Designing for Autonomous Cargo Operations

Brian Moon[a]*, James Bona[b], William Hurley[a]

[a]Perigean Technologies LLC, 8108 Lee Jackson Circle, Spotsylvania, Virginia, 22553, USA
[b]Kutta Technologies, Inc., 2075 West Pinnacle Peak Road Suite 102, Phoenix, AZ, 85027, USA

Abstract

The degree of autonomy in flight operations has reached a level such that envisioned mission complexity can be realistically explored. As the exploration goes deeper, the challenges become more acute, requiring design thinking to work out the implications. This paper describes the process for designing human-system interfaces to enable interaction with a full-size helicopter capable of autonomous planning and mission execution of cargo operations, and the design concepts that attempt to address key challenges to enabling and managing the interaction.
© 2015 The Authors. Published by Elsevier B.V.
Peer-review under responsibility of AHFE Conference.

Keywords: Autonomy; cognitive systems engineering; human-centered computing.

1. Introduction

As autonomous systems reach greater levels of autonomy, new questions emerge about how humans can and should bring autonomous systems into the fold of routine and nonroutine operations. While challenges for making automation a team player have been known for some time [1], the degree of autonomy in flight operations has reached a level such that envisioned mission complexity can be realistically explored. As the exploration goes deeper, the challenges become more acute, requiring design thinking to work out the implications.

Our team is designing interfaces for use by a humans interacting with a full-size helicopter capable of autonomous planning and mission execution of cargo operations. We encountered previously unforeseen design challenges as we conceived modules for pre-planning tasks, mission monitoring, and dynamic replanning, and as we considered the range of interactions between humans and systems that would need to be enabled through the interfaces.

Nomenclature

AACUS	Autonomous Aerial Cargo/Utility System
AVO	Air Vehicle Operator
CONOPS	CONcept of OPerationS
COP	Combat OutPost
CTA	Cognitive Task Analysis
FO	Field Operator
GCS	Ground Control Station
HSI	Human-Systems Interface
LZ	Landing Zone

* Corresponding author. Tel.: 1-540-429-8126; fax: 1-540-786-5367.
E-mail address: brian@perigeantechnologies.com

MOB	Main Operating Base
MPD	Mission Planning Data
TALOS	Tactical Autonomous Aerial LOgistics System

1.1. AACUS and TALOS description

The Office of Naval Research's Autonomous Aerial Cargo/Utility System (AACUS) is an Innovative Naval Prototype program envisioned to create a retrofit perception/planning/human interface system that enables autonomous take-off, flight, and landing of a full-scale rotary-wing aircraft to and from austere, possibly-hostile landing zones, in a tactical manner, with minimal human supervision [2]. The Tactical Autonomous Aerial LOgistics System (TALOS) is currently in its second phase of development by a team led by Aurora Flight Sciences that includes the authors, in order to realize the AACUS vision. TALOS comprises Human-Systems Interfaces (HSIs), Planning Systems, and Perception Systems—all of which are being designed to enable portability across any rotorcraft of sufficient payload capacity [2]. The authors comprise the core team of developers of the HSIs.

The HSI vision for AACUS includes several key challenges that extend autonomous operations:

- Request for resupply and mission monitoring should be enabled through a tablet device requiring minimal training for an operator
- Route planning should be conducted by AACUS, using human constraints and requirements for input
- Minimal human supervision should be necessary during mission execution
- No operator shall have direct control of flight systems.

In addition, the envisioned Concept of Operations (CONOPS) for AACUS presents several challenges for HSI design, including:

- Multiple landing consent modes (i.e., by exception and by consent) should be supported
- AACUS-enabled aircraft should be able to land in austere environments without human intervention
- Operators should be able to wave-off or terminate a mission.

These challenges present the design constraints for the development of HSIs to be used by the intended human teammates of an AACUS system.

1.2. AACUS Human Teammates

Two types of teammates are envisioned for AACUS. An Air Vehicle Operator (AVO) is a Marine at the Main Operating Base (MOB) who has supervisory control of the aircraft through a ground control station (GCS). The AVO's responsibilities include providing mission planning data, and launching and monitoring missions; the AVO will be a specialist trained in these areas. As with other Unmanned Aerial Systems (UASs), the AVO maintains responsibility of an AACUS-enabled aircraft throughout the mission; however, at no time does the AVO assume direct control.

