Research Paper

Integration of Cognitive Task Analysis and Design Thinking for Autonomous Helicopter Displays

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Ensuring that unmanned aerial systems' (UAS) control stations include a tight coupling of systems engineering with human factors, cognitive analysis, and design is key to their success. We describe a combined cognitive task analysis (CTA) and design thinking effort to develop interfaces for an operator controlling an autonomous helicopter, a prototype system that the Office of Naval Research is developing. We first conducted CTA interviews with subject-matter experts having expertise in UAS flight operations, helicopter resupply, military ground forces, and marine airspace control. Data informed the development of analysis products, including human–system interface requirements, which drove the creation of design concepts through ideation sessions using design thinking methods. We validated and refined the design concepts with UAS pilots. We provide an overview of our process, illustrated by details of a timeline display development. Significant aspects of our work include close integration of CTA and design thinking efforts, designing for an "envisioned world" of interaction with highly autonomous helicopter systems, and the importance of knowledge elicitation early in system design. This effort represents a successful demonstration of an innovative design process in developing UAS interfaces.

Keywords: human–automation interaction, CTA, design thinking, human–system interface, flight displays

INTRODUCTION

Today, unmanned systems with ever more sophisticated autonomy capabilities are being built for a range of civilian and military applications. A central challenge in designing effective autonomous systems is ensuring that they take into account user operational and cognitive needs. (Christoffersen & Woods, 2002). In this effort we addressed this challenge by creating and applying a process of iteratively understanding the problem space, generating design products, and validating them to develop intuitive control station interfaces for envisioned-world portable rotorcraft autonomous systems, specifically for the Autonomous Aerial Cargo/Utility System (AACUS). The term *envisioned world* refers to a system that does not exist in today's operational environments (Dekker & Woods, 1997). In a novel combination of cognitive task analysis (CTA) methods and design thinking approaches, we ensured a tight integration of research and design perspectives throughout the development cycle. To illustrate the methods and products associated with each step in the process, we will use the mission timeline, a part of the human–system interface (HSI), as an example.

This research and design effort, beginning in October 2012 and culminating in a flight demonstration in February 2014, was conducted in support of a concept of operations for autonomy that can be ported across helicopter systems to convert them to unmanned, highly autonomous systems for delivering supplies to remote combat outposts (COPs). Helicopters equipped with this technology will be able to respond rapidly regardless of weather conditions, be launched from land and water, fly in high-temperature settings, and autonomously identify and negotiate landing sites in potentially hostile environments (Cummings & Collins, 2011). Such systems can save lives and property by avoiding the necessity

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Journal of Cognitive Engineering and Decision Making
2015, Volume 9, Number 4, December 2015, pp. 283–294
DOI: 10.1177/1555343415602624

to move supplies by road through potentially hostile territory and rugged terrain. We were responsible for designing and testing two interfaces. One was a handheld device interface, intended for non-aviator marines and soldiers at remote outposts to place orders for resupply, monitor missions, and interact with the unmanned helicopter to approve landing, offload the aircraft, and send it on its way (Dominguez, Strouse, Papautsky, & Moon, in press). The second, which is the focus of this paper, was the main operating base (MOB) ground-control station interface, to be used by a trained unmanned aerial systems (UAS) operator responsible for the mission.

We applied CTA methods to understand the mission, the operational context, and operator cognitive needs for this envisioned-world environment. We then used design thinking methods to generate prototypes and design concepts. Finally, we applied CTA methods to evaluate and refine designs, providing validation for the prototyped design concepts that were then coded into software and used in flight test. Next, we identify and describe these steps in detail.

Use of CTA Methods

In the *understand* stage of our process, we used CTA interviews (Crandall, Klein, & Hoffman, 2006). These approaches focus on identifying user needs and requirements through applying structured knowledge elicitation methods to inform technology design. The identified needs and requirements can then be used to iteratively design and validate user interfaces.

UASs may benefit from an analysis of user cognitive needs as they have been susceptible to significantly higher incident rates than manned aircraft (Neville, Blickensderfer, Archer, Kaste, & Luxion, 2012; Tvaryanas, Thompson, & Constable, 2005). Although expert input may be included in the design of some military systems, such as the pilot–vehicle interface concept (Calhoun, 2000; Mulgund, Mulgund, & Zacharias, 1996), limitations still exist. For instance, UASs may be fielded too quickly or be designed with limited accountability for user needs and requirements. Waraich, Mazzuchi, Sarkani, and Rico (2013) suggest that applying human factors standards to the unmanned system domain may help in reduction of incidents and accidents.

