Chung (2016) Assessment of UAV Operator Workload in A Reconfigurable Multi-Touch Ground Control Station Environment
- K. Monk, R. J. Shively, L. Fern and R. C. Rorie (2015) Effects of Display Location and Information Level on UAS Pilot Assessments of a Detect and Avoid System
- K. W. Williams (2012) An Investigation of Sensory Information, Levels of Automation, and Piloting Experience on Unmanned Aircraft Pilot Performance
- L. Damilano, G. Guglieri, F. Quagliotti and I. Sale (2012) FMS for unmanned aerial systems: HMI issues and new interface solutions
- L. Fern and J. Shively (2011) Designing airspace displays to support rapid immersion for UAS handoffs
- L. Fern, C. A. Kenny, R. J. Shively and W. Johnson (2012) UAS integration into the NAS: an examination of baseline compliance in the current airspace system
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- M. B. Cook, H. S. Smallman, F. C. Lacson and D. I. Manes (2010) Situation displays for dynamic UAV replanning: Intuitions and performance for display formats
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- M. H. Draper, J. S. Pack, S. J. Darrah, S. N. Moulton and G. L. Calhoun (2014) Human-Machine Interface development for common airborne sense and avoid program
- R. C. Rorie and L. Fern (2014) UAS measured response the effect of GCS control mode interfaces on pilot ability to comply with ATC clearances
- R. C. Rorie and L. Fern (2015) The impact of integrated maneuver guidance information on UAS pilots performing the Detect and Avoid task
- R. C. Rorie, L. Fern and J. Shively (2016) The Impact of Suggestive Maneuver Guidance on UAS Pilot Performing the Detect and Avoid Function
- S. Watza, E. Mueller and C. Santiago (2016) Piloted Well Clear Performance Evaluation of Detect and Avoid Systems with Suggestive Guidance
- X. Yuan, J. M. Histon and S. Waslander (2014) Survey of Operators' Information Requirements on Individually Operated Unmanned Aircraft Systems

Function Allocation Recommendation Tasks:

- Loss of contingency flight plan automation
- Monitor aircraft position along route

Design Recommendation:
Formats in operational control stations:

- Line format (solid, dashed, or translucent)
- Lines connecting waypoints
- Ownship symbol relative to route
- Route overlaid on map
- Text in a grid
- Text

Destination

Operational Control Stations:

- Advanced Cockpit Ground Control Station
- Piccolo Command Center
- Procerus Virtual Cockpit
- SenseFly eMotion Control Station

Literature:

- B. Donmez, H. Graham and M. Cummings (2008) Assessing the Impact of Haptic Peripheral Displays for UAV Operators
- B. Donmez, M. L. Cummings and H. D. Graham (2009) Auditory decision aiding in supervisory control of multiple unmanned aerial vehicles
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- K. W. Williams (2012) An Investigation of Sensory Information, Levels of Automation, and Piloting Experience on Unmanned Aircraft Pilot Performance
- L. Damilano, G. Guglieri, F. Quagliotti and I. Sale (2012) FMS for unmanned aerial systems: HMI issues and new interface solutions

- L. Fern and J. Shively (2011) Designing airspace displays to support rapid immersion for UAS handoffs
- L. Fern, C. A. Kenny, R. J. Shively and W. Johnson (2012) UAS integration into the NAS: an examination of baseline compliance in the current airspace system
- L. Fern, R. C. Rorie, J. S. Pack, R. J. Shively and M. H. Draper (2015) An evaluation of Detect and Avoid (DAA) displays for unmanned aircraft systems: The effect of information level and display location on pilot performance
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- R. C. Rorie and L. Fern (2014) UAS measured response the effect of GCS control mode interfaces on pilot ability to comply with ATC clearances
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- R. C. Rorie, L. Fern and J. Shively (2016) The Impact of Suggestive Maneuver Guidance on UAS Pilot Performing the Detect and Avoid Function
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Function Allocation Recommendation Tasks:

- Loss of contingency flight plan automation
- Monitor aircraft position along route

Design Recommendation:

Formats in operational control stations:

- Line format (solid, dashed, or translucent)
- Lines connecting waypoints
- Ownship symbol relative to route
- Route overlaid on map
- Text in a grid
- Text

Dew point

Literature:

- Federal Aviation Administration (2017). Aeronautical Information Manual.

Distance to destination

Operational Control Stations:

- Piccolo Command Center

Design Recommendation:

Formats in operational control stations:

- Text

Distance to next waypoint

Operational Control Stations:

- Procerus Virtual Cockpit
- X-Gen Control Station

Literature:

- C. Fuchs, C. Borst, G. C. de Croon, M. R. van Paassen and M. Mulder (2014) An ecological approach to the supervisory control of UAV swarms
- C. Kenny, R. J. Shively and K. Jordan (2014) Unmanned Aircraft System (UAS) Delegation of Separation in NextGen Airspace
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- L. Fern, C. A. Kenny, R. J. Shively and W. Johnson (2012) UAS integration into the NAS: an examination of baseline compliance in the current airspace system

Design Recommendation:

Formats in operational control stations:

- Text

Emergency landing area(s)

Operational Control Stations:

- Advanced Cockpit Ground Control Station
- Piccolo Command Center
- Procerus Virtual Cockpit
- SenseFly eMotion Control Station

Literature:

- B. Donmez, H. Graham and M. Cummings (2008) Assessing the Impact of Haptic Peripheral Displays for UAV Operators
- B. Donmez, M. L. Cummings and H. D. Graham (2009) Auditory decision aiding in supervisory control of multiple unmanned aerial vehicles
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- X. Yuan, J. M. Histon and S. Waslander (2014) Survey of Operators' Information Requirements on Individually Operated Unmanned Aircraft Systems

Function Allocation Recommendation Tasks:

- Loss of contingency flight plan automation
- Monitor aircraft position along route

Design Recommendation:

Formats in operational control stations:

- Line format (solid, dashed, or translucent)
- Lines connecting waypoints
- Ownship symbol relative to route
- Route overlaid on map
- Text in a grid
- Text

Estimated arrival time

Operational Control Stations:

- Advanced Cockpit Ground Control Station
- Piccolo Command Center
- Procerus Virtual Cockpit
- SenseFly eMotion Control Station

Literature:

- B. Donmez, H. Graham and M. Cummings (2008) Assessing the Impact of Haptic Peripheral Displays for UAV Operators
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Function Allocation Recommendation Tasks:

- Loss of contingency flight plan automation
- Monitor aircraft position along route

Design Recommendation: Formats in operational control stations: • Line format (solid, dashed, or translucent) • Lines connecting waypoints • Ownship symbol relative to route • Route overlaid on map • Text in a grid • Text

Estimated flight range remaining

Operational Control Stations: • SenseFly eMotion Control Station
Design Recommendation: Formats in operational control stations: • Text

Estimated time enroute

Operational Control Stations: • Piccolo Command Center
Design Recommendation: Formats in operational control stations: • Text

Flight mode annunciation

Operational Control Stations: • Advanced Cockpit Ground Control Station • Piccolo Command Center • Procerus Virtual Cockpit • SenseFly eMotion Control Station • X-Gen Control Station
Design Recommendation: Formats in operational control stations: • Color-coded indicator • Data tag text • Text

Flight plan type (IFR vs. VFR)

Operational Control Stations:

- Advanced Cockpit Ground Control Station
- Piccolo Command Center
- Procerus Virtual Cockpit
- SenseFly eMotion Control Station

Literature:

- B. Donmez, H. Graham and M. Cummings (2008) Assessing the Impact of Haptic Peripheral Displays for UAV Operators
- B. Donmez, M. L. Cummings and H. D. Graham (2009) Auditory decision aiding in supervisory control of multiple unmanned aerial vehicles
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Function Allocation Recommendation Tasks:

- Loss of contingency flight plan automation
- Monitor aircraft position along route

Design Recommendation:

Formats in operational control stations:

- Line format (solid, dashed, or translucent)
- Lines connecting waypoints
- Ownship symbol relative to route
- Route overlaid on map
- Text in a grid
- Text

Flight surface positions

Operational Control Stations:

- Advanced Cockpit Ground Control Station

Design Recommendation:

Formats in operational control stations:

- Color-coded text
- Text and up/down arrow

Flight time elapsed

Operational Control Stations: • SenseFly eMotion Control Station
Literature: • B. Donmez, H. Graham and M. Cummings (2008) Assessing the Impact of Haptic Peripheral Displays for UAV Operators • B. Donmez, M. L. Cummings and H. D. Graham (2009) Auditory decision aiding in supervisory control of multiple unmanned aerial vehicles • C. Kenny, R. J. Shively and K. Jordan (2014) Unmanned Aircraft System (UAS) Delegation of Separation in NextGen Airspace • H. Graham and M. Cummings (2007) Assessing the Impact of Auditory Peripheral Displays for UAV Operators • L. Fern and J. Shively (2011) Designing airspace displays to support rapid immersion for UAS handoffs • L. Fern, C. A. Kenny, R. J. Shively and W. Johnson (2012) UAS integration into the NAS: an examination of baseline compliance in the current airspace system • T. H. Kamine and G. A. Bendrick (2009) Visual Display Angles of Conventional and a Remotely Piloted Aircraft
Design Recommendation: Formats in operational control stations: • Text

Ground speed

Operational Control Stations: • Advanced Cockpit Ground Control Station • Procerus Virtual Cockpit • SenseFly eMotion Control Station • X-Gen Control Station
Function Allocation Recommendation Tasks: • Control aircraft speed along taxi route • Perform brake check • Slow aircraft to taxi speed
Design Recommendation: Formats in operational control stations: • Text

Ground track

Operational Control Stations:

- X-Gen Control Station

Literature:

- C. Santiago and E. R. Mueller (2015) Pilot Evaluation of a UAS Detect-and-Avoid System's Effectiveness in Remaining Well Clear
- F. Friedman-Berg, J. Rein and N. Racine (2014) Minimum visual information requirements for detect and avoid in unmanned aircraft systems
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- S. Watza, E. Mueller and C. Santiago (2016) Piloted Well Clear Performance Evaluation of Detect and Avoid Systems with Suggestive Guidance

Function Allocation Recommendation Tasks:

- Manage horizontal flight path

Heading target

Operational Control Stations:

- Piccolo Command Center

Function Allocation Recommendation Tasks:

- Command aircraft heading

Design Recommendation:

Formats in operational control stations:

- Text
- Text in pop-up window

Inactive flight plan(s)

Operational Control Stations:

- X-Gen Control Station

Indicated airspeed

Relevant Certified Federal Regulation(s):

- 14 CFR 23.1303(a)
- 14 CFR 23.1303(e)
- 14 CFR 23.1303(g)(1)
- 14 CFR 23.1543(b)(2)
- 14 CFR 23.1543(b)(3)
- 14 CFR 23.1543(b)(4)
- 14 CFR 23.1543(b)(5)
- 14 CFR 23.1543(c)
- 14 CFR 23.1543(d)
- 14 CFR 25.1303(b)(1)
- 14 CFR 25.1303(c)(1)
- 14 CFR 25.1303(c)(2)
- 14 CFR 25.1563
- 14 CFR 91.205(b)(1)
- 14 CFR 91.603

Operational Control Stations:

- Advanced Cockpit Ground Control Station
- Piccolo Command Center
- Procerus Virtual Cockpit
- SenseFly eMotion Control Station
- X-Gen Control Station

Literature:

- A. C. Trujillo, R. W. Ghatas, R. Mcadaragh, D. W. Burdette, J. R. Comstock, L. E. Hempley and H. Fan (2015) Small Unmanned Aircraft Systems Integration into the National Airspace System Visual-Line-of-Sight Human-in-the-Loop Experiment
- B. Donmez, H. Graham and M. Cummings (2008) Assessing the Impact of Haptic Peripheral Displays for UAV Operators
- C. Fuchs, C. Borst, G. C. de Croon, M. R. van Paassen and M. Mulder (2014) An ecological approach to the supervisory control of UAV swarms
- C. Kenny, R. J. Shively and K. Jordan (2014) Unmanned Aircraft System (UAS) Delegation of Separation in NextGen Airspace
- C. Santiago and E. R. Mueller (2015) Pilot Evaluation of a UAS Detect-and-Avoid System's Effectiveness in Remaining Well Clear
- F. Friedman-Berg, J. Rein and N. Racine (2014) Minimum visual information requirements for detect and avoid in unmanned aircraft systems
- G. R. Arrabito, G. Ho, Y. Li, W. Giang, C. M. Burns, M. Hou and P. Pace (2013) Multimodal Displays for Enhancing Performance in a Supervisory Monitoring Task Reaction Time to Detect Critical Events
- H. Graham and M. Cummings (2007) Assessing the Impact of Auditory Peripheral Displays for UAV Operators
- J. D. Stevenson, S. O'Young and L. Rolland (2015) Assessment of alternative manual control methods for small unmanned aerial vehicles

- J. Haber and J. Chung (2016) Assessment of UAV Operator Workload in A Reconfigurable Multi-Touch Ground Control Station Environment
- J. S. Pack, M. H. Draper, S. J. Darrah, M. P. Squire and A. Cooks (2015) Exploring Performance Differences Between UAS Sense-and-Avoid Displays
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- L. Fern, C. A. Kenny, R. J. Shively and W. Johnson (2012) UAS integration into the NAS: an examination of baseline compliance in the current airspace system
- L. Fern, R. C. Rorie, J. S. Pack, R. J. Shively and M. H. Draper (2015) An evaluation of Detect and Avoid (DAA) displays for unmanned aircraft systems: The effect of information level and display location on pilot performance
- M. F. L. De Vries, G. J. M. Koeners, F. D. Roefs, H. T. A. Van Ginkel and E. Theunissen (2006) Operator support for time-critical situations: Design and evaluation
- R. C. Rorie and L. Fern (2014) UAS measured response the effect of GCS control mode interfaces on pilot ability to comply with ATC clearances
- R. C. Rorie and L. Fern (2015) The impact of integrated maneuver guidance information on UAS pilots performing the Detect and Avoid task
- T. H. Kamine and G. A. Bendrick (2009) Visual Display Angles of Conventional and a Remotely Piloted Aircraft

Function Allocation Recommendation Tasks:

- Determine top of descent
- Landing decision
- Manage airspeed
- Monitor aircraft airspeed in relation to scheduled takeoff speeds
- Monitor airspeed in comparison to configuration-based airspeed limits

Applicability:

- Commuter category airplanes for which airspeed limitations vary with altitude
- For (1) Turbine engine powered airplanes and (2) Other airplanes for which VMO/MMO and VD/MD are established under 23.335(b)(4) and 23.1505(c) if VMO/MMO is greater than 0.8 VD/MD
- For airplanes for which a maximum operating speed VMO/MMO is established
- For airplanes with compressibility limitations not otherwise indicated to the pilot by the airspeed indicating system
- For large and transport category aircraft
- For reciprocating multiengine-powered airplanes of 6,000 pounds or less maximum weight
- For VFR flight during the day or night, IFR flight, and night vision goggle operations
- If VNE or VNO vary with altitude
- Minimum required flight and navigation instrument

Design Recommendations:

Design guidance in FARs:

- Aural alert
- Aural warning
- Blue radial line
- Green arc with lower limit at VS1 with maximum weight and landing gear and flaps retracted, and the upper limit at the maximum structural cruising speed VNO
- Red radial line for VMO/MMO must be made at the lowest value of VMO/MMO established for any altitude up to the maximum operating altitude for the airplane
- White arc with the lower limit at VSO at the maximum weight and the upper limit at the flaps-extended speed VFE
- Yellow arc extending from the red line specified in (b)(1) to the upper limit of the green arc specified in (b)(3)