The second teammate is a Marine Field Operator (FO) at a Combat OutPost (COP). The FO can initiate an Assault Support Request (ASR) to be serviced by an AACUS-enabled aircraft, and can monitor mission progress. As the aircraft nears the COP, the FO can interact with it in order to provide consent to land, the requirement for which is determined during planning. Once resupply is complete, the FO ensures that conditions are safe for take-off, and initiates take-off. The FO need not have received specialized training, but will know the tactics, techniques and procedures for managing landing zones.

1.3. AACUS Interfaces

The two human roles required the design of two distinct HSIs. For the MOB AVO, the HSI must enable planning, and execution functions for both the TALOS system and the aircraft on which it is deployed. The envisioned MOB AVO workstation will include two monitors for separate-but-interactive visualization of the two systems. For the COP FO HSI, all functions must be executed on a tablet-scale application that is readable and interoperable in field conditions. All iconography and palettes are expected to conform to standards [3].

2. Design Process

The design process for TALOS HSI has followed a cognitive systems engineering approach [4]. Phase I of the effort involved significant planning, research, and design. Phase II is focused on design and adaptations, and initial work toward measurement.

2.1. Phase I Design Activities and Results

During the first phase of development, design activities included cognitive task analysis (CTA), followed by a series of design workshop and validation studies [5]. Specifically, the CTA [N=22] was geared toward understanding and supporting the envisioned world of the COP FO, with participants including helicopter and UAS pilots and instructors and Marines with COP experience [5]. Design workshops drew on CTA data, design thinking techniques, and the envisioned constraints to yield design concepts that were instantiated in an app for deployment on an iPad mini. Wireframes and storyboards were developed as artifacts to describe the designs. Validation activities include design reviews of the artifacts and an evaluation of the training time necessary to gain working familiarity with the app [N=13] [5]. Phase I activities were also conducted for MOB AVO HSI, including a review of CTA data, design workshop, development of storyboards, validation reviews, and software instantiation [6]. However, the primary focus for Phase I activities was on COP design.

Figures 1a and b show screenshots of the Phase I designs. Fig. 1a shows the mission monitoring screen for the COP HSI, which presents a highly abstracted view of the mission, as well as a vertical profile view. The design intent was to provide enough information to the FO such that resupply planning could proceed at the COP without overwhelming the FO with details of the mission execution. Fig. 1b shows the MOB screen layout, where the design approach is to present a large, primary display of information in the center, surrounded by a rich periphery of auxiliary information. Each panel is a separated but integrated executable, allowing for future reconfiguration.

a b

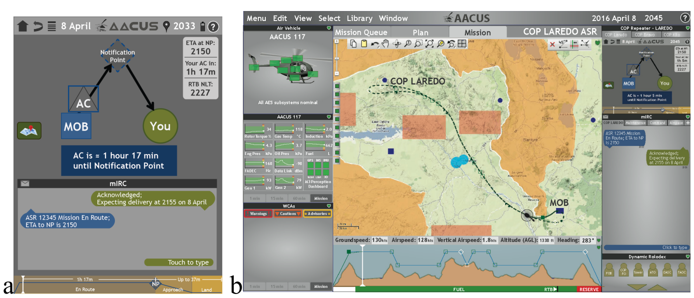

Fig. 1. (a) Phase I COP HSI Design; (b) Phase I MOB HSI Design.

Flight demonstration of TALOS was conducted in February 2014, and included use of the COP app on an iPad mini. The FO role was performed by a Marine with 15 minutes of training. Observations of use and feedback from the participant demonstrated the functionality, intuitiveness, and ease-of-use of the COP HSI and device [2]. While flight demonstrations did not assess the entire planning to mission monitoring to LZ operations cycle, some of the app features surfaced several design considerations. For example, the FO expressed a desire for improved orientation support with regard to the FO's position, the landing zone (LZ), and the aircraft.

2.2. Phase II Design Activities

Phase II activities have expanded the design process in several ways. The knowledge and code base from the collective Phase I activities are providing guidance, which are being challenged by new CONOP and program goals. An example of a new CONOP goal is the desire to serve multiple requests for any given mission—the Phase I activities addressed one request per mission. An example of a new program goal is portability across devices—the Phase I activities designed toward iOS operating system while the Phase II activities designed toward the Android operating system.