CTA methods are used to elicit experts' tacit knowledge, and design thinking methods are used to apply that knowledge. The integration of design thinking methods with CTA, a novel approach in military systems development, provides an opportunity to leverage creativity across the entire team of stakeholders to yield interfaces that support operational and cognitive needs.

Use of Design Thinking Methods

For prototyping and generating design concepts that took place in the *generate* step of our process, we used design thinking methods. Successful products in the consumer electronics field led us to ask whether the integration of processes that incorporate creativity and imagination might be beneficial in UAS control station development. The consumer electronics field has been dominated by companies such as Apple, whose success has been attributed to, among other factors, the use of teams that include broad and deep expertise as well as frequent cross-team conversations about design (Dubberly, 2012; Isaacson, 2011). Defense system development is not consumer electronics development, but UAS control systems operators arguably require more intuitive and engaging designs to support performance and effectiveness of operations and relieve some of the training burden. Design thinking as an approach includes traditional participatory design that emerged in the 1970s as means for eliciting user input and incorporating users' direct participation in the design of user interfaces (Sanders, 2008). It is also used to support designing for future stakeholders (Björgvinsson, Ehn, & Hillgren, 2012; Brown, 2009).

The principles of design thinking include innovation, collaboration among stakeholders, and early prototyping (Brown, 2009). These goals are supported through engaging relevant stakeholders in ideation sessions, or design workshops, that encourage thinking outside the box and rapidly mocking up ideas to envision the intended designs and present to the group for discussion (Brown, 2009). Although empirical research suggests that group ideation sessions may not yield as many ideas as proponents claim (Osborn, 1963), they are effective at bringing together multiple knowledge bases and building on one another's contributions (Paulus, 2006) to generate novel ideas. The workshop atmosphere is intended to be free of judgment to encourage creativity and imagination. To support our goal of developing an intuitive display, the design professional on our team organized and led a series of design workshops (similar to IBM workshops as discussed in Dubberly, 2012) that enabled combining the perspectives and expertise of cognitive engineers, software designers, and UAS pilots. Bringing multiple disciplines together to innovate in a creative environment was an important element in dealing with the envisioned-world problem posed by the AACUS.

Understanding and Designing for an "Envisioned-World Problem"

Designing interfaces for controlling a helicopter with portable autonomy while supporting an untrained operator who also has wave-off and redirect capability is an envisioned-world problem. Potter, Roth, Woods, and Elm (2000) provide a useful model for the process of bridging the gap between CTA and design requirements for envisioned-world systems. Steps include first exploring the current world and then exploring the envisioned world by examining both "how the world works" (context) and "how people work in the world" (tasks). The authors illustrate the use of this model in the development of a graphic user interface of a National Ground Intelligence Center's military capabilities spectrum model. Our integration of CTA and design thinking was informed by this model. We blurred the lines between the current and the envisioned world by applying scenario-based simulation interview methods to ask current-world experts to extrapolate their knowledge into the envisioned world. We used simulation interview findings to create a background context for the questions posed at the design workshops. To understand the context and the tasks involved in supervising autonomous helicopter resupply in remote, contested environments, we collected domain-relevant knowledge from multiple perspectives, specifically those having experience in flying helicopters, flying UASs, and receiving resupply at remote outposts.

METHODS AND RESULTS

Although the focus of the current paper is on understanding the problem space and designing interfaces for the air vehicle operator only at a MOB, to adequately convey how we arrived at the designs, we will describe our process across the entire effort, which involved developing handheld-device interfaces for the non-aviator COP operator as well. Here we will describe each of the *understand, generate*, and *validate* steps pertaining to the timeline portion of the interface, illustrated by interview excerpts, requirements, design concepts, resulting designs, and validation results. This approach, supported by our team composition (cognitive engineers and design personnel), allowed for both cognitive and design thinking perspectives to be represented at every step of the process, with the outcomes of each previous step feeding the methods of the next step.

Understand

In accordance with the Potter et al. (2000) model of envisioned-world exploration, we first strove to understand the current work and context of helicopter resupply missions. In addition to reviewing the relevant publications and technical reports, we collected data from a sample of UAS operators, helicopter pilots, and marines with experience receiving helicopter resupply in the operational context (COPs, forward operating bases [FOBs]).