Formats in operational control stations:

- Color coded text and color coded speed tape
- Tape and text
- Text
- Text and bug
- Text and speed tape
- Text in pop-up window

Indicated airspeed target

Operational Control Stations:

- Piccolo Command Center
- Procerus Virtual Cockpit
- SenseFly eMotion Control Station
- X-Gen Control Station

Function Allocation Recommendation Tasks:

- Manage airspeed

Design Recommendation:

Formats in operational control stations:

- Text
- Text and bug
- Text in pop-up window

Indicated altitude

Relevant Certified Federal Regulation(s):

- 14 CFR 23.1303(b)

- 14 CFR 23.1303(g)(1)
- 14 CFR 23.1305(b)(5)
- 14 CFR 23.1543(c)
- 14 CFR 23.1543(d)
- 14 CFR 25.1303(b)(2)
- 14 CFR 25.1305(b)(3)
- 14 CFR 91.205(b)(2)
- 14 CFR 91.205(b)(8)
- 14 CFR 91.205(d)(5)
- 14 CFR 91.205(h)(7)
- 14 CFR 91.219(b)(1)

Operational Control Stations:

- Advanced Cockpit Ground Control Station
- Piccolo Command Center
- Procerus Virtual Cockpit
- SenseFly eMotion Control Station
- X-Gen Control Station

Literature:

- A. C. Trujillo, R. W. Ghatas, R. Mcadaragh, D. W. Burdette, J. R. Comstock, L. E. Hempley and H. Fan (2015) Small Unmanned Aircraft Systems Integration into the National Airspace System Visual-Line-of-Sight Human-in-the-Loop Experiment
- B. Donmez, H. Graham and M. Cummings (2008) Assessing the Impact of Haptic Peripheral Displays for UAV Operators
- C. Fuchs, C. Borst, G. C. de Croon, M. R. van Paassen and M. Mulder (2014) An ecological approach to the supervisory control of UAV swarms
- C. Kenny, R. J. Shively and K. Jordan (2014) Unmanned Aircraft System (UAS) Delegation of Separation in NextGen Airspace
- C. Santiago and E. R. Mueller (2015) Pilot Evaluation of a UAS Detect-and-Avoid System's Effectiveness in Remaining Well Clear
- F. Friedman-Berg, J. Rein and N. Racine (2014) Minimum visual information requirements for detect and avoid in unmanned aircraft systems
- G. L. Calhoun, C. A. Miller, T. C. Hughes and M. H. Draper (2014) UAS sense and avoid system interface design and evaluation
- G. R. Arrabito, G. Ho, Y. Li, W. Giang, C. M. Burns, M. Hou and P. Pace (2013) Multimodal Displays for Enhancing Performance in a Supervisory Monitoring Task Reaction Time to Detect Critical Events
- H. Graham and M. Cummings (2007) Assessing the Impact of Auditory Peripheral Displays for UAV Operators
- J. D. Stevenson, S. O'Young and L. Rolland (2015) Assessment of alternative manual control methods for small unmanned aerial vehicles
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- K. Monk, R. J. Shively, L. Fern and R. C. Rorie (2015) Effects of Display Location and Information Level on UAS Pilot Assessments of a Detect and Avoid System
- K. W. Williams (2012) An Investigation of Sensory Information, Levels of Automation, and Piloting Experience on Unmanned Aircraft Pilot Performance
- L. Damilano, G. Guglieri, F. Quagliotti and I. Sale (2012) FMS for unmanned aerial systems: HMI issues and new interface solutions
- L. Fern, C. A. Kenny, R. J. Shively and W. Johnson (2012) UAS integration into the NAS: an examination of baseline compliance in the current airspace system
- L. Fern, R. C. Rorie, J. S. Pack, R. J. Shively and M. H. Draper (2015) An evaluation of Detect and Avoid (DAA) displays for unmanned aircraft systems: The effect of information level and display location on pilot performance
- M. B. Cook, H. S. Smallman, F. C. Lacson and D. I. Manes (2009) Design and validation of a synthetic task environment to study dynamic unmanned aerial vehicle re-planning
- M. B. Cook, H. S. Smallman, F. C. Lacson and D. I. Manes (2010) Situation displays for dynamic UAV replanning: Intuitions and performance for display formats
- M. F. L. De Vries, G. J. M. Koeners, F. D. Roefs, H. T. A. Van Ginkel and E. Theunissen (2006) Operator support for time-critical situations: Design and evaluation
- M. H. Draper, J. S. Pack, S. J. Darrah, S. N. Moulton and G. L. Calhoun (2014) Human-Machine Interface development for common airborne sense and avoid program
- M. Hou, G. Ho, G. R. Arrabito, S. Young and S. Yin (2013) Effects of display mode and input method for handheld control of micro aerial vehicles for a reconnaissance mission
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- R. C. Rorie and L. Fern (2015) The impact of integrated maneuver guidance information on UAS pilots performing the Detect and Avoid task
- R. C. Rorie, L. Fern and J. Shively (2016) The Impact of Suggestive Maneuver Guidance on UAS Pilot Performing the Detect and Avoid Function
- S. Watza, E. Mueller and C. Santiago (2016) Piloted Well Clear Performance Evaluation of Detect and Avoid Systems with Suggestive Guidance
- X. Yuan, J. M. Histon and S. Waslander (2014) Survey of Operators' Information Requirements on Individually Operated Unmanned Aircraft Systems

Function Allocation Recommendation Tasks:

- Check for positive rate of climb
- Determine top of descent
- Manage altitude
- Monitor aircraft altitude along route
- Set altimeter for transition level/altitude

Applicability:

- Commuter category airplanes for which airspeed limitations vary with altitude
- For airplanes for which a maximum operating speed VMO/MMO is established
- For reciprocating engine-powered airplanes
- For turbojet-powered civil airplanes
- For VFR flight during the day or night, IFR flight, and night vision goggle operations
- If VNE or VNO vary with altitude
- IFR flight
- Minimum required flight and navigation instrument
- Night vision goggle operations

Design Recommendation:

Design guidance in CFRs:

- Red radial line for VMO/MMO must be made at the lowest value of VMO/MMO established for any altitude up to the maximum operating altitude for the airplane
- Sequence of both aural and visual signals in sufficient to establish level flight

Formats in operational control stations:

- Color coded text and color coded altitude tape
- Color-coded route segments
- Data tag text
- Route overlaid on vertical profile
- Tape and text
- Text
- Text and altitude tape
- Text and bug
- Text in a grid
- Text in pop-up window

Landing gear control position

Operational Control Stations:

- Advanced Cockpit Ground Control Station

Design Recommendation:

Formats in operational control stations:

- Scale

Landing gear status

Relevant Certified Federal Regulation(s):

- 14 CFR 91.205(b)(10)

Operational Control Stations:
- Advanced Cockpit Ground Control Station
- X-Gen Control Station

Applicability:
For VFR flight during the day or night, IFR flight, and night vision goggle operations

Design Recommendation:
Formats in operational control stations:
- Color-coded indicator
- Text

Latitude

Operational Control Stations:
- Piccolo Command Center
- Procerus Virtual Cockpit
- SenseFly eMotion Control Station
- X-Gen Control Station

Function Allocation Recommendation Tasks:
- Command aircraft heading
- Ensure aircraft is in safe location for landing
- Identify touchdown target on first third of runway
- Manage horizontal flight path
- Monitor aircraft position along route
- Turn aircraft off runway

Design Recommendation:
Formats in operational control stations:
- Text
- Text in pop-up window
- UA symbol on map

Lift/drag device position

Relevant Certified Federal Regulation(s):
- 14 CFR 23.1305(b)(3)
- 14 CFR 23.1543(b)(4)
- 14 CFR 23.207(a)
- 14 CFR 23.677(a)
- 14 CFR 23.699(a)
- 14 CFR 23.729(f)

- 14 CFR 25.1305(b)(2)
- 14 CFR 25.1563
- 14 CFR 25.207(a)
- 14 CFR 25.677(b)
- 14 CFR 25.699(a)
- 14 CFR 25.729(e)(2)-(3), (7)
- 14 CFR 25.1563

Operational Control Stations:

- Advanced Cockpit Ground Control Station
- Piccolo Command Center
- Procerus Virtual Cockpit

Function Allocation Recommendation Tasks:

- Monitor airspeed in comparison to configuration-based airspeed limits

Applicability:

- For reciprocating engine-powered commuter category airplanes
- if (1) any flap position other than retracted or fully extended is used to show compliance with performance requirements
- "Unless (a) a direct operating mechanism provides a sense of ""feel and position; or (2) The flap position is readily determined without seriously detracting from other piloting duties"

Design Recommendation:

Design guidance in CFRs:

- Aural warning
- Visual warning itself is not acceptable
- Warning may be furnished either through the inherent aerodynamic qualities of the airplane or by a device that will give clearly distinguishable indications under expected conditions of flight.
- White arc with the lower limit at VSO at the maximum weight and the upper limit at the flaps-extended speed VFE

Formats in operational control stations:

- Color-coded text
- Scale
- Text and scale
- Text in pop-up window

Lift/drag device position target

Operational Control Stations:

- Piccolo Command Center

Design Recommendation: Formats in operational control stations: • Text in pop-up window

Loiter area(s)

Operational Control Stations: • Piccolo Command Center
Design Recommendation: Formats in operational control stations: • Circular routes overlaid on map

Loiter waypoint direction

Operational Control Stations: • Piccolo Command Center
Design Recommendation: Formats in operational control stations: • Text in pop-up window

Loiter waypoint radius

Operational Control Stations: • Piccolo Command Center
Design Recommendation: Formats in operational control stations: • Text in pop-up window

Loiter waypoint time

Operational Control Stations: • Piccolo Command Center

Design Recommendation:
Formats in operational control stations:
- Text in pop-up window

Longitude

Operational Control Stations:
- Piccolo Command Center
- Procerus Virtual Cockpit
- SenseFly eMotion Control Station
- X-Gen Control Station

Function Allocation Recommendation Tasks:
- Command aircraft heading
- Ensure aircraft is in safe location for landing
- Identify touchdown target on first third of runway
- Manage horizontal flight path
- Monitor aircraft position along route
- Turn aircraft off runway

Design Recommendation:
Formats in operational control stations:
- Text
- Text in pop-up window
- UA symbol on map

Lost command/control link elapsed time

Function Allocation Recommendation Tasks:
- Lost command and/or control link

Magnetic heading

Relevant Federal Aviation Regulation(s):
- 14 CFR 25.1303(a)(3)
- 14 CFR 25.1303(b)(6)
- 14 CFR 23.1303(c)
- 14 CFR 23.1327
- 14 CFR 25.1327
- 14 CFR 91.205(b)(3)
- 14 CFR 91.205(d)(9)

Operational Control Stations:

- Advanced Cockpit Ground Control Station
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- X-Gen Control Station

Literature:

- A. C. Trujillo, R. W. Ghatas, R. Mcadaragh, D. W. Burdette, J. R. Comstock, L. E. Hempley and H. Fan (2015) Small Unmanned Aircraft Systems Integration into the National Airspace System Visual-Line-of-Sight Human-in-the-Loop Experiment
- B. Donmez, H. Graham and M. Cummings (2008) Assessing the Impact of Haptic Peripheral Displays for UAV Operators
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- F. Friedman-Berg, J. Rein and N. Racine (2014) Minimum visual information requirements for detect and avoid in unmanned aircraft systems
- G. L. Calhoun, C. A. Miller, T. C. Hughes and M. H. Draper (2014) UAS sense and avoid system interface design and evaluation
- G. R. Arrabito, G. Ho, Y. Li, W. Giang, C. M. Burns, M. Hou and P. Pace (2013) Multimodal Displays for Enhancing Performance in a Supervisory Monitoring Task Reaction Time to Detect Critical Events
- H. Graham and M. Cummings (2007) Assessing the Impact of Auditory Peripheral Displays for UAV Operators
- J. D. Stevenson, S. O'Young and L. Rolland (2015) Assessment of alternative manual control methods for small unmanned aerial vehicles
- J. Haber and J. Chung (2016) Assessment of UAV Operator Workload in A Reconfigurable Multi-Touch Ground Control Station Environment
- J. S. Pack, M. H. Draper, S. J. Darrah, M. P. Squire and A. Cooks (2015) Exploring Performance Differences Between UAS Sense-and-Avoid Displays
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- K. W. Williams (2012) An Investigation of Sensory Information, Levels of Automation, and Piloting Experience on Unmanned Aircraft Pilot Performance
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- L. Fern, C. A. Kenny, R. J. Shively and W. Johnson (2012) UAS integration into the NAS: an examination of baseline compliance in the current airspace system
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- M. F. L. De Vries, G. J. M. Koeners, F. D. Roefs, H. T. A. Van Ginkel and E. Theunissen (2006) Operator support for time-critical situations: Design and evaluation

- M. H. Draper, J. S. Pack, S. J. Darrah, S. N. Moulton and G. L. Calhoun (2014) Human-Machine Interface development for common airborne sense and avoid program
- M. Hou, G. Ho, G. R. Arrabito, S. Young and S. Yin (2013) Effects of display mode and input method for handheld control of micro aerial vehicles for a reconnaissance mission
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- R. C. Rorie and L. Fern (2015) The impact of integrated maneuver guidance information on UAS pilots performing the Detect and Avoid task
- R. C. Rorie, L. Fern and J. Shively (2016) The Impact of Suggestive Maneuver Guidance on UAS Pilot Performing the Detect and Avoid Function
- S. Watza, E. Mueller and C. Santiago (2016) Piloted Well Clear Performance Evaluation of Detect and Avoid Systems with Suggestive Guidance
- T. H. Kamine and G. A. Bendrick (2009) Visual Display Angles of Conventional and a Remotely Piloted Aircraft
- W. Rodes and L. Gugerty (2012) Effects of electronic map displays and individual differences in ability on navigation performance
- X. Yuan, J. M. Histon and S. Waslander (2014) Survey of Operators' Information Requirements on Individually Operated Unmanned Aircraft Systems

Function Allocation Recommendation Tasks:

- Command aircraft heading
- Maintain runway centerline
- Manage horizontal flight path

Applicability:

- For VFR flight during the day or night, IFR flight, and night vision goggle operations
- IFR flight
- Installed at each pilot station
- Minimum required flight and navigation instrument
- Must be visible from each pilot station

Design Recommendation:

Design guidance in CFRs:

- Gyroscopically stabilized, magnetic, or non-magnetic)
- Non-stabilized magnetic compass

Formats in operational control stations:

- Text
- Text and compass rose
- Text and heading tape
- Text in pop-up window

Maximum altitude

Operational Control Stations:
- SenseFly eMotion Control Station

Function Allocation Recommendation Tasks:
- Manage altitude

Design Recommendation:
Formats in operational control stations:
- Text

Maximum flaps extended speed (V_{FE})

Function Allocation Recommendation Tasks:
- Monitor airspeed in comparison to configuration-based airspeed limits

Maximum landing gear extended speed (V_{LE})

Function Allocation Recommendation Tasks:
- Monitor airspeed in comparison to configuration-based airspeed limits

Maximum landing gear operating speed (V_{LO})

Relevant Certified Federal Regulation(s):
- 14 CFR 23.1563(b)