Inputs to the design process have also evolved. Whereas Phase I focused deeply on the FO role and sought inputs from personnel with knowledge about resupply requests and LZ operations, key foci for Phase II are the role, responsibilities, and requirements for the MOB AVO. Given AACUS' radical departure from current operations, in many ways the MOB AVO is an envisioned role, requiring design thinking processes that help stakeholders provide design guidance about an envisioned world [7]. While personnel with UAS operational experience are a critical source for guidance, the logistics community has also emerged as a new key design stakeholder.

The primary design activities for Phase II have been a design workshop, the generation of design artifacts, and a series of design reviews. The main focus of the design workshop was the MOB HSI. The Phase I design was reconsidered, given the new CONOP and program goals. However, the overarching design approach—i.e., reconfigurable panels for central and peripheral information and action—was retained. The workshop participants also addressed the COP HSI with an eye toward updating previous designs and introducing new features. An example of the latter is the inclusion of audial and haptic alerts to bring the FO's attention to the COP HSI at critical junctures. A new set of wireframes and storyboard artefacts were developed to convey the Phase II design directions. Each of the communities noted above provided review of the artefacts to enable an iterative design process.

These Phase II design activities brought several design challenges into high relief. The remainder of this paper discusses the challenges and the concepts suggested to meet them. It is important to note that the design concepts are and will be at varying levels of maturity: some have been implemented, some will be implemented, and some will remain conceptual. The discussion treats them in their envisioned, functioning implementation.

3. Design Challenges and Concepts

Under a CONOP involving one resupply per mission, the MOB AVO's task responsibilities are relatively straightforward: receive and approve the request, approve the point-to-point route plan, and monitor mission execution. These tasks grow in complexity, however, by the number of resupply request that may be serviced for any given mission. During planning, the MOB AVO must now deconflict multiple requests, which may involve considerations of priority of the requests, sequencing of the delivery order, load arrangement onto the aircraft—all of which must be considered in the context of mission parameters such as altitude and cruising speeds. These new complexities implicate the need for the MOB AVO to also engage the logistics community and personnel who approve air worthiness, in addition to multiple COP FOs, throughout the planning process.

These considerations led to the first major redesign of the Phase I concept; namely, a need separate the Plan from the Execution mode. The Plan and Execute modes toggle, yet both retain the panel-based configuration. Figures 2a and b show the design concepts for two stages of the Plan mode. Fig. 2a shows how the MOB AVO will work through a request queue to build segments of the mission based on ASRs from several of the COPs that fall under the AVO's area of operations. The segments, coupled with the mission parameters that will govern the entire mission, comprise the Mission Planning Data (MPD) package, which is provided to TALOS as the input to its route planning process. Fig. 2b shows a later stage, after TALOS has provided a candidate mission that has been approved by the AVO. Notably, each stage is governed by process stage-gates—subsequent stages are available only after a stage-gate has been satisfied. For example, a MPD package cannot be sent to TALOS unless the total payload is under the aircraft's payload capacity. Satisfying this stage-gate, while attempting to service all ASRs with available supplies, is not a trivial matter. The design concept for planning includes notional functions to enable interfacing with the logistics community and conducting local deconfliction, for example, deconflicting requested delivery times and sequences.

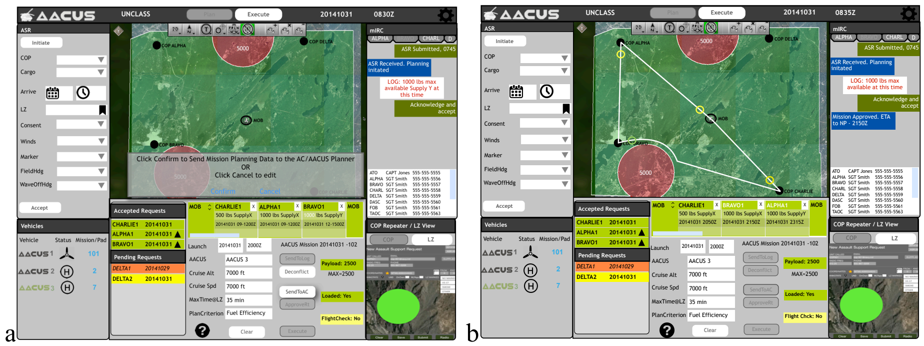

Fig. 2. (a) MOB HSI MPD package; (b) MOB HSI route approval.