Literature review. We reviewed published descriptions of UASs and operations, helicopter operations, resupply and medical evacuation missions, remote COP/FOB environments, concept of operations, and peer-reviewed research literature in the UAS domain. We also examined a U.S. Navy lessons-learned document from a prior unmanned helicopter demonstration program (which had more limited autonomy capabilities). On the basis of these documents and the existing literature on UAS challenges and design (e.g., Neville et al., 2012; Tvaryanas et al., 2005), we developed a list of questions that represented gaps in knowledge in UAS operations and design. We used these questions to create interview guides to carry out knowledge elicitation with domain experts.

CTA interviews. Using multiple CTA methods (Crandall et al., 2006), we captured the critical tasks and their relationships, beginning interview sessions with the task diagram method (Hutton & Militello, 1996). To understand the associated challenges of operational experience relevant to future unmanned helicopter resupply, we applied the critical decision method (CDM), a type of CTA method (Crandall et al., 2006; Klein, Calderwood, & Macgregor, 1989). In this method, a domain expert is asked to recount a particularly challenging incident in which his or her skills were applied. Probes are then used to elicit aspects of expertise. To flesh out the envisioned-world aspects of the current problem, we used simulation interviews (Hutton & Militello, 1996) to walk through a range of anticipated AACUS mission scenarios and anomalies.

Our initial sample included retired helicopter pilots ($n = 3$) and retired Army Special Operations Forces (SOF; $n = 3$). Through these interviews, we gained an understanding of the operational and organizational context that our target operator will experience when conducting resupply missions with the system. Armed with this understanding, we interviewed marine UAS operators at a Marine Corps base and marine instructors at the Basic School in Quantico Marine Corps Base having either pilot or ground-based casualty evacuation and resupply experience ($n = 16$). Table 1 (see also Dominguez et al., in press) summarizes each data collection event (including validation events), indicating background and number of participants, location, date, focus of interview, and analysis products resulting from the events. Analysis products represented in Table 1 will be covered in greater detail in subsequent sections.

We gathered detailed information about mission tasks and timelines and about the target operational environment. As an example of the latter, one marine officer who had been stationed at a COP in Afghanistan provided detailed sketches and procedures along with the context of how resupply is requested; how landing zones are designated, manned, and secured; and how marines interact with the incoming aircraft. This information was used by members of the AACUS engineering team to develop the project's concept of operations. We also asked each domain expert about the tasks associated with each mission phase and their sequence as well as the operator needs and requirements. The mission phases that we elaborated on in these interview questions were as follows:

1. Mission assignment and planning
2. Loading and takeoff
3. En route
4. Approach, imaging, and landing
5. On-ground interaction
6. Takeoff and transfer

Data analysis. We analyzed interview data (notes and audio) using methods for content analysis of qualitative data (Crandall et al., 2006; Miles & Huberman, 1994; Silverman, 2001) with the goal of achieving domain understanding that includes operations at all nodes (i.e., main bases and outposts) and what each operator needs to know, decide, and do across the timeline of an autonomous helicopter resupply mission. In multiple stages (including data review, category coding and data extraction, and synthesis and integration of findings), four researchers took passes through the data to identify and capture common patterns in participants' responses. We paid specific attention to mission phases, their sequence, and the factors that would potentially facilitate or hinder effective interaction with the new AACUS technologies. We identified tasks and events known to occur along phases of a resupply mission timeline; this timeline provided us with a useful structure for organizing the data. Interviewees indicated they would need explicit representation and in-depth understanding of the unfolding mission timeline; therefore, providing timeline-oriented mission details became a requirement for the HSI.

We developed a general resupply mission timeline framework based on descriptions elicited in the earliest interviews, elucidating on information needs across the mission phases described earlier. This framework served as both a guide for subsequent interview questions and an analysis tool for structuring data. To flesh out the envisioned mission timeline, we systematically pulled from interview notes the tasks and information needs associated with each mission