Function Allocation Recommendation Tasks:
- Monitor airspeed in comparison to configuration-based airspeed limits

Maximum operating limit speed (V_{MO})

Relevant Certified Federal Regulation(s):
- 14 CFR 23.1303(g)(1)
- 14 CFR 23.1543(d)
- 14 CFR 25.1563
- 14 CFR 25.1563
- 14 CFR 91.603

Function Allocation Recommendation Tasks:
- Manage airspeed

Applicability:
- Commuter category airplanes for which airspeed limitations vary with altitude
- For airplanes for which a maximum operating speed V_{MO}/M_{MO} is established
- For large and transport category aircraft

Design Recommendation:
Design guidance in CFRs:
- Aural alert
- Red radial line for V_{MO}/M_{MO} must be made at the lowest value of V_{MO}/M_{MO} established for any altitude up to the maximum operating altitude for the airplane

Maximum operating maneuvering speed (V_O)

Relevant Certified Federal Regulation(s):
- 14 CFR 23.1351(d)(2)
- 14 CFR 23.1563(a)
- 14 CFR 25.1351(b)(6)

Operational Control Stations:
- Advanced Cockpit Ground Control Station
- Piccolo Command Center
- Procerus Virtual Cockpit
- SenseFly eMotion Control Station
- X-Gen Control Station

Applicability:
- For commuter category airplanes

Design Recommendation:
Formats in operational control stations:
- Color-coded text and color-coded gauge
- Text
- Text and color-coded scale
- Text and scale

Maximum speed for normal operations (V_{NO})

Function Allocation Recommendation Tasks:
- Manage airspeed

Navigation aid status

Operational Control Stations: • Advanced Cockpit Ground Control Station • SenseFly eMotion Control Station
Design Recommendation: Formats in operational control stations: • Line format (solid, dashed, and translucent) • Text

Never-exceed speed (V_{NE})

Relevant Certified Federal Regulation(s): • 14 CFR 23.1543(b)(1) • 14 CFR 25.1563
Function Allocation Recommendation Tasks: • Manage airspeed
Design Recommendation: Design guidance in CFRs: • Red radial line

Optimal climb speed

Function Allocation Recommendation Tasks: • Manage airspeed • Monitor airspeed in comparison to configuration-based airspeed limits

Optimal cruise speed

Function Allocation Recommendation Tasks: • Manage airspeed

Optimal descent speed

Function Allocation Recommendation Tasks: • Manage airspeed • Determine approach profile

Origin

Operational Control Stations:

- Advanced Cockpit Ground Control Station
- Piccolo Command Center
- Procerus Virtual Cockpit
- SenseFly eMotion Control Station

Literature:

- B. Donmez, H. Graham and M. Cummings (2008) Assessing the Impact of Haptic Peripheral Displays for UAV Operators
- B. Donmez, M. L. Cummings and H. D. Graham (2009) Auditory decision aiding in supervisory control of multiple unmanned aerial vehicles
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- G. L. Calhoun, C. A. Miller, T. C. Hughes and M. H. Draper (2014) UAS sense and avoid system interface design and evaluation
- G. L. Calhoun, M. Draper, C. Miller, H. Ruff, C. Breeden and J. Hamell (2013) Adaptable automation interface for multi-unmanned aerial systems control: Preliminary usability evaluation
- H. Graham and M. Cummings (2007) Assessing the Impact of Auditory Peripheral Displays for UAV Operators
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- L. Damilano, G. Guglieri, F. Quagliotti and I. Sale (2012) FMS for unmanned aerial systems: HMI issues and new interface solutions
- L. Fern and J. Shively (2011) Designing airspace displays to support rapid immersion for UAS handoffs
- L. Fern, C. A. Kenny, R. J. Shively and W. Johnson (2012) UAS integration into the NAS: an examination of baseline compliance in the current airspace system
- L. Fern, R. C. Rorie, J. S. Pack, R. J. Shively and M. H. Draper (2015) An evaluation of Detect and Avoid (DAA) displays for unmanned aircraft systems: The effect of information level and display location on pilot performance
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- M. B. Cook, H. S. Smallman, F. C. Lacson and D. I. Manes (2010) Situation displays for dynamic UAV replanning: Intuitions and performance for display formats

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Function Allocation Recommendation Tasks:

- Loss of contingency flight plan automation
- Monitor aircraft position along route

Design Recommendation:

Formats in operational control stations:

- Line format (solid, dashed, or translucent)
- Lines connecting waypoints
- Ownship symbol relative to route
- Route overlaid on map
- Text in a grid
- Text

Pilot identification data

Literature:

- Federal Aviation Administration (2017). Aeronautical Information Manual.

Pitch angle target

Function Allocation Recommendation Tasks:

- Lift off/rotate
- Perform landing/touchdown

Pitch attitude

Relevant Certified Federal Regulation(s):

- 14 CFR 23.1305(b)(8)

- 14 CFR 23.1305(e)(2)
- 14 CFR 23.677(a)
- 14 CFR 25.1303(b)(5)
- 14 CFR 25.1305(e)(1)
- 14 CFR 25.677(b)
- 14 CFR 91.205(d)(8)
- 14 CFR 91.205(h)(5)

Operational Control Stations:

- Advanced Cockpit Ground Control Station
- Piccolo Command Center
- Procerus Virtual Cockpit
- SenseFly eMotion Control Station
- X-Gen Control Station

Literature:

- A. C. Trujillo, R. W. Ghatas, R. Mcadaragh, D. W. Burdette, J. R. Comstock, L. E. Hempley and H. Fan (2015) Small Unmanned Aircraft Systems Integration into the National Airspace System Visual-Line-of-Sight Human-in-the-Loop Experiment
- C. Kenny, R. J. Shively and K. Jordan (2014) Unmanned Aircraft System (UAS) Delegation of Separation in NextGen Airspace
- F. Friedman-Berg, J. Rein and N. Racine (2014) Minimum visual information requirements for detect and avoid in unmanned aircraft systems
- G. R. Arrabito, G. Ho, Y. Li, W. Giang, C. M. Burns, M. Hou and P. Pace (2013) Multimodal Displays for Enhancing Performance in a Supervisory Monitoring Task Reaction Time to Detect Critical Events
- L. Fern, C. A. Kenny, R. J. Shively and W. Johnson (2012) UAS integration into the NAS: an examination of baseline compliance in the current airspace system
- T. H. Kamine and G. A. Bendrick (2009) Visual Display Angles of Conventional and a Remotely Piloted Aircraft

Function Allocation Recommendation Tasks:

- Lift off/rotate
- Perform landing/touchdown

Applicability:

- For reciprocating engine-powered airplanes
- For turbopropeller-powered airplanes
- IFR flight and night vision goggle operations
- Installed at each pilot station

Design Guidance:

Design guidance in CFRs:

- Artificial horizon

Formats in operational control stations: • Attitude indicator • Attitude indicator and scale • Text

Planned cruise altitude

Operational Control Stations: • Advanced Cockpit Ground Control Station • Piccolo Command Center • Procerus Virtual Cockpit • SenseFly eMotion Control Station • X-Gen Control Station
Function Allocation Recommendation Tasks: • Monitor aircraft altitude along route
Design Recommendation: Formats in operational control stations: • Text • Text and bug • Text in pop-up window

Position relative to desired flight route

Operational Control Stations: • Advanced Cockpit Ground Control Station • SenseFly eMotion Control Station
Function Allocation Recommendation Tasks: • Command aircraft heading
Design Recommendation: Formats in operational control stations: • Navigation display • Text

Position relative to desired glidepath

Operational Control Stations:
- Advanced Cockpit Ground Control Station
- Piccolo Command Center

Design Recommendation:
Formats in operational control stations:
- Glideslope indicator (scale)

Position relative to desired path over ground

Operational Control Stations:
- Advanced Cockpit Ground Control Station
- Piccolo Command Center

Design Recommendation:
Formats in operational control stations:
- Localizer indicator (scale)

Position relative to desired taxi route

Function Allocation Recommendation Tasks:
- Determine runway turn-off
- Turn aircraft off runway

Position relative to taxiway centerline

Function Allocation Recommendation Tasks:
- Control aircraft track along taxi route

Precipitation

Literature:
- Federal Aviation Administration (2017). Aeronautical Information Manual.

Procedure

Operational Control Stations:
- Advanced Cockpit Ground Control Station

Function Allocation Recommendation Tasks:

- Perform system health and status intervention
- Degraded aircraft position reporting
- Loss of contingency flight plan automation
- Lost command and/or control link
- Visual observer failure

Design Recommendation:

Formats in operational control stations:

- Text

Quality of information reported by navigation aid

Operational Control Stations:

- Procerus Virtual Cockpit
- SenseFly eMotion Control Station

Design Recommendation:

Formats in operational control stations:

- Color-coded indicator
- Signal strength symbol
- Text

Rate of turn

Relevant Certified Federal Regulation(s):

- 14 CFR 25.1303(b)(f)
- 14 CFR 91.205(d)(3)

Applicability:

- IFR flight
- Installed at each pilot station

Roll attitude/bank angle

Relevant Certified Federal Regulation(s):

- 14 CFR 23.1305(b)(5)
- 14 CFR 25.1303(b)(5)
- 14 CFR 25.1305(b)(3)
- 14 CFR 91.205(d)(8)
- 14 CFR 91.205(h)(5)

Operational Control Stations:

- Advanced Cockpit Ground Control Station
- Piccolo Command Center
- Procerus Virtual Cockpit
- SenseFly eMotion Control Station
- X-Gen Control Station

Literature:

- A. C. Trujillo, R. W. Ghatas, R. Mcadaragh, D. W. Burdette, J. R. Comstock, L. E. Hempley and H. Fan (2015) Small Unmanned Aircraft Systems Integration into the National Airspace System Visual-Line-of-Sight Human-in-the-Loop Experiment
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- F. Friedman-Berg, J. Rein and N. Racine (2014) Minimum visual information requirements for detect and avoid in unmanned aircraft systems
- G. R. Arrabito, G. Ho, Y. Li, W. Giang, C. M. Burns, M. Hou and P. Pace (2013) Multimodal Displays for Enhancing Performance in a Supervisory Monitoring Task Reaction Time to Detect Critical Events
- L. Fern, C. A. Kenny, R. J. Shively and W. Johnson (2012) UAS integration into the NAS: an examination of baseline compliance in the current airspace system
- T. H. Kamine and G. A. Bendrick (2009) Visual Display Angles of Conventional and a Remotely Piloted Aircraft

Function Allocation Recommendation Tasks:

- Lift off/rotate
- Perform landing/touchdown

Applicability:

- For reciprocating engine-powered airplanes
- IFR flight and night vision goggle operations
- Installed at each pilot station

Design Recommendation:

Design guidance in CFRs:

- Artificial horizon

Formats in operational control stations:

- Attitude indicator
- Attitude indicator and scale
- Text
- Text in pop-up window

Roll attitude/bank angle target

Operational Control Stations: • Piccolo Command Center
Design Recommendation: Formats in operational control stations: • Text in pop-up window

Rotation speed (V_R)

Function Allocation Recommendation Tasks: • Monitor aircraft airspeed in relation to scheduled takeoff speeds

Route of flight

Operational Control Stations: • Advanced Cockpit Ground Control Station • Piccolo Command Center • Procerus Virtual Cockpit • SenseFly eMotion Control Station
Literature: • B. Donmez, H. Graham and M. Cummings (2008) Assessing the Impact of Haptic Peripheral Displays for UAV Operators • B. Donmez, M. L. Cummings and H. D. Graham (2009) Auditory decision aiding in supervisory control of multiple unmanned aerial vehicles • C. Fuchs, C. Borst, G. C. de Croon, M. R. van Paassen and M. Mulder (2014) An ecological approach to the supervisory control of UAV swarms • C. Kenny, R. J. Shively and K. Jordan (2014) Unmanned Aircraft System (UAS) Delegation of Separation in NextGen Airspace • C. Santiago and E. R. Mueller (2015) Pilot Evaluation of a UAS Detect-and-Avoid System's Effectiveness in Remaining Well Clear • G. L. Calhoun, C. A. Miller, T. C. Hughes and M. H. Draper (2014) UAS sense and avoid system interface design and evaluation • G. L. Calhoun, M. Draper, C. Miller, H. Ruff, C. Breeden and J. Hamell (2013) Adaptable automation interface for multi-unmanned aerial systems control: Preliminary usability evaluation • H. Graham and M. Cummings (2007) Assessing the Impact of Auditory Peripheral Displays for UAV Operators • J. Haber and J. Chung (2016) Assessment of UAV Operator Workload in A Reconfigurable Multi-Touch Ground Control Station Environment • K. Monk, R. J. Shively, L. Fern and R. C. Rorie (2015) Effects of Display Location and Information Level on UAS Pilot Assessments of a Detect and Avoid System

- K. W. Williams (2012) An Investigation of Sensory Information, Levels of Automation, and Piloting Experience on Unmanned Aircraft Pilot Performance
- L. Damilano, G. Guglieri, F. Quagliotti and I. Sale (2012) FMS for unmanned aerial systems: HMI issues and new interface solutions
- L. Fern and J. Shively (2011) Designing airspace displays to support rapid immersion for UAS handoffs
- L. Fern, C. A. Kenny, R. J. Shively and W. Johnson (2012) UAS integration into the NAS: an examination of baseline compliance in the current airspace system
- L. Fern, R. C. Rorie, J. S. Pack, R. J. Shively and M. H. Draper (2015) An evaluation of Detect and Avoid (DAA) displays for unmanned aircraft systems: The effect of information level and display location on pilot performance
- M. B. Cook, H. S. Smallman, F. C. Lacson and D. I. Manes (2009) Design and validation of a synthetic task environment to study dynamic unmanned aerial vehicle re-planning
- M. B. Cook, H. S. Smallman, F. C. Lacson and D. I. Manes (2010) Situation displays for dynamic UAV replanning: Intuitions and performance for display formats
- M. F. L. De Vries, G. J. M. Koeners, F. D. Roefs, H. T. A. Van Ginkel and E. Theunissen (2006) Operator support for time-critical situations: Design and evaluation
- M. H. Draper, J. S. Pack, S. J. Darrah, S. N. Moulton and G. L. Calhoun (2014) Human-Machine Interface development for common airborne sense and avoid program
- R. C. Rorie and L. Fern (2014) UAS measured response the effect of GCS control mode interfaces on pilot ability to comply with ATC clearances
- R. C. Rorie and L. Fern (2015) The impact of integrated maneuver guidance information on UAS pilots performing the Detect and Avoid task
- R. C. Rorie, L. Fern and J. Shively (2016) The Impact of Suggestive Maneuver Guidance on UAS Pilot Performing the Detect and Avoid Function
- S. Watza, E. Mueller and C. Santiago (2016) Piloted Well Clear Performance Evaluation of Detect and Avoid Systems with Suggestive Guidance
- X. Yuan, J. M. Histon and S. Waslander (2014) Survey of Operators' Information Requirements on Individually Operated Unmanned Aircraft Systems

Function Allocation Recommendation Tasks:

- Determine runway turn-off
- Loss of contingency flight plan automation
- Monitor aircraft position along route
- Obtain taxi route
- Turn aircraft off runway

Design Recommendation:

Formats in operational control stations:

- Line format (solid, dashed, or translucent)
- Lines connecting waypoints
- Ownship symbol relative to route
- Route overlaid on map
- Text

- Text and symbol
- Text in a grid
- Text in pop-up window

Runway elevation (altitude)

Function Allocation Recommendation Tasks:

- Determine approach profile

Runway status

Function Allocation Recommendation Tasks:

- Obtain airport data

Runway visual range

Literature:

- Federal Aviation Administration (2017). Aeronautical Information Manual.