Thus, the design goal for planning was to enable the MOB AVO to manage the planning process in concert with all teammates, including TALOS. Using the peripheral panels, the MOB AVO will be able, to different degrees, to see into teammates' planning activities. Chatboxes will be available for text communications, and provide updated telephone contact information for all teammates. The COP repeater panel will show the COP HSI for any given COP—which will double as a learning support capability where new COP FOs may need assistance. The Vehicle panel will provide status updates for the AACUS-enabled fleet. Future panels may provide additional insight into the logistics community. Providing this level of awareness is critical for "effective coordination to take place during the course of the joint activity. [T]here has to be a reasonable level of *interpredictability*. In highly interdependent activities, it becomes possible to plan one's own actions (including coordination actions) only when what others will[/can] do can be accurately predicted." [1]

The culmination of the planning process is the command given by the MOB AVO to execute the mission. In an early design concept, the planning process culminated with a command to launch. During design review with Marines, however, it was suggested that a MOB AVO will likely prefer to launch the aircraft in Execute mode where the mission is visible and execution-relevant commands are available. Uncovering this key design feature drove home the importance of user-centered design.

In Execute mode, the panel configuration toggles to review information and actions that are necessary for mission supervision, as shown in Figures 3a and b. The panels on the right remain unchanged to provide seamless chat communications and views of the COP HSI, to include a birds eye view of the LZ as the aircraft approaches. Panels on the left provide current and trending data for TALOS-specific subsystems, communications, and onboard cameras that can toggle between views of the aircraft bay and out the front of the aircraft. A map-based view of the mission and progress is provided in the center-top panel, complete with avionics display information with *current* readings. The center-bottom panel shows a vertical profile of the mission, including *estimated* times of arrival, landing consent mode indicators (yellow/green "IP" circles), aircraft state indicators (in-flight, cleared for landing, landed, ascending, cruise, descending), and dynamic fuel display. Progress of the mission is displayed by the current state indicator bar 'consuming' the vertical profile, which is a common technique in avionics displays [8]. Figures 3a and b demonstrate snapshots of progress, where Fig. 3a shows the mission at initial launch and Fig. 3b shows a much later point. Available actions for Launch, Replan, and Abort become available at bottom as appropriate given the stage of the mission.

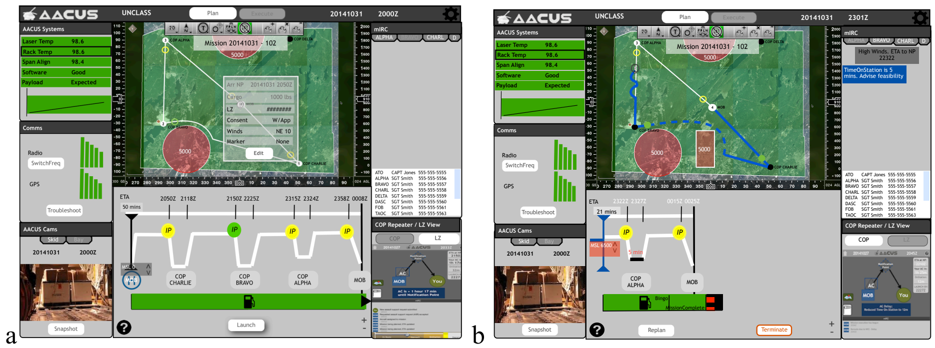

Fig. 3. (a) Execute mode at launch; (b) Execute mode at later stage of mission.

Thus, the Execute panel configuration is intended to support mission monitoring. Specific design features, particularly of the center panels, express sensitivity to the challenges of “making automation a ‘team player’ in joint human-agent activity [1]. In addition to the interpredictability challenge noted above, other challenges include:

- teammates must be able to adequately model the other participants’ intents and actions vis-à-vis the state and evolution of the joint activity—e.g., are they having trouble? are they on a standard path proceeding smoothly? how have others adapted to disruptions to the plan?
- teammates must be able to participate in the management of attention
- teammates must be able to engage in goal negotiation
- controlling the costs of coordinated activity.

Each of these challenges is intensified with consideration of the envisioned AACUS operating environment that includes austere and dangerous conditions, bandwidth constraints, and communications outages. These challenges and intensifiers were the context in which specific design features were crafted.