TABLE 1: Data Collection Events Across the AACUS Project

Data Collection Event	Method	Background of Participants	*n*	Location	Date	Focus of Interview	Analysis Products
1	Interviews	Tier 1 Army Special Operations Forces retirees	3	Phone	November 2012	Resupply, insertion, extraction	Timeline, HSI requirements
2	Interviews	Retired helicopter pilots	3	Phone	November 2012	Helicopter pilot perspective for insertion and extraction	Timeline, HSI requirements
3	Interviews	Marine unmanned helicopter and UAS pilots	12	Marine Corps base	February 2013	UAS operations, contingencies, planning	HSI requirements
4	Interviews	Marine instructors at the Basic School with CASEVAC experience	4	Quantico, Virginia	Feb. 2013	Contingency planning, timing considerations, and system trust	HSI requirements
5	Validation	Marine unmanned helicopter and UAS pilots	1	Phone	March 2013	Validate COP design concepts	Design concepts
6	Validation	UAS pilots	4	ONR contract or offices	October 2013	Validate MOB design concepts	Design concepts

Note. AACUS = Autonomous Aerial Cargo/Utility System; CASEVAC = casualty evacuation and resupply; COP = combat outpost; HSI = human–system interface; MOB = main operating base; ONR = Office of Naval Research; UAS = unmanned aerial system.

phase and clustered them according to the order of execution. Additionally, we noted instances in which tasks were identified as being particularly challenging. The timeline served as a living document as it was iteratively updated and populated by both new and more detailed interview findings. Next, we offer interview quotes from UAS pilots that provide insight into the timeline-related information needs that both COP and MOB operators will require when accomplishing the envisioned mission.

1. When asked "How might the MOB interface support collaboration and coordination between operators and vehicle?" the UAS pilot response was,

    > Providing as much information as the interface can bring in. Obviously where the aircraft is, what's it doing, how much time it's going to take for us to get there, when are you going to be here, how long will it take you to deliver the load or whatever you are going to do here, when can you leave. And they can plan all their operations around that.

2. When projecting what information a COP operator would require from the aircraft and the MOB operator, the UAS pilot response was,

    > Estimated time of arrival [ETA] and updated location/updated landing zone. This is where we are, this is where it's saying we need to go—it should give you a warm fuzzy, letting you know that you are aligned with the system. Would also need an altitude indicator, a countdown to ETA, and a planned recovery site.

Generate

HSI requirements. Our team was responsible for developing HSI requirements to the broader AACUS project team. We developed HSI requirements from interview data in a systematic and iterative approach. Examples of requirements were elicited via multiple interview techniques, such as CDM, simulation interviews, and direct questions, and reflect tasks that are particularly challenging. They do not align directly to mission phases. By reviewing interview notes, two researchers nominated, drafted, elicited feedback on, and refined requirements. We organized HSI requirements into the following categories, based on a coding process: mission planning, situation awareness, dynamic replanning, authority/control, perception, communications, and usability. Here are two examples of HSI requirements we developed to inform design of the mission timeline design:

- The COP and MOB HSIs shall enable the user to visualize and follow the mission plan as it is carried out. (mission planning category)
- The COP HSI shall provide a graphical mission timeline indicating ETAs to the notification point and to landing time, and required departure time as driven by fuel state. (situation awareness category)

Multiple data points drove the HSI requirement to effectively support operator situation awareness via the envisioned mission timeline (including past, present, and future status of the aircraft).

"How might we" (HMW) questions and design workshop. We generated design concepts at a 3-day workshop planned and facilitated by team's design professional. The workshop attendees included two UAS pilots, the AACUS program manager, cognitive researchers, and software developers, for a total of 10 individuals. Participation by the program manager and software engineers was essential in aligning the design work with the larger engineering effort. To provide a context and a common ground on the domain and the design problem, we used HSI requirements and task and timeline descriptions from interviews. The format of the workshop was intentionally participatory, intended to leverage each attendee's knowledge and input in a creative, collaborative, and relaxed setting.

Based on HSI requirements, we created a list of key HMW questions that, when addressed, provided the design seeds to create a MOB interface. During the design workshop, we used these HMW questions to methodically explore what an interface might provide to allow a MOB operator to successfully plan, direct, monitor, replan and otherwise interact with an AACUS-enabled helicopter. Each HMW question served as the basis for a group ideation session, with participants explaining ideas as they posted sticky notes on a foam core board at the front of the room. Participants were encouraged to build on others' ideas with a "Yes, and . . ." elaboration as they explained and posted further notes. Following ideation sessions, participants created low-fidelity paper prototypes in smaller groups of two to three individuals, based on thematic clusters of the sticky-note ideas. To support the creation of prototypes by all participants via sketching, collaging, and layering, we provided them with modeling tools, such as colored markers, tape, glue, rulers, stickers, foam core board, onion skin (translucent) paper, and pins. Next, participants presented their designs to the group for discussion, highlighting intended features and functionalities. We videotaped each presentation and discussion to create a record for later review when designing displays following the workshop.