Selected navigation aid

Operational Control Stations:

- X-Gen Control Station

Function Allocation Recommendation Tasks:

- Tune applicable navigation avionics

Design Recommendation:

Formats in operational control stations:

- Text

Slip/skid

Relevant Certified Federal Regulation(s):

- 14 CFR 25.1303(b)(f)
- 14 CFR 91.205(d)(4)

Applicability:
- IFR flight
- Installed at each pilot station

Special use airspace boundaries

Relevant Certified Federal Regulation(s):
- 14 CFR Part 73

Literature:
- Federal Aviation Administration (2017). Aeronautical Information Manual.

Stall speed (V_S)

Relevant Certified Federal Regulation(s):
- 14 CFR 1.1

Function Allocation Recommendation Tasks:
- Manage airspeed

Stall speed in landing configuration (V_{S0})

Relevant Certified Federal Regulation(s):
- 14 CFR 1.1

Function Allocation Recommendation Tasks:
- Manage airspeed

Steering angle

Operational Control Stations:
- Advanced Cockpit Ground Control Station

Design Recommendation:
Formats in operational control stations:
- Text

Takeoff decision speed (V_1)

Function Allocation Recommendation Tasks:
- Monitor aircraft airspeed in relation to scheduled takeoff speeds

Takeoff safety speed (V_2)

Function Allocation Recommendation Tasks:

- Monitor aircraft airspeed in relation to scheduled takeoff speeds

Taxi route

Literature:

- K. W. Williams (2004). A summary of unmanned aircraft accident/incident data: Human factors implications.

Function Allocation Recommendation Tasks:

- Control aircraft track along taxi route
- Determine runway turn-off
- Turn aircraft off runway

Taxiway status

Literature:

- G. R. Arrabito, G. Ho, Y. Li, W. Giang, C. M. Burns, M. Hou and P. Pace (2013) Multimodal Displays for Enhancing Performance in a Supervisory Monitoring Task Reaction Time to Detect Critical Events
- H. A. Ruff, M. H. Draper, L. G. Lu, M. R. Poole and D. W. Repperger (2000) Haptic feedback as a supplemental method of alerting UAV operators to the onset of turbulence

Function Allocation Recommendation Tasks:

- Control aircraft track along taxi route
- Determine runway turn-off
- Turn aircraft off runway

Terrain/obstacle height

Operational Control Stations:

- Advanced Cockpit Ground Control Station
- Piccolo Command Center
- SenseFly eMotion Control Station

Literature:

- G. L. Calhoun, M. Draper, C. Miller, H. Ruff, C. Breeden and J. Hamell (2013) Adaptable automation interface for multi-unmanned aerial systems control: Preliminary usability evaluation

- J. C. Macbeth, M. L. Cummings, L. F. Bertuccelli and A. Surana (2012) Interface Design for Unmanned Vehicle Supervision through Hybrid Cognitive Task Analysis
- J. Haber and J. Chung (2016) Assessment of UAV Operator Workload in A Reconfigurable Multi-Touch Ground Control Station Environment
- M. B. Cook and H. S. Smallman (2010) When plans change: Task analysis and taxonomy of 3-D situation awareness challenges of UAV replanning
- M. B. Cook, H. S. Smallman, F. C. Lacson and D. I. Manes (2009) Design and validation of a synthetic task environment to study dynamic unmanned aerial vehicle re-planning
- M. B. Cook, H. S. Smallman, F. C. Lacson and D. I. Manes (2010) Situation displays for dynamic UAV replanning: Intuitions and performance for display formats
- M. F. L. De Vries, G. J. M. Koeners, F. D. Roefs, H. T. A. Van Ginkel and E. Theunissen (2006) Operator support for time-critical situations: Design and evaluation
- R. C. Rorie and L. Fern (2014) UAS measured response the effect of GCS control mode interfaces on pilot ability to comply with ATC clearances
- S. R. Dixon, C. D. Wickens and D. Chang (2005) Mission control of multiple unmanned aerial vehicles: A workload analysis
- W. Rodes and L. Gugerty (2012) Effects of electronic map displays and individual differences in ability on navigation performance

Function Allocation Recommendation Tasks:

- Determine approach profile
- Determine descent profile

Design Recommendation:

Formats in operational control stations:

- Color map overlay
- Enhanced vision system
- Graphic overlay
- Out-window view
- Synthetic visualization
- Vertical profile display

Throttle position

Relevant Certified Federal Regulation(s):

- 14 CFR 23.729(f)
- 14 CFR 25.729(e)(2)-(3), (7)

Operational Control Stations:

- Piccolo Command Center

Function Allocation Recommendation Tasks:

- Source
- Lift off/rotate
- Perform landing/touchdown
- Reduce power to thrust required for landing
- Smoothly advance power to takeoff (full) thrust

Design Recommendation:

Design guidance in CFRs:

- Aural warning

Formats in operational control stations:

- Text and color-coded scale

Thrust level

Relevant Certified Federal Regulation(s):

- 14 CFR 23.1305(d)(1)
- 14 CFR 23.1305(d)(2)
- 14 CFR 25.1305(d)(1)
- 14 CFR 25.1305(d)(2)
- 14 CFR 25.1331(k)

Applicability:

For turbojet/turbofan engine-powered airplanes

Thrust reverser position

Relevant Certified Federal Regulation(s):

- 14 CFR 23.1305(d)(2)
- 14 CFR 25.1305(d)(2)

Applicability:

For turbojet/turbofan engine-powered airplanes

Time of day

Relevant Certified Federal Regulation(s):

- 14 CFR 25.1303(a)(2)
- 14 CFR 91.205(d)(6)

Operational Control Stations: • Advanced Cockpit Ground Control Station
Applicability: • IFR flight • Must be visible from each pilot station
Design Recommendation: Design guidance in CFRs: • Display hours, minutes, and seconds with a sweep-second pointer or digital presentation • Sweep-second pointer or digital presentation Formats in operational control stations: • Text

Time of day (destination)
This information element was suggested by a subject matter expert.

Time of day (origin)
This information element was suggested by a subject matter expert.

Time to destination

Operational Control Stations: • SenseFly eMotion Control Station
Literature: • B. Donmez, H. Graham and M. Cummings (2008) Assessing the Impact of Haptic Peripheral Displays for UAV Operators • H. Graham and M. Cummings (2007) Assessing the Impact of Auditory Peripheral Displays for UAV Operators
Design Recommendation: Formats in operational control stations: • Text

Time to next waypoint

Operational Control Stations: • Procerus Virtual Cockpit
Design Recommendation: Formats in operational control stations:

- Text

Transponder code

Operational Control Stations:
- Advanced Cockpit Ground Control Station

Design Recommendation:
Formats in operational control stations:
- Text

Transponder status

Literature:
- Access 5 (2005) Step 1: Human System Integration (HSI) FY05 Pilot-Technology Interface Requirements for Command, Control, and Communications (C3)

Trim device position

Relevant Certified Federal Regulation(s):
- 14 CFR 23.677(a)
- 14 CFR 25.677(b)

Operational Control Stations:
- Advanced Cockpit Ground Control Station

Design Recommendation:
Formats in operational control stations:
- Text
- Scale

True airspeed

Relevant Certified Federal Regulation(s):
- 14 CFR 23.1323(a)

Operational Control Stations:
- Advanced Cockpit Ground Control Station
- X-Gen Control Station

True heading

Relevant Certified Federal Regulation(s):

- 14 CFR 25.1303(a)(3)
- 14 CFR 25.1303(b)(6)
- 14 CFR 23.1303(c)
- 14 CFR 23.1327
- 14 CFR 25.1327
- 14 CFR 91.205(b)(3)
- 14 CFR 91.205(d)(9)

Operational Control Stations:

- Advanced Cockpit Ground Control Station
- Piccolo Command Center
- Procerus Virtual Cockpit
- SenseFly eMotion Control Station
- X-Gen Control Station

Literature:

- A. C. Trujillo, R. W. Ghatas, R. Mcadaragh, D. W. Burdette, J. R. Comstock, L. E. Hempley and H. Fan (2015) Small Unmanned Aircraft Systems Integration into the National Airspace System Visual-Line-of-Sight Human-in-the-Loop Experiment
- B. Donmez, H. Graham and M. Cummings (2008) Assessing the Impact of Haptic Peripheral Displays for UAV Operators
- C. Kenny, R. J. Shively and K. Jordan (2014) Unmanned Aircraft System (UAS) Delegation of Separation in NextGen Airspace
- C. Santiago and E. R. Mueller (2015) Pilot Evaluation of a UAS Detect-and-Avoid System's Effectiveness in Remaining Well Clear
- F. Friedman-Berg, J. Rein and N. Racine (2014) Minimum visual information requirements for detect and avoid in unmanned aircraft systems
- G. L. Calhoun, C. A. Miller, T. C. Hughes and M. H. Draper (2014) UAS sense and avoid system interface design and evaluation
- G. R. Arrabito, G. Ho, Y. Li, W. Giang, C. M. Burns, M. Hou and P. Pace (2013) Multimodal Displays for Enhancing Performance in a Supervisory Monitoring Task Reaction Time to Detect Critical Events
- H. Graham and M. Cummings (2007) Assessing the Impact of Auditory Peripheral Displays for UAV Operators
- J. D. Stevenson, S. O'Young and L. Rolland (2015) Assessment of alternative manual control methods for small unmanned aerial vehicles
- J. Haber and J. Chung (2016) Assessment of UAV Operator Workload in A Reconfigurable Multi-Touch Ground Control Station Environment
- J. S. Pack, M. H. Draper, S. J. Darrah, M. P. Squire and A. Cooks (2015) Exploring Performance Differences Between UAS Sense-and-Avoid Displays
- K. Monk, R. J. Shively, L. Fern and R. C. Rorie (2015) Effects of Display Location and Information Level on UAS Pilot Assessments of a Detect and Avoid System
- K. W. Williams (2012) An Investigation of Sensory Information, Levels of Automation, and Piloting Experience on Unmanned Aircraft Pilot Performance

- L. Damilano, G. Guglieri, F. Quagliotti and I. Sale (2012) FMS for unmanned aerial systems: HMI issues and new interface solutions
- L. Fern, C. A. Kenny, R. J. Shively and W. Johnson (2012) UAS integration into the NAS: an examination of baseline compliance in the current airspace system
- L. Fern, R. C. Rorie, J. S. Pack, R. J. Shively and M. H. Draper (2015) An evaluation of Detect and Avoid (DAA) displays for unmanned aircraft systems: The effect of information level and display location on pilot performance
- M. F. L. De Vries, G. J. M. Koeners, F. D. Roefs, H. T. A. Van Ginkel and E. Theunissen (2006) Operator support for time-critical situations: Design and evaluation
- M. H. Draper, J. S. Pack, S. J. Darrah, S. N. Moulton and G. L. Calhoun (2014) Human-Machine Interface development for common airborne sense and avoid program
- M. Hou, G. Ho, G. R. Arrabito, S. Young and S. Yin (2013) Effects of display mode and input method for handheld control of micro aerial vehicles for a reconnaissance mission
- R. Arteaga, R. Kotcher, M. Cavalin and M. Dandachy (2016) Application of an ADS-B Sense and Avoid Algorithm
- R. C. Rorie and L. Fern (2014) UAS measured response the effect of GCS control mode interfaces on pilot ability to comply with ATC clearances
- R. C. Rorie and L. Fern (2015) The impact of integrated maneuver guidance information on UAS pilots performing the Detect and Avoid task
- R. C. Rorie, L. Fern and J. Shively (2016) The Impact of Suggestive Maneuver Guidance on UAS Pilot Performing the Detect and Avoid Function
- S. Watza, E. Mueller and C. Santiago (2016) Piloted Well Clear Performance Evaluation of Detect and Avoid Systems with Suggestive Guidance
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- W. Rodes and L. Gugerty (2012) Effects of electronic map displays and individual differences in ability on navigation performance
- X. Yuan, J. M. Histon and S. Waslander (2014) Survey of Operators' Information Requirements on Individually Operated Unmanned Aircraft Systems

Function Allocation Recommendation Tasks:

- Command aircraft heading
- Maintain runway centerline
- Manage horizontal flight path

Applicability:

- For VFR flight during the day or night, IFR flight, and night vision goggle operations
- IFR flight
- Installed at each pilot station
- Minimum required flight and navigation instrument
- Must be visible from each pilot station

Design Recommendation:

Design guidance in CFRs:

- Gyroscopically stabilized, magnetic, or non-magnetic)
- Non-stabilized magnetic compass

Formats in operational control stations:
- Text
- Text and compass rose
- Text and heading tape
- Text in pop-up window

Vertical speed

Relevant Certified Federal Regulation(s):
- 14 CFR 23.1543(b)(5)
- 14 CFR 25.1303(b)(3)

Operational Control Stations:
- Piccolo Command Center

Function Allocation Recommendation Tasks:
- Check for positive rate of climb
- Manage vertical speed

Applicability:
- Installed at each pilot station
- For reciprocating multiengine-powered airplanes of 6,000 pounds or less maximum weight

Design Recommendation:
Design guidance in CFRs:
- Blue radial line

Formats in operational control stations:
- Text in pop-up window
- Vertical speed tape

Visibility

Literature:
- Federal Aviation Administration (2017). Aeronautical Information Manual.