The need to model intents and actions vis-à-vis the state and evolution of the joint activity drove the design of the mission views—i.e., the birds eye map and vertical profile views. Current, known state will be available in the map view, along with the route, while intended actions will be available in the vertical profile. There are several cues that will indicate to the AVO that a significant diversion from the intended plan is occurring. These include colored, historical tracks of the flight path shown on the birds eye map view, change of color of current state indicator bar to red to indicate delays at LZs, and use of dashed lines and flashing time updates to indicate freshly replanned segments. Figures 4a and b show close-up views of some of the design concepts for indicating changes to intents and actions.

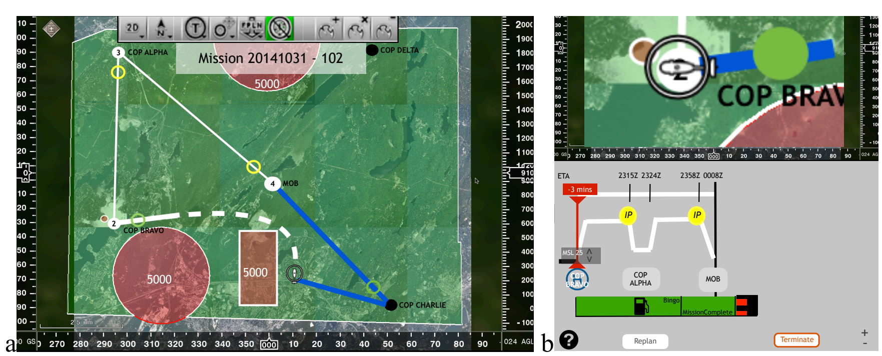

Fig. 4. (a) MOB HSI dash lined indicator for route change; (b) second picture.

Modeling intents and actions can, at times, conflict with the need to manage attention. The notion of ‘significant diversion’ is one that will evolve with AACUS. In piloted operations, the pilot would decide at which point to notify teammates about a change from the intended plan; the AACUS-enabled aircraft will need to determine thresholds for reporting ‘alertable’ events. For example, AACUS will be able to sense obstacles and avoid them. Doing so may result in a change to the flight path—i.e., altitude and/or route. Such a change may be visible on the birds eye map view, which provides real-time location information under conditions of communications linkage. However, the change may not necessarily be an alertable event on the vertical profile view, particularly if the change does not affect the remainder of the flight plan. Any delay could result in alertable events and the need to do on-the-fly replanning and updates to teammates who remain to be serviced by the mission. There are also several ways by which time can be gained throughout a mission, and replanning that may need to occur early in a mission may not affect subsequent segments.

Thus, the design goal for modeling intents and actions of TALOS to support the situational awareness of the AVO is to provide trending and current data, and the intended plan across several parameters (i.e., time, state, location, fuel capacity). These will enable the AVO to predict future states, take action, and coordinate with other teammates if necessary, as the mission evolves. The design concepts will allow for exploration of thresholds during future iterative design activities, which will shape the need to reduce, increase, or revise alerting functions, for both the MOB AVO and COP FO.

Designing for goal negotiation has also been challenging in Phase II. During Phase I design, development, and flight testing, significant effort was focused on goal negotiation between the COP FO and TALOS at the critical juncture landing. The guiding management principle was landing by consent, and features were designed and tested that enabled the FO and TALOS to negotiate a specific touchdown point within a landing zone [2]. In Phase II, focus has shifted toward negotiating broader mission goals. Negotiation begins in planning when the MOB AVO provides the MPD package to TALOS, and TALOS in turn provides a route plan intended to satisfy the parameters of the MPD package. The AVO has approval authority over the route plan, and can adjust the MPD if necessary to meet goals that may not be explicit in the MPD package.

In some cases, mission goals may shift so dramatically that replanning becomes necessary. For example, operations may require redirecting an ongoing mission to service an urgent request. Replanning design features are shown in Figures 5a and b. The design concept is to enable the MOB AVO to conduct replanning from the Execute mode by presenting the planning tools as a translucent overlay. The AVO can replan an ongoing mission by reviewing the current cargo to evaluate whether it can service the urgent request, revise parameters of the mission that are revisable (i.e., sequence but not cargo revisions), delete and add new mission segments, and upload the new plan to TALOS—all while maintaining awareness of the ongoing mission (Fig 5a). As with other updates, all affected teammates will be automatically alerted to plan changes, and teammates whose resupply was canceled will return to the queue for the next planning cycle (Fig 5b).