Wheel brake position

Operational Control Stations:

- Advanced Cockpit Ground Control Station
- X-Gen Control Station

Function Allocation Recommendation Tasks:

- Control aircraft speed along taxi route
- Perform brake check
- Smoothly advance power to takeoff (full) thrust

Design Recommendation:

Formats in operational control stations:

- Text
- Scale
- Color-coded indicator

Wind direction

Operational Control Stations:

- Procerus Virtual Cockpit
- SenseFly eMotion Control Station
- X-Gen Control Station

Literature:

- B. Kayayurt and I. Yayla (2013) Application of STANAG 4586 standard for Turkish Aerospace Industries UAV systems
- C. Fuchs, C. Borst, G. C. de Croon, M. R. van Paassen and M. Mulder (2014) An ecological approach to the supervisory control of UAV swarms
- C. Kenny, R. J. Shively and K. Jordan (2014) Unmanned Aircraft System (UAS) Delegation of Separation in NextGen Airspace
- D. T. Williamson, M. H. Draper, G. L. Calhoun and T. P. Barry (2005) Commercial speech recognition technology in the military domain: Results of two recent research efforts
- G. L. Calhoun, M. Draper, C. Miller, H. Ruff, C. Breeden and J. Hamell (2013) Adaptable automation interface for multi-unmanned aerial systems control: Preliminary usability evaluation
- G. R. Arrabito, G. Ho, Y. Li, W. Giang, C. M. Burns, M. Hou and P. Pace (2013) Multimodal Displays for Enhancing Performance in a Supervisory Monitoring Task Reaction Time to Detect Critical Events
- H. A. Ruff, M. H. Draper, L. G. Lu, M. R. Poole and D. W. Repperger (2000) Haptic feedback as a supplemental method of alerting UAV operators to the onset of turbulence
- J. D. Stevenson, S. O'Young and L. Rolland (2015) Assessment of alternative manual control methods for small unmanned aerial vehicles
- L. Fern and J. Shively (2011) Designing airspace displays to support rapid immersion for UAS handoffs

- L. Fern, C. A. Kenny, R. J. Shively and W. Johnson (2012) UAS integration into the NAS: an examination of baseline compliance in the current airspace system
- R. Hopcroft, E. Burchat, and J. Vince (2006) Unmanned Aerial Vehicles for Maritime Patrol: Human Factors Issues
- S. R. Dixon, C. D. Wickens and D. Chang (2005) Mission control of multiple unmanned aerial vehicles: A workload analysis
- W. Rodes and L. Gugerty (2012) Effects of electronic map displays and individual differences in ability on navigation performance

Function Allocation Recommendation Tasks:

- Determine approach profile
- Determine descent profile
- Determine top of descent
- Obtain airport data

Design Recommendation:

Formats in operational control stations:

- Chevron direction
- Compass
- Text

Wind speed

Operational Control Stations:

- Procerus Virtual Cockpit
- SenseFly eMotion Control Station
- X-Gen Control Station

Literature:

- B. Kayayurt and I. Yayla (2013) Application of STANAG 4586 standard for Turkish Aerospace Industries UAV systems
- C. Fuchs, C. Borst, G. C. de Croon, M. R. van Paassen and M. Mulder (2014) An ecological approach to the supervisory control of UAV swarms
- C. Kenny, R. J. Shively and K. Jordan (2014) Unmanned Aircraft System (UAS) Delegation of Separation in NextGen Airspace
- D. T. Williamson, M. H. Draper, G. L. Calhoun and T. P. Barry (2005) Commercial speech recognition technology in the military domain: Results of two recent research efforts
- G. L. Calhoun, M. Draper, C. Miller, H. Ruff, C. Breeden and J. Hamell (2013) Adaptable automation interface for multi-unmanned aerial systems control: Preliminary usability evaluation
- G. R. Arrabito, G. Ho, Y. Li, W. Giang, C. M. Burns, M. Hou and P. Pace (2013) Multimodal Displays for Enhancing Performance in a Supervisory Monitoring Task Reaction Time to Detect Critical Events

- H. A. Ruff, M. H. Draper, L. G. Lu, M. R. Poole and D. W. Repperger (2000) Haptic feedback as a supplemental method of alerting UAV operators to the onset of turbulence
- J. D. Stevenson, S. O'Young and L. Rolland (2015) Assessment of alternative manual control methods for small unmanned aerial vehicles
- L. Fern and J. Shively (2011) Designing airspace displays to support rapid immersion for UAS handoffs
- L. Fern, C. A. Kenny, R. J. Shively and W. Johnson (2012) UAS integration into the NAS: an examination of baseline compliance in the current airspace system
- R. Hopcroft, E. Burchat, and J. Vince (2006) Unmanned Aerial Vehicles for Maritime Patrol: Human Factors Issues
- S. R. Dixon, C. D. Wickens and D. Chang (2005) Mission control of multiple unmanned aerial vehicles: A workload analysis
- W. Rodes and L. Gugerty (2012) Effects of electronic map displays and individual differences in ability on navigation performance

Function Allocation Recommendation Tasks:

- Determine approach profile
- Determine descent profile
- Determine top of descent
- Obtain airport data

Design Recommendation:

Formats in operational control stations:

- Chevron direction
- Compass
- Text

Yaw attitude

Operational Control Stations:

- Advanced Cockpit Ground Control Station
- X-Gen Control Station

Design Recommendation:

Formats in operational control stations:

- Text
- Text and scale

Literature Referenced in Appendix E3

Access 5. (2005a). *Step 1: Human System Integration (HSI) FY05 Pilot-Technology Interface Requirements for Collision Avoidance*. Retrieved from http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20080016729.pdf

Access 5. (2005b). *Step 1: Human System Integration (HSI) FY05 Pilot-Technology Interface Requirements for Command, Control, and Communications (C3)*. Retrieved from http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20080017389.pdf

Access 5. (2006). *Step 1: Human System Interface (HSI) Functional Requirements Document (FRD)*. Retrieved from http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20080017284.pdf

Arrabito, G. R., Ho, G., Li, Y., Giang, W., Burns, C. M., Hou, M., & Pace, P. (2013). *Multimodal Displays for Enhancing Performance in a Supervisory Monitoring Task Reaction Time to Detect Critical Events.* Paper presented at the Proceedings of the Human Factors and Ergonomics Society Annual Meeting.

Arteaga, R., Kotcher, R., Cavalin, M., & Dandachy, M. (2016). *Application of an ADS-B Sense and Avoid Algorithm*. Paper presented at the AIAA Flight Testing Conference.

Balzer, W. K., Doherty, M. E., & O'Connor, R. (1989). Effects of cognitive feedback on performance. *Psychological Bulletin, 106*(3), 410.

Bisantz, A. M., Kirlik, A., Gay, P., Phipps, D. A., Walker, N., & Fisk, A. D. (2000). Modeling and analysis of a dynamic judgment task using a lens model approach. *Systems, Man and Cybernetics, Part A: Systems and Humans, IEEE Transactions on, 30*(6), 605-616.

Blickensderfer, B., Buker, T. J., Luxion, S. P., Lyall, B., Neville, K., & Williams, K. W. (2012). *The design of the UAS ground control station: Challenges and solutions for ensuring safe flight in civilian skies.* Paper presented at the Proceedings of the Human Factors and Ergonomics Society Annual Meeting.

Bolton, M. L., & Bass, E. J. (2009). Comparing perceptual judgment and subjective measures of spatial awareness. *Applied ergonomics, 40*(4), 597-607.

Brunswik, E. (1956). *Perception and the representative design of psychological experiments*: Univ of California Press.

Calhoun, G., Draper, M., Ruff, H., Fontejon, J., & Guilfoos, B. (2003). *Evaluation of tactile alerts for control station operation.* Paper presented at the Proceedings of the Human Factors and Ergonomics Society Annual Meeting.

Calhoun, G. L., Draper, M., Miller, C., Ruff, H., Breeden, C., & Hamell, J. (2013). *Adaptable automation interface for multi-unmanned aerial systems control:Preliminary usability evaluation.* Paper presented at the 57th Human Factors and Ergonomics Society Annual Meeting - 2013, HFES 2013, September 30, 2013 - October 4, 2013, San Diego, CA, United states.

Calhoun, G. L., Draper, M. H., Guilfoos, B. J., & Ruff, H. A. (2005). *Tactile and aural alerts in high auditory load UAV control environments.* Paper presented at the Proceedings of the Human Factors and Ergonomics Society Annual Meeting.

Calhoun, G. L., Fontejon, J. V., Draper, M. H., Ruff, H. A., & Guilfoos, B. J. (2004). *Tactile versus aural redundant alert cues for UAV control applications.* Paper presented at the Proceedings of the Human Factors and Ergonomics Society Annual Meeting.

Calhoun, G. L., Miller, C. A., Hughes, T. C., & Draper, M. H. (2014). *UAS sense and avoid system interface design and evaluation.* Paper presented at the Proceedings of the Human Factors and Ergonomics Society Annual Meeting.

Cook, M. B., & Smallman, H. S. (2010). *When plans change: Task analysis and taxonomy of 3-D situation awareness challenges of UAV replanning*. Retrieved from http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA525217

Cook, M. B., Smallman, H. S., Lacson, F. C., & Manes, D. I. (2009). *Design and validation of a synthetic task environment to study dynamic unmanned aerial vehicle re-planning.* Paper presented at the Proceedings of the Human Factors and Ergonomics Society Annual Meeting.

Cook, M. B., Smallman, H. S., Lacson, F. C., & Manes, D. I. (2010). *Situation displays for dynamic UAV replanning: Intuitions and performance for display formats.* Paper presented at the Proceedings of the Human Factors and Ergonomics Society Annual Meeting.

Cooksey, R. W. (1996). *Judgment analysis: Theory, methods, and applications*: Academic Press.

Cummings, M. L., Marquez, J. J., & Visser, M. (2007). *Shadow TUAV Single Operator Consolidation: Display Assessment*. Retrieved from http://hdl.handle.net/1721.1/46728

Damilano, L., Guglieri, G., Quagliotti, F., & Sale, I. (2012). FMS for unmanned aerial systems: HMI issues and new interface solutions. *Journal of intelligent & robotic systems, 65*(1-4), 27-42.

De Vries, M. F. L., Koeners, G. J. M., Roefs, F. D., Van Ginkel, H. T. A., & Theunissen, E. (2006). *Operator support for time-critical situations: Design and evaluation.* Paper presented at the 25th DASC Digital Avionics Systems Conference - Network-Center Environment: The Impact on Avionics and Systems, October 15, 2006 - October 19, 2006, Portland, OR, United states.

Dixon, S. R., Wickens, C. D., & Chang, D. (2005). Mission control of multiple unmanned aerial vehicles: A workload analysis. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 47*(3), 479-487.

Donmez, B., Cummings, M. L., & Graham, H. D. (2009). Auditory decision aiding in supervisory control of multiple unmanned aerial vehicles. *Human Factors: The Journal of the Human Factors and Ergonomics Society*.

Donmez, B., Graham, H., & Cummings, M. (2008). *Assessing the Impact of Haptic Peripheral Displays for UAV Operators*. Retrieved from http://dspace.mit.edu/handle/1721.1/46737

Draper, M. H., Pack, J. S., Darrah, S. J., Moulton, S. N., & Calhoun, G. L. (2014). *Human-Machine Interface development for common airborne sense and avoid program.* Paper presented at the Proceedings of the Human Factors and Ergonomics Society Annual Meeting.

Elliott, L. R., Coovert, M. D., Prewett, M., Walvord, A. G., Saboe, K., & Johnson, R. (2009). *A review and meta analysis of vibrotactile and visual information displays*. Retrieved from http://www.dtic.mil/dtic/tr/fulltext/u2/a506628.pdf

Endsley, M. R. (1995a). Measurement of situation awareness in dynamic systems. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 37*(1), 65-84.

Endsley, M. R. (1995b). Toward a theory of situation awareness in dynamic systems. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 37*(1), 32-64.

Endsley, M. R., Selcon, S. J., Hardiman, T. D., & Croft, D. G. (1998). *A comparative analysis of SAGAT and SART for evaluations of situation awareness.* Paper presented at the Proceedings of the Human Factors and Ergonomics Society Annual Meeting.

Federal Aviation Administration. (2013). *Integration of Civil Unmanned Aircraft Systems (UAS) in the National Airspace System (NAS) Roadmap*. Retrieved from http://www.faa.gov/uas/media/uas_roadmap_2013.pdf

Federal Aviation Administration. (2014). *Aeronautical Information Manual*. Retrieved from https://www.faa.gov/air_traffic/publications/media/aim_basic_4-03-14.pdf

Feitshans, G. L., Rowe, A. J., Davis, J. E., Holland, M., & Berger, L. (2008). *Vigilant spirit control station (VSCS)—'The face of COUNTER'.* Paper presented at the Proceedings of AIAA Guidance, Navigation and Control Conf. Exhibition.

Fern, L., Kenny, C. A., Shively, R. J., & Johnson, W. (2012). *UAS integration into the NAS: an examination of baseline compliance in the current airspace system.* Paper presented at the Proceedings of the Human Factors and Ergonomics Society Annual Meeting.

Fern, L., Rorie, R. C., Pack, J. S., Shively, R. J., & Draper, M. H. (2015). *An evaluation of Detect and Avoid (DAA) displays for unmanned aircraft systems: The effect of information level and display location on pilot performance.* Paper presented at the Proceedings of 15th AIAA Aviation Technology, Integration, and Operations Conference.

Fern, L., & Shively, J. (2011). *Designing airspace displays to support rapid immersion for UAS handoffs.* Paper presented at the Proceedings of the Human Factors and Ergonomics Society Annual Meeting.

Fern, L., & Shively, R. J. (2009). *A comparison of varying levels of automation on the supervisory control of multiple UASs.* Paper presented at the AUVSI Unmanned Systems North America Conference 2009, August 10, 2009 - August 13, 2009, Washington, DC, United states.

Fitts, P. M. (1954). The information capacity of the human motor system in controlling the amplitude of movement. *Journal of experimental psychology, 47*(6), 381.

Friedman-Berg, F., Rein, J., & Racine, N. (2014). *Minimum visual information requirements for detect and avoid in unmanned aircraft systems.* Paper presented at the Proceedings of the Human Factors and Ergonomics Society Annual Meeting.

Fuchs, C., Borst, C., de Croon, G. C., van Paassen, M. R., & Mulder, M. (2014). An ecological approach to the supervisory control of UAV swarms. *International Journal of Micro Air Vehicles, 6*(4), 211-229.

Graham, H., & Cummings, M. (2007). *Assessing the Impact of Auditory Peripheral Displays for UAV Operators*. Retrieved from http://dspace.mit.edu/handle/1721.1/46735

Green, D. M., & Swets, J. A. (1989). *Signal Detection Theory and Psychophysics*. New York: John Wiley and Sons.

Haber, J., & Chung, J. (2016). Assessment of UAV Operator Workload in A Reconfigurable Multi-Touch Ground Control Station Environment. *Journal of Unmanned Vehicle Systems*(ja).

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. *Advances in psychology, 52*, 139-183.

Hobbs, A., & Lyall, B. (2015). *Human Factors Guidelines for Unmanned Aircraft System Ground Control Stations*. Retrieved from http://humanfactors.arc.nasa.gov/publications/GCS_HF%20_Prelim_Guidelines_Hobbs_Lyall.pdf

Hobbs, A., & Shively, R. J. (2013). Human Factors Guidelines for UAS in the National Airspace System. *Proceedings of Association for Unmanned Vehicle Systems International (AUVSI), 12*, 15.

Hocraffer, A., & Nam, C. S. (2017). A meta-analysis of human-system interfaces in unmanned aerial vehicle (UAV) swarm management. *Applied ergonomics, 58*, 66-80.

Holmqvist, K., Nystrom, M., Andersson, R., Dewhurst, R., Jarodzka, H., & van de Weijer, J. (2011). *Eye tracking: a comprehensive guide to methods and measures*. New York: Oxford University Press.

Hopcroft, R., Burchat, E., & Vince, J. (2006). *Unmanned aerial vehicles for maritime patrol: human factors issues*. Retrieved from http://www.dtic.mil/dtic/tr/fulltext/u2/a454918.pdf

Hou, M., Ho, G., Arrabito, G. R., Young, S., & Yin, S. (2013). Effects of display mode and input method for handheld control of micro aerial vehicles for a reconnaissance mission. *IEEE Transactions on Human-Machine Systems, 43*(2), 149-160.

Hughes, M. F., & Takallu, M. (2002). Terrain portrayal for head-down displays experiment.

Hursch, C. J., Hammond, K. R., & Hursch, J. L. (1964). Some methodological considerations in multiple-cue probability. *Psychological Review, 71*, 42-60.

Kamine, T. H., & Bendrick, G. A. (2009). Visual Display Angles of Conventional and a Remotely Piloted Aircraft. *Aviation, space, and environmental medicine, 80*(4), 409-413.

Kayayurt, B., & Yayla, İ. (2013). *Application of STANAG 4586 standard for Turkish Aerospace Industries UAV systems.* Paper presented at the 2013 IEEE/AIAA 32nd Digital Avionics Systems Conference (DASC).

Kenny, C., Shively, R. J., & Jordan, K. (2014). *Unmanned Aircraft System (UAS) Delegation of Separation in NextGen Airspace*. Retrieved from http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20140017682.pdf

Lam, T. M., Mulder, M., & van Paassen, M. M. (2007). Haptic Interface For UAV Collision Avoidance. *The International Journal of Aviation Psychology, 17*(2), 167-195. doi:10.1080/10508410701328649

Lee, J.-W., & Yates, J. F. (1992). How quantity judgment changes as the number of cues increases: An analytical framework and review. *Psychological Bulletin, 112*(2), 363.

Macbeth, J. C., Cummings, M. L., Bertuccelli, L. F., & Surana, A. (2012). *Interface Design for Unmanned Vehicle Supervision through Hybrid Cognitive Task Analysis.* Paper presented at the Proceedings of the Human Factors and Ergonomics Society Annual Meeting.

Monk, K., Shively, R. J., Fern, L., & Rorie, R. C. (2015). *Effects of Display Location and Information Level on UAS Pilot Assessments of a Detect and Avoid System.* Paper presented at the Proceedings of the Human Factors and Ergonomics Society Annual Meeting.

Mueller, E., Santiago, C., & Watza, S. (2016). Piloted Well Clear Performance Evaluation of Detect and Avoid Systems with Suggestive Guidance.

Murphy, A. H. (1988). Skill scores based on the mean square error and their relationships to the correlation coefficient. *Monthly weather review, 116*(12), 2417-2424.

Nehme, C. E., Crandall, J. W., & Cummings, M. (2007). *An operator function taxonomy for unmanned aerial vehicle missions.* Paper presented at the 12th international command and control research and technology symposium.

Neville, K., Blickensderfer, B., Archer, J., Kaste, K., & Luxion, S. P. (2012). *A cognitive work analysis to identify human-machine interface design challenges unique to uninhabited*

aircraft systems. Paper presented at the Proceedings of the Human Factors and Ergonomics Society Annual Meeting.

Oncu, M., & Yildiz, S. (2014). *An analysis of human causal factors in Unmanned Aerial Vehicle (UAV) accidents*. Retrieved from http://calhoun.nps.edu/bitstream/handle/10945/44637/14Dec_Oncu_Yildiz.pdf?sequence=1

Pack, J. S., Draper, M. H., Darrah, S. J., Squire, M. P., & Cooks, A. (2015). *Exploring Performance Differences Between UAS Sense-and-Avoid Displays.* Paper presented at the Proceedings of the Human Factors and Ergonomics Society Annual Meeting.

Rodes, W., & Gugerty, L. (2012). Effects of electronic map displays and individual differences in ability on navigation performance. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 54*(4), 589-599.

Rorie, R. C., & Fern, L. (2014). *UAS measured response the effect of GCS control mode interfaces on pilot ability to comply with ATC clearances.* Paper presented at the Proceedings of the Human Factors and Ergonomics Society Annual Meeting.

Rorie, R. C., & Fern, L. (2015). *The impact of integrated maneuver guidance information on UAS pilots performing the Detect and Avoid task.* Paper presented at the Proceedings of the Human Factors and Ergonomics Society Annual Meeting.

Rorie, R. C., Fern, L., & Shively, J. (2016). *The Impact of Suggestive Maneuver Guidance on UAS Pilot Performing the Detect and Avoid Function*. Paper presented at the AIAA Infotech@ Aerospace.

RTCA Inc. (2010). *Operational services and environmental definition (OSED) for unmanned aircraft systems (uas)*. Retrieved from http://www.rtca.org

Ruff, H. A., Draper, M. H., Lu, L. G., Poole, M. R., & Repperger, D. W. (2000). *Haptic feedback as a supplemental method of alerting UAV operators to the onset of turbulence.* Paper presented at the Proceedings of the Human Factors and Ergonomics Society Annual Meeting.

Santiago, C., & Mueller, E. R. (2015). *Pilot Evaluation of a UAS Detect-and-Avoid System's Effectiveness in Remaining Well Clear.* Paper presented at the Eleventh UAS/Europe Air Traffic Management Research and Development Seminar (ATM2015).

Scheff, S. (2014). Ground Control Station Catalog.

Schreiber, B. T., Lyon, D. R., Martin, E. L., & Confer, H. A. (2002). *Impact of prior flight experience on learning Predator UAV operator skills. Mesa, AZ: Air Force Research Laboratory; 2002 Feb. Report No*. Retrieved from http://www.dtic.mil/dtic/tr/fulltext/u2/a401588.pdf

Selcon, S., & Taylor, R. (1990). Evaluation of the Situational Awareness Rating Technique(SART) as a tool for aircrew systems design. *AGARD, Situational Awareness in Aerospace Operations 8 p(SEE N 90-28972 23-53).*

Stark, J. M., Comstock, J. R., Prinzel, L. J., Burdette, D. W., & Scerbo, M. W. (2001). *A preliminary examination of situation awareness and pilot performance in a synthetic vision environment.* Paper presented at the Proceedings of the Human Factors and Ergonomics Society Annual Meeting.

Stevenson, J. D., O'Young, S., & Rolland, L. (2015). Assessment of alternative manual control methods for small unmanned aerial vehicles. *Journal of Unmanned Vehicle Systems, 3*(3), 73-94.

Stewart, T. R. (1990). A decomposition of the correlation coefficient and its use in analyzing forecasting skill. *Weather and forecasting, 5*(4), 661-666.

Stewart, T. R., & Lusk, C. M. (1994). Seven components of judgmental forecasting skill: Implications for research and the improvement of forecasts. *Journal of Forecasting, 13*(7), 579-599.

Takallu, M., Wong, D., Bartolone, A., Hughes, M., & Glaab, L. (2004). *Interaction between various terrain portrayals and guidance/tunnel symbology concepts for general aviation synthetic vision displays during a low en-route scenario.* Paper presented at the Digital Avionics Systems Conference, 2004. DASC 04. The 23rd.

Taylor, R. (1990). Situational Awareness Rating Technique(SART): The development of a tool for aircrew systems design. *AGARD, Situational Awareness in Aerospace Operations 17 p(SEE N 90-28972 23-53)*.

Trujillo, A. C., Ghatas, R. W., Mcadaragh, R., Burdette, D. W., Comstock, J. R., Hempley, L. E., & Fan, H. (2015). Small Unmanned Aircraft Systems Integration into the National Airspace System Visual-Line-of-Sight Human-in-the-Loop Experiment.

Tucker, L. R. (1964). A suggested alternative formulation in the developments by Hursch, Hammond, and Hursch, and by Hammond, Hursch, and Todd. *Psychological Review, 71*(6), 528.

Wickens, C. D., & Dixon, S. (2002). *Workload demands of remotely piloted vehicle supervision and control: (1) single vehicle performance*. Retrieved from http://www.dtic.mil/dtic/tr/fulltext/u2/a496813.pdf

Wickens, C. D., Dixon, S., & Chang, D. (2003). *Using interference models to predict performance in a multiple-task UAV environment-2 UAVs*. Retrieved from http://www.aviation.illinois.edu/avimain/papers/research/pub_pdfs/techreports/03-09.pdf

Wickens, C. D., Lee, J. D., Liu, Y., & Gordon Becker, S. E. (2003). *An Introduction to Human Factors Engineering*: Prentice-Hall, Inc.

Williams, K. W. (2004). *A summary of unmanned aircraft accident/incident data: Human factors implications*. Retrieved from http://www.dtic.mil/get-tr-doc/pdf?AD=ADA460102

Williams, K. W. (2007). *An assessment of pilot control interfaces for unmanned aircraft*. Retrieved from http://www.faa.gov/data_research/research/med_humanfacs/oamtechreports/2000s/media/200708.pdf

Williams, K. W. (2012). *An Investigation of Sensory Information, Levels of Automation, and Piloting Experience on Unmanned Aircraft Pilot Performance*. Retrieved from http://www.faa.gov/data_research/research/med_humanfacs/oamtechreports/2010s/media/201204.pdf

Williamson, D. T., Draper, M. H., Calhoun, G. L., & Barry, T. P. (2005). Commercial speech recognition technology in the military domain: Results of two recent research efforts. *International Journal of Speech Technology, 8*(1), 9-16.

11. APPENDIX E4: FULL SET OF MINIMUM INFORMATION RECOMMENDATIONS

This appendix contains the full set of recommendations for the information elements, encompassing both Project A7 and Project A10 scopes.

11.1 INFORMATION SPANNING MULTIPLE CONTEXTS

11.1.1 Aircraft Identification

The RPIC needs to know the aircraft identifier for radio communications, filing flight plans and other activities in all contexts. Aircraft type is necessary for the flight plan. The values for these information elements would be fixed for a UA. Table 17 contains our recommendations.

Table 17. Information elements and recommendations for aircraft identification information.

Information Element	Control Attribute	Availability Recommendation
Aircraft ID	Constant	Always Displayed
Aircraft type	Constant	Source Outside Control Station Displays

SME Comments—Regarding aircraft ID, one SME suggested that "This could be a placard or just a piece of tape, but it is usually in the flight station. It just does not need to be on the screen."

- Response/Rebuttal: The aircraft ID in a manned aircraft is visible during preflight (on the aircraft) and the manned aircraft pilot can interrogate it. However during the flight this is not possible for a manned aircraft. Interrogation is not possible for remote pilots even during preflight as they are not co-located with the aircraft.

Regarding aircraft type, one SME suggested it should be optional. "The system does not need to tell the RPIC the aircraft type/model. I should know the type/model, and it is in the manual."

- Response/Rebuttal: The recommendation does not require the aircraft type to be contained on the displays, but rather in an external medium (such as the manual).

11.1.2 Time

The RPIC needs to have accurate time information in all contexts. Regarding time of day: it is required per 14 CFR 91.205(d)(6). The values for time of day are not recommended to be modifiable by the RPIC. Table 18 contains our recommendations.

Table 18. Information elements and recommendations for time information.

Information Element	Control Attribute	Availability Recommendation
Time of day	Other	Always Displayed
Time of day (origin)	Other	Optional
Time of day (destination)	Other	Optional

SME Comments—One SME suggested adding more information: “I suggest adding ‘sunrise’ and ‘sunset’ as optional, since some aircraft will have day and night restrictions.”

- Response/Rebuttal: These information elements were not added, as presentation of time of day can be used to determine whether it is day or night.

11.1.3 Flight Parameters

Most flight parameters are recommended to always be displayed. However, ground speed and true airspeed are recommended to be optionally available. Table 19 contains our recommendations.

Table 19. Information elements and recommendations for flight parameters.

Information Element	Control Attribute	Availability Recommendation			
		Taxi	Takeoff	Aviate	Landing
Altitude above ground level (absolute)	Combination	Always Displayed	Always Displayed	Always Displayed	Always Displayed
Angle of attack	RPIC	N/A	Optional	Optional	Optional
Density altitude	Combination	N/A	Optional	Optional	Optional
Ground speed	Combination	Available at RPIC Request	Available at RPIC Request	Available at RPIC Request	Available at RPIC Request
Ground track	Combination	Optional	Optional	Optional	Optional
Indicated airspeed	RPIC	Always Displayed	Always Displayed	Always Displayed	Always Displayed
Indicated altitude	Combination	Always Displayed	Always Displayed	Always Displayed	Always Displayed
Latitude	Combination	Always Displayed	Always Displayed	Always Displayed	Always Displayed
Longitude	Combination	Always Displayed	Always Displayed	Always Displayed	Always Displayed
Magnetic heading	RPIC	Always Displayed	Always Displayed	Always Displayed	Always Displayed
Pitch attitude	RPIC	Always Displayed	Always Displayed	Always Displayed	Always Displayed
Rate of turn	RPIC	N/A	Optional	Optional	Optional
Roll attitude/bank angle	RPIC	Always Displayed	Always Displayed	Always Displayed	Always Displayed
Slip/skid	RPIC	Always Displayed	Always Displayed	Always Displayed	Always Displayed
True airspeed	Combination	N/A	Optional	Optional	Optional
True heading[1]	Combination	Optional	Optional	Optional	Optional
Vertical speed	Combination	N/A	Always Displayed	Always Displayed	Always Displayed
Yaw attitude	RPIC	Optional	Optional	Optional	Optional

[1]True heading should be “always displayed” if magnetic heading is not presented to the RPIC in the control station. The control station should clearly indicate whether the heading being presented to the RPIC is the true heading or the magnetic heading.

SME Comments—There was a lack of consensus with respect to SME input regarding ground speed, altitude above ground level, true heading, and magnetic heading.

- Regarding ground speed: One SME indicated it should be optional across all phases of flight.
    - Response/Rebuttal: There could be instances for which the RPIC needs to know the ground speed, such as during approach and landing or during taxi, where the RPIC does not have the out-the-window visual cues that give an indication of UA ground speed that a manned pilot has.
- Regarding altitude above ground level, one SME indicated it should be optional.
    - Response/Rebuttal: Terrain awareness is an important factor in aviation safety and controlled flight into terrain (CFIT) continues to be a safety concern for manned aircraft (Boeing Company, 2015; International Air Transportation Association, 2015); removing the pilot from the cockpit (along with information from out-the-window view) can exacerbate the issue. If AGL is not presented, the RPIC will have to reference a static terrain map to calculate distance above ground. This is very different from manned operation, in which the RPIC can make a judgment on whether the aircraft is clear of terrain and obstacles by simply looking out the window during visual meteorological conditions. This reflects HF-STD-001B is meant for ATC design, but it is applicable here because Section 5.1.1.10 states that systems should avoid increasing demands for cognitive resources and Section 5.1.12.3 states that displays should provide information in a usable format (Federal Aviation Administration, 2016).
- Regarding true heading and magnetic heading, SME input ranged from always displayed to optional. One SME suggested that "Having either true heading or magnetic heading 'always displayed' is fine, but the control station would have to indicate which one it is so the RPIC would not have to search the control station displays further for that information." Another SME suggested that "Typical commands reference magnetic heading, so this should be 'Available at RPIC Request'."
    - Response/Rebuttal: The recommendation for true heading is "optional" with the caveat that true heading should be "always displayed" (and labeled clearly to ensure the RPIC knows it is true heading) if the control station does not present the RPIC with the magnetic heading.

11.1.4 Targets

Flight targets can support RPIC awareness of the state of the UA compared to the desired state, but are not considered a minimum information need as recommended in Table 20.

Table 20. Information elements and recommendations for targets.

Information Element	Control Attribute	Availability Recommendation		
		Takeoff	Aviate	Landing
Altitude target	RPIC	Optional	Optional	Optional
Heading target	RPIC	Optional	Optional	Optional
Indicated airspeed target	RPIC	Optional	Optional	Optional
Vertical speed target	RPIC	Optional	Optional	Optional
Roll attitude/bank angle target	RPIC	Optional	Optional	Optional
Pitch angle target	RPIC	Optional	Optional	Optional

11.1.5 Constraints and V-Speeds

Constraints should be available as appropriate for their context. For example, landing gear and flaps information may not be critical if they are not being used. Note that some constraints are dependent on the aircraft type; for example, we did not include minimum control speed (V_{MC}) since it assumes an aircraft with multiple powerplants. Table 21 contains our recommendations.

Table 21. Information elements and recommendations for constraints and V-speeds.