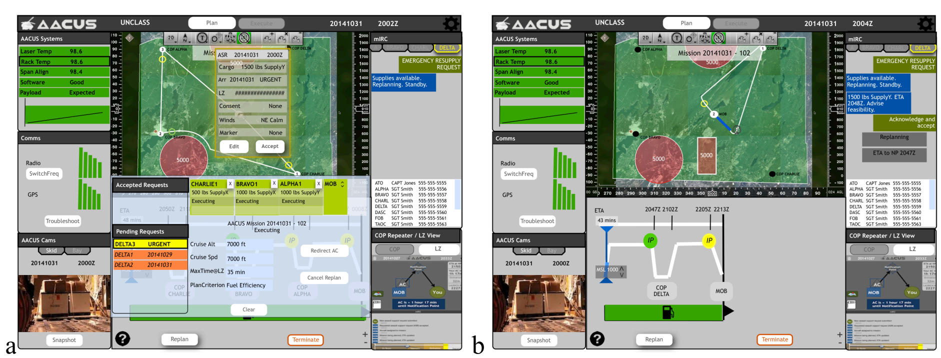

Fig. 5. (a) Replanning overlay; (b) Update to replanned mission.

Regarding updates to the intended plan, the design concepts for the Phase II COP FO HSI have taken seriously the challenge of controlling the costs of coordinated activity – i.e., the additional attention and communication requirements that attend to coordination. The COP HSI is intentionally designed to abstract the data to the most critical variable for resupply planning: time. A COP FO should be kept apprised of developments in the mission to the extent that they affect LZ operations at that COP. The mission abstraction helps to control the costs of the coordination activity on the part of the COP FO. The addition of audial and haptic alerts—as well as control over how the alerts should behave—are intended to help an FO keep awareness over the mission to the extent the FO deems necessary. Phase II tests will include management by exception scenarios in which the FO will not actively participate in the selection of touchdown points—costs of coordination on the part of the COP FO are intended to be greatly reduced.

In addition to the design considerations, personnel and training requirements began to emerge as the potential extent of AACUS' reach into operations began to be realized. Current UAS operators undergo extensive training to learn how to directly control their UASs at various points in a mission. Because the MOB AVO will not directly control an AACUS-enabled aircraft, such training requirements may be greatly reduced, if not eliminated. Yet, the level of understanding of the logistics process may increase in importance, as the preparation of the MPD package becomes a core responsibility for the MOB AVO.

5. Future Work

Many of the design concepts have been instantiated in software code. Some will be instantiated in Phase III. Design checkouts of prototype versions of the AVO and FO HSI using simulated flight will be ongoing throughout Spring and Summer 2015. As the software code matures and evaluation environments take shape, it is expected that the coded designs will be subjected to evaluation with increasing levels of fidelity. In preparation for such evaluations, Technical Performance Measures have been developed that will address learnability, effectiveness and efficiency of task completion and coordination, situation awareness, usability display quality, and trust.

Acknowledgements

This work was funded by the Office of Naval Research, under contract N00014-12-C-0671. The support of ONR is gratefully acknowledged.

References

[1] G. Klein, D. Woods, J. Bradshaw, R. Hoffman & P. Feltovich, IEEE Intelligent Systems, 19(6), 2004, 91-95.
[2] J. Paduano, J. Wissler, G. Drozeski, M. Piedmonte, N. Dadkhah, J. Francis, C. Shortlidge, C., et al. TALOS: An Unmanned Cargo Delivery System for Rotorcraft Landing to Unprepared Sites. American Helicopter Society 71st Annual Forum and Technology Display. 2015.
[3] SWFTS Display Standards and Conventions, Version 07-prelim, 5/17/2013.
[4] L. Militello, C. Dominguez, G. Lintern & G. Klein, 13(3), 2010, 261-273.
[5] C. Dominguez, R. Strouse, L. Papautsky, & B. Moon. Cognitive Design of an App Enabling Remote Bases to Receive Unmanned Helicopter Resupply. Journal of Human-Robot Interaction. In press.
[6] L. Papautsky, C. Dominguez, R. Strouse, & B. Moon. Integration of CTA and Design Thinking in Designing Autonomous Helicopter Displays. Human Factors and Ergonomics Society. In press.
[7] D. Woods & S. Dekker, Theoretical issues in ergonomics science, 1(3), 2000, 272-282.
[8] A. Alexander & C. Wickens, 3D Navigation and Integrated Hazard Display in Advanced Avionics: Performance, Situation Awareness, and Workload, 2007.