Information Element	Control Attribute	Availability Recommendation		
		Takeoff	**Aviate**	**Landing**
Maximum altitude	Constant	Optional	Optional	Optional
Maximum flaps extended speed (V_{FE})	Constant	Always Displayed	Always Displayed	Always Displayed
Maximum landing gear extended speed (V_{LE})	Constant	Context Dependent	Context Dependent	Context Dependent
Maximum landing gear operating speed (V_{LO})	Constant	Always Displayed	Always Displayed	Always Displayed
Maximum operating limit speed (V_{MO})	Constant	Always Displayed	Always Displayed	Always Displayed
Maximum operating maneuvering speed (V_O)	Constant	Always Displayed	Always Displayed	Always Displayed
Maximum speed for normal operations (V_{NO})	Constant	Always Displayed	Always Displayed	Always Displayed
Never-exceed speed (V_{NE})	Constant	Always Displayed	Always Displayed	Always Displayed
Optimal climb rate	Combination	Optional	Optional	Optional
Optimal cruise speed	Combination	N/A	Optional	N/A
Optimal descent rate	Combination	Optional	Optional	Optional
Rotation speed (V_R)	Combination	Context Dependent	N/A	N/A
Stall speed (V_S)	Constant	Always Displayed	Always Displayed	Always Displayed
Stall speed in landing configuration (V_{S0})	Constant	Always Displayed	Always Displayed	Always Displayed
Takeoff decision speed (V_1)	Combination	Context Dependent	N/A	N/A
Takeoff safety speed (V_2)	Combination	Context Dependent	N/A	N/A

11.1.6 UA Device Control

Device control can be specific to phase of flight but some devices are used across contexts. For example, wheel braking is not relevant when not on the ground. Flight mode annunciation is included to represent an indication of which flight mode(s) are engaged and

disengaged at any time. Since the flight mode is specific to the aircraft type and its equipment, we do not list all possible flight modes but instead use this term for all related annunciations. Table 22 contains our recommendations.

Table 22. Information elements and recommendations for UA device control information.

Information Element	Control Attribute	Availability Recommendation			
		Taxi	Takeoff	Aviate	Landing
Throttle position	RPIC	Always Displayed	Always Displayed	Always Displayed	Always Displayed
Thrust level	RPIC	Optional	Optional	Optional	Optional
Thrust reverser position	RPIC	Always Displayed	Always Displayed	Always Displayed	Always Displayed
Flight surface positions	RPIC	Optional	Optional	Optional	Optional
Control device position[1]	RPIC	Always Displayed	Always Displayed	Always Displayed	Always Displayed
Trim device position	RPIC	Always Displayed	Always Displayed	Always Displayed	Always Displayed
Landing gear control position	RPIC	Always Displayed	Always Displayed	Always Displayed	Always Displayed
Landing gear status	Combination	Always Displayed	Always Displayed	Always Displayed	Always Displayed
Lift/drag device position	RPIC	Always Displayed	Always Displayed	Always Displayed	Always Displayed
Lift/drag device position target	RPIC	Always Displayed	Always Displayed	Always Displayed	Always Displayed
Wheel brake position[2]	RPIC	Context Dependent	Context Dependent	N/A	Context Dependent
Flight mode annunciation[3]	RPIC	Always Displayed	Always Displayed	Always Displayed	Always Displayed

[1]Since this work is control device agnostic, this information element refers to the position of any control device contained in the control station, including but not limited to a yoke, pedals, joystick, or on-screen interface.
[2]Although context dependent, this information is recommended to always be provided when the landing gear is down.
[3]The modes used by a manufacturer may differ but what modes are engaged and not engaged should be annunciated

SME Comments—There was disagreement among the SMEs for flight mode annunciation. One SME commented: "I suggest making this optional. Or, if you are referring to alerting, I suggest making this context-dependent."

- Response/Rebuttal: Mode awareness is a known safety issue for automated aircraft (Sarter & Woods, 1995). For aircraft that have multiple autopilot modes, it is critical that the mode is apparent to the RPIC. 14 CFR 25.1302(c) states that operationally-relevant behavior of the installed equipment must be (1) predictable and unambiguous, and (2) designed to enable the flightcrew to intervene in a manner appropriate to the task. In other words, operationally relevant system behavior should be predictable and unambiguous, enabling a qualified flightcrew to know what the system is doing and why (Yeh et al., 2013).

11.1.7 Airport

Because there will be a VO, Airport information can be obtained from the VO, ATIS, and other sources outside of the control station. However, Recommendation 1 in the subsequent cognitive walkthrough research (Project A10 Task CS-5, Appendix E), conducted based on the information recommendations developed here, suggested that the CS should contain a dynamic map of the airport surface with UA position overlaid on the map. For this reason, we recommended that airport configuration be available at RPIC request (rather than being available on a source outside the control station, which was the recommendation prior to conducting the cognitive walkthrough). Table 23 contains our recommendations.

Table 23. Information elements and recommendations for airport information.

Information Element	Control Attribute	Availability Recommendation		
		Taxi	Takeoff	Landing
Runway status	Combination	Source Outside of Control Station Displays	Source Outside of Control Station Displays	Source Outside of Control Station Displays
Runway elevation (altitude)	Constant (once the runway has been selected)	Source Outside of Control Station Displays	Source Outside of Control Station Displays	Source Outside of Control Station Displays
Airport configuration	Constant	Available at RPIC Request	Available at RPIC Request	Available at RPIC Request

11.1.8 Onboard Equipment

This section reflects recommendations for onboard equipment, settings, and status relevant across flight contexts. Table 24 contains our recommendations.

Table 24. Information elements and recommendations for onboard equipment.

Information Element	Control Attribute	Availability Recommendation
Altimeter setting	RPIC	Always Displayed
Aircraft external lights status	RPIC	Always Displayed
Transponder code[1]	RPIC	Always Displayed
Transponder status	Other	Always Displayed

[1]In this work, installation and maintenance are not addressed. There are many information elements associated with transponders such as the address and mode and they could change if a transponder is moved from one aircraft to another.

11.2 TAXI

Steering angle refers to the angle that the aircraft is steering while taxiing; a generic term is used since the method of aircraft taxi is dependent on the aircraft. For aircraft that are taxied via nose wheel steering, this refers to the nose wheel angle. For aircraft that are taxied via thrust and brakes, this refers to the angle that the aircraft is turning. Table 25 contains our recommendations.

Table 25. Information elements and recommendations for taxi.

Information Element	Control Attribute	Availability Recommendation
Position relative to taxiway centerline	Combination	Source Outside of Control Station Displays
Steering angle	RPIC	Context Dependent
Taxiway status	Other	Source Outside of Control Station Displays

SME Comments—One SME had a suggestion for additional information to be added: “I suggest adding ‘position relative to my taxi plan’ because many times, being in the center of the taxiway is not where you want to taxi.”

- Response/Rebuttal: This information element is included in the Section 11.4.2.

11.3 APPROACH AND LANDING

In addition to the information elements presented in Section 11.1, the recommendations below are for the approach and landing phases of flight. Table 26 contains our recommendations.

Table 26. Information elements and recommendations for approach and landing.

Information Element	Control Attribute	Availability Recommendation
Position relative to desired glidepath	Combination	Context Dependent
Position relative desired path over ground	Combination	Context Dependent

11.4 NAVIGATE

The information in this section refers to recommendations for navigation in the air as well as navigation while taxiing.

11.4.1 Flight Plan

In addition to information contained in Section 11.7 (e.g., airspace, terrain, and weather information), the information elements that follow are recommended for route planning. The flight time information element is a temporal representation of the aircraft range, accounting for fuel onboard or maximum battery life. Table 27 contains our recommendations.

Table 27. Information elements and recommendations for flight plan information.

Information Element	Control Attribute	Availability Recommendation
Flight time elapsed	Combination	Optional
Origin	RPIC	Source Outside of Control Station Displays
Destination	RPIC	Source Outside of Control Station Displays
Alternate airport	RPIC	Source Outside of Control Station Displays
Flight plan type (IFR vs. VFR)	RPIC	Source Outside of Control Station Displays
Departure time	RPIC	Source Outside of Control Station Displays
Estimated time enroute	RPIC	Optional
Estimated arrival time	RPIC	Source Outside of Control Station Displays
Planned cruise altitude	RPIC	Source Outside of Control Station Displays
Route of flight	RPIC	Source Outside of Control Station Displays
Pilot identification data	RPIC	Source Outside of Control Station Displays
Active flight plan	RPIC	Source Outside of Control Station Displays
Inactive flight plan(s)	RPIC	Source Outside of Control Station Displays
Charts/terminal procedures	Constant	Source Outside of Control Station Displays
Taxi route	RPIC	Source Outside of Control Station Displays

SME Comments—One SME commented about the alternate airport: “If the RPIC has an emergency, the alternate airport should be ‘pushed’ to the operator. This would result in one less thing to consider when the heat is on.”

- Response/Rebuttal: Since the alternate airport is accessible to the RPIC (e.g., via the filed flight plan), the added step of “pushing” the information to the RPIC can be considered higher than minimum. “Pushing” the information could interrupt the RPIC’s emergency procedure, which counters Yeh et al. (2013) assertion that routine information may be stored and presented at an appropriate time so as not to disrupt the flightcrew in performing other critical tasks.

11.4.2 Flight Progress Monitoring

Aircraft position relative to filed flight route and planned taxi route account for the lateral, vertical, and temporal dimensions. Regarding the planned taxi route, the lateral position is the aircraft position relative to taxiway centerline. Table 28 contains our recommendations.

Table 28. Information elements and recommendations for flight progress monitoring.

Information Element	Control Attribute	Availability Recommendation
Time to destination	Combination	Optional
Distance to destination	Combination	Optional
Estimated flight range remaining	Combination	Optional
Time to next waypoint	Combination	Optional
Distance to next waypoint	Combination	Optional
Position relative to desired flight route	Combination	Optional
Position relative to desired taxi route	Combination	Optional

SME Comments—Regarding time to next waypoint, one SME commented: "Time to any waypoint should be accessible. The RPIC may want to know where and when (s)he is currently and will be in the future."

- Response/Rebuttal: Since this information is not flight critical and can be derived from other information elements available to the RPIC, it is "optional."

11.4.3 Navigation Equipment

Navigation equipment is platform specific; some UAS are equipped with ground-based navigation equipment while others use only satellite-based navigation equipment. The terms in the table that follow are meant to account for both types of navigation. Table 29 contains our recommendations.

Table 29. Information elements and recommendations for navigation equipment.

Information Element	Control Attribute	Availability Recommendation
Selected navigation aid	RPIC	Context Dependent
Navigation aid status	Other	Context Dependent
Quality of information reported by navigation aid	Other	Context Dependent
Source of the reported UA position information	Combination	Available at RPIC Request

SME Comments—One SME suggested "…adding 'available navigation aids' as a context-dependent information element."

- Response/Rebuttal: This would require the UAS to have a database of navigation aids, making this higher than a minimum requirement. Therefore, the information element was not added to the recommendations.

11.5 COMMUNICATE

This section contains information items for communication with external human agents (such as a VO or air traffic control) as well as communication between the control station and UA. With respect to communication, this work assumes that voice communications are accomplished via radios. It is recommended that the RPIC know what radio is active and its status and settings. Communication with the UA is through commands sent from the control station to the UA. Table 30 contains our recommendations.

Table 30. Information elements and recommendations for communication information.

Information Element	Control Attribute	Availability Recommendation
Active communication radio	RPIC	Always Displayed
ATC clearance	Combination	Source Outside of Control Station Displays
ATC contact information	Constant	Source Outside of Control Station Displays
Communication channel (ATC)	RPIC	Always Displayed
Communication frequency (ATC)	RPIC	Always Displayed
Communication radio signal strength (ATC)	Other	Optional
Communication channel (VO)	RPIC	Context Dependent
Communication frequency (VO)	RPIC	Context Dependent
Communication radio signal strength (VO)	Other	Optional
Command sent status	Other	Always Displayed

SME Comments—While all SMEs agreed with the recommendations, they also made suggestions for additional items.

- One SME suggested "I am not sure if it is an FAA requirement, but some radios also have 'last radio selected' and 'loaded radio' representing the next radio the RPIC wants."
  - Response/Rebuttal: This is not a flight critical function and is considered higher than a minimum requirement, so it was not added to the recommendations.
- One SME suggested "This list looks like it is referring to one radio. I suggest changing it to reflect a primary and secondary radio."
  - Response/Rebuttal: The minimum requirement for manned IFR flight is one radio (14 CFR 91.205(d)(2)), so no changes were made to the recommendations.
- One SME suggested "Some UAS will start using DataComm instead of voice communications. Perhaps that should be considered in this section as well"

    - Response/Rebuttal: Data communication capability is not a flight critical function and is considered a higher level of automation than voice communication. Therefore, it was not added to the recommendations.
- One SME suggested "Contact information for ATC should be provided and should be context-dependent"
    - Response/Rebuttal: ATC contact information was added to the list of information elements, but since it is available in mediums outside the control station, such as via communication channels and aeronautical charts, it has been assigned an availability of "Source Outside Control Station."

11.6 CONTINGENCY

The contingencies addressed in the scope of this work are

a) degraded UA position reporting,
b) loss of command/control link,
c) loss of contingency flight planning automation, and
d) VO failure (VO unavailable or loss of communication).

Below, first the items relevant to all four contingency areas are presented and then each is addressed.

11.6.1 All Contingencies

For each of the contingencies, it is recommended that the RPIC be able to determine the active contingency plan and to review the procedure. If the issue cannot be rectified, it is recommended that the RPIC have available the loiter and ditch information. Table 31 contains our recommendations.

Table 31. Information elements and recommendations for all contingencies.

Information Element	Control Attribute	Availability Recommendation
Active contingency plan(s)	RPIC	Optional
Emergency landing area(s)	RPIC	Optional
Loiter area(s)	RPIC	Optional
Loiter waypoint direction	RPIC	Context Dependent
Loiter waypoint radius	RPIC	Optional
Loiter waypoint time	RPIC	Optional
Procedure	RPIC	Optional

11.6.2 Degraded UA Position Contingency

For the degraded UA position reporting contingency, it is recommended that the RPIC know the status of the system such as whether it is operational and its accuracy. Table 32 contains our recommendations.

Table 32. Information elements and recommendations for degraded UA position reporting.

Information Element	Control Attribute	Availability Recommendation
Aircraft position reporting system status	Other	Context Dependent

11.6.3 Loss of Command/Control Link Contingency

The information elements in this subsection refer to the command/control link with the UA, and not communication radios. For the loss of command/control link contingency, it is recommended that the RPIC know the C2 link status, including the signal frequency and strength. If there is a loss of command/control link, it is recommended that the RPIC know how long the loss has occurred in order to initiate associated procedures. Table 33 contains our recommendations.

Table 33. Information elements and recommendations for loss of command/control link.

Information Element	Control Attribute	Availability Recommendation
Command/control downlink signal strength	Other	Always Displayed
Command/control link frequency	RPIC	Always Displayed
Command/control link strength safe operating range/location	Other	Always Displayed
Command/control uplink signal strength	Other	Always Displayed
Lost command/control link elapsed time	Other	Context Dependent

SME Comments—There was some disagreement on the recommendations.

- General Comment: "It may not be a bad idea to call out 'secondary links.' Larger UAS may have more than one C2 link, and a minimum requirement would be 'context-dependent.' So, the first four items would be 'primary' and another four would be listed as 'secondary'."
    - Response/Rebuttal: Having multiple links is considered higher than a minimum requirement, so the suggested changes were not made to the recommendations.
- Regarding command/control downlink signal strength: "This could potentially be changed to 'context-dependent' such that the RPIC is alerted when signal strength is degraded."
    - Response/Rebuttal: While the function allocation recommendation for lost command/control link is to alert the RPIC when the signal degrades (Pankok, Bass, Walker, et al., 2017), RPIC awareness of C2 link strength is crucial for safe operation, so the recommendation has not changed based on this comment.
- Regarding lost command/control link elapsed time: "This should be changed to 'optional.' The RPIC can start a timer if the alert/warning comes on."
    - Response/Rebuttal: The function allocation recommendation for lost C2 link is to alert the RPIC when the lost link exceeds a threshold amount of time (Pankok, Bass, Walker, et al., 2017), so in accordance with the SME comment, this

recommendation has remained unchanged since the information is presented to the pilot when the context is degraded C2 link.

11.6.4 Loss of Flight Planning Automation Contingency

For the loss of flight planning automation contingency, it is recommended that the RPIC has access to status information in order to know about the need to initiate associated procedures. If the RPIC discovers that the contingency flight planning automation is inoperative at a time when it is needed (e.g.,, when the command/control link is lost), there may be insufficient time to address the problem. Therefore, the contingency flight planning automation system status should be always displayed, so that when the automation becomes inoperative, the RPIC can address the issue before a contingency plan is required. Table 34 contains our recommendations.

Table 34. Information elements and recommendations for time.

Information Element	Control Attribute	Availability Recommendation
Contingency flight planning automation system status	Other	Always Displayed

11.7 ENVIRONMENT

11.7.1 Airspace

Airspace information would help the pilot avoid areas in which the UA should not be operated. This type of information could also be addressed outside of the control station displays, such as with aeronautical charts. With respect to representation, this type of information could be overlaid onto an egocentric navigation display or displayed in a static digital chart or map. Table 35 contains our recommendations.

Table 35. Information elements and recommendations for airspace information.

Information Element	Control Attribute	Availability Recommendation
Airspace boundaries	Other	Source Outside of Control Station Displays
Special use airspace boundaries	Other	Source Outside of Control Station Displays

11.7.2 Terrain

It is recommended that terrain information be available when the UA is near the ground. While this information could be addressed outside of the control station displays, safety could be compromised as the RPIC lacks the robust out-the-window view that a traditional manned pilot has during visual meteorological conditions. Table 36 contains our recommendations.

Table 36. Information elements and recommendations for terrain information.

Information Element	Control Attribute	Availability Recommendation
Terrain/obstacle height	Other	Optional

SME Comments—One SME commented "This should be optional. Pilots do this in IFR all the time. I have shot many approaches where only the runway lights could be seen through the fog or I broke out at 200ft. I had to determine my height above ground from other information (chart, altimeter, location on approach, etc.). If there was a working radar altimeter, that was extra."

- Response/Rebuttal: Assuming the altitude AGL is displayed in the control station, the terrain/obstacle height should be optional.

11.7.3 Weather

In both visual and instrument meteorological conditions, the RPIC could benefit from some real-time weather data to determine whether the UA is flying in visual or instrument meteorological conditions. This information could be received using data sources outside of the control station. The RPIC would benefit from wind speed and direction information, especially when flying near the ground. RPICs flying below 18,000 feet require atmospheric pressure. RPICs concerned about the potential for icing would benefit from air temperature information. Table 37 contains our recommendations.

Table 37. Information elements and recommendations for weather information.

Information Element	Control Attribute	Availability Recommendation
Air temperature (static or outside)	Other	Context Dependent
Atmospheric pressure	Other	Source Outside of Control Station Displays
Cloud cover/height	Other	Source Outside of Control Station Displays
Dew point	Other	Source Outside of Control Station Displays
Precipitation	Other	Source Outside of Control Station Displays
Runway visual range	Other	Source Outside of Control Station Displays
Visibility	Other	Source Outside of Control Station Displays
Wind direction	Other	Source Outside of Control Station Displays
Wind speed	Other	Source Outside of Control Station Displays

SME Comments—One SME disagreed with the recommendations for wind speed and wind direction: "Since speeds are so closely tied to winds, I recommend they be 'always displayed'."

- Response/Rebuttal: Myriad weather information is available to inform pilot decision-making, including observations of wind conditions on the ground such as Meteorological Terminal Aviation Routine Weather Reports (METAR); observations of winds aloft such as Pilot Weather Reports (PIREP); and wind condition forecasts such as the Terminal Aerodrome Forecast (TAF), Aviation Area Forecast (FA), Winds and Temperatures Aloft

Forecast (FB), Airmen's Meteorological Information (AIRMET), Significant Meteorological Information (SIGMET), and Convective SIGMETs. Since these sources are already available to the RPIC, adding these information sources to the control station would be considered higher than a minimum requirement.

11.8 HANDOVER OF CONTROL

The handover task analysis and function allocation recommendations indicated that there are three types of associated information. One set of information is associated with the status of the communication links between the CS and the UA. Another set of information is associated with the communication between the two RPICs. The third set of information is associated with the communication content between the RPICs. With respect to the former, it is recommended that these information elements are always displayed. Table 38 contains our recommendations.

Table 38. Information elements and recommendations for handover link status.

Information Element	Control Attribute	Availability Recommendation
Command/control downlink connection status	Combination	Always Displayed
Command/control uplink connection status	Combination	Always Displayed

With respect to the communication between the RPICs, the communication channels and frequencies are recommended to be context dependent, but the radio signal strength is optional since the signal strength can be determined via the clarity of the line. Table 39 contains our recommendations.

Table 39. Information elements and recommendations for handover communication.

Information Element	Control Attribute	Availability Recommendation
Communication channel (CS)	RPIC	Context Dependent
Communication frequency (CS)	RPIC	Context Dependent
Communication radio signal strength (CS)	Other	Optional

With respect to the content of the information that is communicated between the receiving RPIC and the transferring RPIC, no new information elements were identified that were not already identified as part of the other tasks. While there will be UA-specific information elements to be verbally communicated, the table below lists the information elements that are recommended to be available for all UAS handovers. Table 40 contains our recommendations.

Table 40. Information elements and recommendations for handover information.

Information Element	Control Attribute	Availability Recommendation
Active contingency plan(s)	RPIC	Optional
Altitude above ground level (absolute)	Combination	Always Displayed
ATC clearance	Combination	Source Outside of Control Station Displays
Command/control downlink signal strength	Other	Always Displayed
Command/control uplink signal strength	Other	Always Displayed
Indicated altitude	Combination	Always Displayed
Indicated airspeed	RPIC	Always Displayed
Magnetic heading	RPIC	Always Displayed

SME Comments: SMEs generally agreed with the information recommendations, with a few exceptions detailed in the following bullets.

- Regarding altitude, one SME suggested that altitude above ground level should be always displayed as well as altitude above mean sea level.
    - Response/rebuttal: Altitude above ground level has been added since it was already always displayed in the control station (see Section 11.1.3).
- Regarding the ATC clearances, one SME indicated, "While this information is nice, I do not believe it should be always displayed. It is not required in manned aircraft."
    - Response/rebuttal: We have changed the availability of "ATC clearance" to "Source Outside Control Station" in accordance with the comment.
- Regarding information deemed safety critical by the pilot that is handing over control, one SME indicated, "Based on my experience, determining safety critical information should be an institutional decision, not an RPIC decision. Standardization across the crew force is important here."
    - Response/rebuttal: This comment addresses procedures and not automation or information requirements, so no changes were made to the recommendations in accordance with this comment.
- One SME recommended additional information elements for UA status: next waypoint, ATC frequency, and secondary command link integrity.
    - Response/rebuttal: Per the CS-3 recommendations, "route of flight" and "ATC communication frequency" are available to the RPIC, so the recommendation was not changed. Regarding "secondary link integrity", the assumptions state that the UA contains a single uplink/downlink connection, so this information element was not added.
- One SME commented that the CS should display the uplink/downlink connection status of the other CS- "This information should be made available inside the CS."

- Response/rebuttal: This information can be conveyed via voice communication, so this suggestion reflects a higher than minimum information requirement. The recommendation was not changed.

11.9 RECOMMENDATIONS

The recommendations to support control station considerations for integrating UAS flying in the NAS can be summarized based on the characteristics of the information elements described in this report and summarized in Table 44.

Information elements that are recommended to always be displayed (Table 41) would yield recommendations like the following:

> It is recommended the control station have the capability to display <*information element*> at all times.

Table 41. Information elements that should be displayed at all times.

Information Element: Always Displayed
Active communication radio
Aircraft external lights status
Aircraft ID
Altimeter setting
Altitude above ground level (absolute)
Command sent status
Command/control downlink connection status
Command/control downlink signal strength
Command/control link frequency
Command/control link strength safe operating range/location
Command/control uplink connection status
Command/control uplink signal strength
Communication channel (ATC)
Communication frequency (ATC)
Contingency flight planning automation system status
Control device position
Flight mode annunciation
Indicated airspeed
Indicated altitude
Landing gear control position
Landing gear status
Latitude
Lift/drag device position
Lift/drag device position target
Longitude
Magnetic heading
Maximum flaps extended speed (V_{FE})

Maximum landing gear operating speed (V_{LO})
Maximum operating limit speed (V_{MO})
Maximum operating maneuvering speed (V_O)
Maximum speed for normal operations (V_{NO})
Never-exceed speed (V_{NE})
Pitch attitude
Roll attitude/bank angle
Slip/skid
Stall speed (V_S)
Stall speed in landing configuration (V_{S0})
Throttle position
Thrust reverser position
Time of day
Transponder code
Transponder status
Trim device position
Vertical speed

Information elements that are recommended to be displayed during specific contexts (Table 42) would yield recommendations like the following:

> The control station is recommended to have the capability to always display <*information element*> when <*context*>.

Table 42. Information elements that are context dependent.

Information Element	Context
Air temperature (static or outside)	For reciprocating engine-powered airplanes
Aircraft position reporting system status	When the quality of the information being reported has degraded
Communication channel (CS)	When communication with another CS is required
Communication channel (VO)	When communication with a VO is required
Communication frequency (CS)	When communication with another CS is required
Communication frequency (VO)	When communication with a VO is required
Loiter waypoint direction	When loiter area is used
Lost command/control link elapsed time	When loss of command/control link
Maximum landing gear extended speed (V_{LE})	When in takeoff, final approach and landing phases
Navigation aid status	When navigation aid is selected
Position relative desired path over ground	When in final approach and landing phases
Position relative to desired glidepath	When in final approach and landing phases

Quality of information reported by navigation aid	When navigation aid is selected
Rotation speed (V_R)	Takeoff
Selected navigation aid	When navigation aid is selected
Steering angle	Taxi
Takeoff decision speed (V_1)	Takeoff
Takeoff safety speed (V_2)	Takeoff
Wheel brake position	Taxi

Information elements that are recommended to be displayed at the RPIC's request (Table 43) would yield recommendations like the following:

> The control station is recommended to have the capability to display <*information element*> at the pilot's request.

Table 43. Information elements that are available at RPIC request.

Information Element: RPIC Request
Airport configuration
Ground speed
Source of the reported UA position information

Information elements that are optional would not lead to specific recommendations but could lead to design guidance or suggestions.

Information elements that can be obtained outside of the control station displays would not lead to recommendations.

Information elements that can be controlled directly by the RPIC would yield two types of recommendations like the following:

> The control station is recommended to have the capability for the pilot to enter a value for <*information element*> for upload to the UA.
>
> The control station is recommended to have the capability for the pilot to view the commanded value for <*information element*>.

In addition, for every information element that can be controlled directly by the RPIC, the design recommendation is for the display to include the value of related information elements that change as a result. For example, if the RPIC changes the landing gear control position, the control station display is recommended to make the landing gear status visible to the RPIC. For information elements that are influenced by an agent or force external to the UAS, or those influenced in combination, the design recommendation is for the display to include the value of related information elements that change as a result.

A summary of the categorizations for all of the information elements is contained in Table 44.

Table 44. Summary of information element characteristics informing recommendations.

Recommended Availability	Control Attribute	Information Element
Optional	Combination	Density altitude Distance to destination Distance to next waypoint Estimated flight range remaining Flight time elapsed Ground track Optimal climb rate Optimal cruise speed Optimal descent rate Position relative to desired flight route Position relative to desired taxi route Time to destination Time to next waypoint True airspeed True heading
Optional	Constant	Maximum altitude
Optional	Other	Communication radio signal strength (ATC) Communication radio signal strength (CS) Communication radio signal strength (VO) Terrain/obstacle height Time of day (destination) Time of day (origin)
Optional	RPIC	Active contingency plan(s) Altitude target Angle of attack Emergency landing area(s) Estimated time enroute Flight surface positions Heading target Indicated airspeed target Loiter area(s) Loiter waypoint radius Loiter waypoint time Pitch angle target Procedure Rate of turn Roll attitude/bank angle target Thrust level Vertical speed target Yaw attitude

Context Dependent	Combination	Position relative desired path over ground Position relative to desired glidepath Rotation speed (V_R) Takeoff decision speed (V_1) Takeoff safety speed (V_2)
Context Dependent	Constant	Maximum landing gear extended speed (V_{LE})
Context Dependent	Other	Air temperature (static or outside) Aircraft position reporting system status Lost command/control link elapsed time Navigation aid status Quality of information reported by navigation aid
Context Dependent	RPIC	Communication channel (CS) Communication channel (VO) Communication frequency (CS) Communication frequency (VO) Loiter waypoint direction Selected navigation aid Steering angle Wheel brake position
Always Displayed	Combination	Altitude above ground level (absolute) Command/control downlink connection status Command/control uplink connection status Indicated altitude Landing gear status Latitude Longitude Vertical speed
Always Displayed	Constant	Aircraft ID Maximum flaps extended speed (V_{FE}) Maximum landing gear operating speed (V_{LO}) Maximum operating limit speed (V_{MO}) Maximum operating maneuvering speed (V_O) Maximum speed for normal operations (V_{NO}) Never-exceed speed (V_{NE}) Stall speed (V_S) Stall speed in landing configuration (V_{S0})
Always Displayed	Other	Command sent status Command/control downlink signal strength Command/control link strength safe operating range Command/control uplink signal strength Contingency flight planning automation system status Time of day Transponder status

Always Displayed	RPIC	Active communication radio Aircraft external lights status Altimeter setting Command/control link frequency Communication channel (ATC) Communication frequency (ATC) Control device position Flight mode annunciation Indicated airspeed Landing gear control position Lift/drag device position Lift/drag device position target Magnetic heading Pitch attitude Roll attitude/bank angle Slip/skid Throttle position Thrust reverser position Transponder code Trim device position
Available at RPIC Request	Combination	Ground speed Source of the reported UA position information
Available at RPIC Request	Constant	Airport configuration
Source Outside of Control Station Displays	Combination	ATC clearance Position relative to taxiway centerline Runway status
Source Outside of Control Station Displays	Constant	Aircraft type ATC contact information Charts/terminal procedures Runway elevation (altitude)
Source Outside of Control Station Displays	Other	Airspace boundaries Atmospheric pressure Cloud cover/height Dew point Precipitation Runway visual range Special use airspace boundaries Taxiway status Visibility Wind direction Wind speed

Source Outside of Control Station Displays	RPIC	Active flight plan Alternate airport Departure time Destination Estimated arrival time Flight plan type (IFR vs. VFR) Inactive flight plan(s) Origin Pilot identification data Planned cruise altitude Route of flight Taxi route