To support idea generation for a mission timeline concept, we asked, "How might we display mission data as the AACUS mission is en route?" Workshop attendees generated numerous ideas to address this question. Figure 1 shows a sampling of the sticky notes generated in this ideation session, with particular focus on how to represent time. Some specific examples included representing time in a Gantt-type chart, potentially superimposed onto elevation, with key information, such as ETA, called out in a salient manner. Several paper prototypes were developed to support these ideas. Figure 2 shows a photograph of one of these prototype designs, depicting the aircraft progressing through mission phases at the bottom of the screen. This feature was adopted into the design concepts.

Prior to the workshop, we planned to complete approximately nine brainstorming/prototyping/presentation cycles over 3 days, with nine different HMW questions, each cycle requiring about 2 hr. We caucused at the end of each day to replan, knowing the agenda might play out differently. In actuality, each cycle required more time, and we completed five HMW question cycles and one final HMW design cycle to bring all elements into a dashboard design.

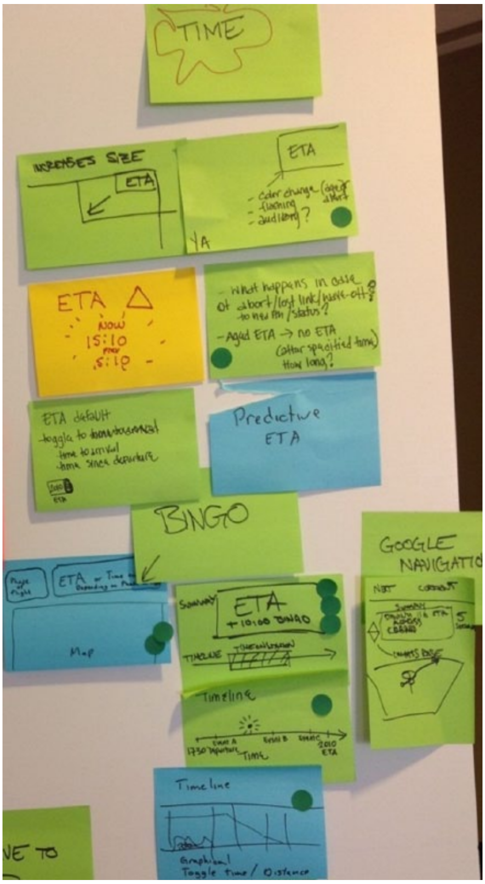

Figure 1. Examples of design ideas in response to the "how might we" question, "How might we display mission data as the Autonomous Aerial Cargo/Utility System mission is en route?"

Design concepts. Postworkshop design concept selection and integration was led by the design professional and supported by cognitive engineers. Hand-drawn workshop prototypes and their features directly informed the design concepts, as did human factors design principles for the effective use of color, font size, groupings, length, angle, area, volume (Cleveland & McGill, 1986; Smith & Mosier, 1986; Tufte, 1990), and number (Yntema & Mueser, 1960). The screen design that emerged reflects workshop participants' concept of a large, primary display of information in the center surrounded by a rich periphery of auxiliary information, with capability to move peripheral information to the center as users desire. The mission-focused center screen is bordered by an

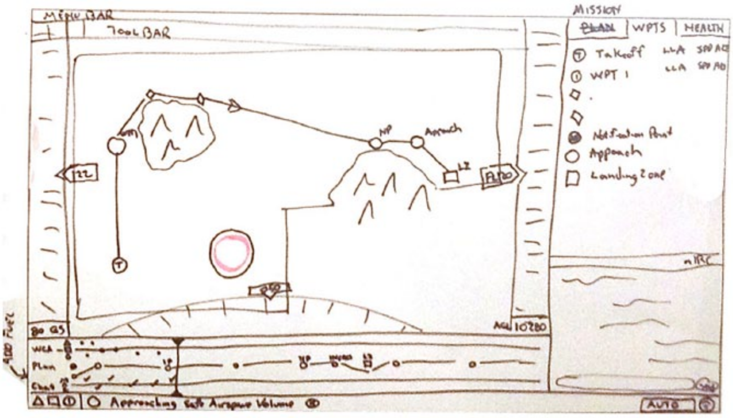

Figure 2. Example of a low-fidelity paper prototype representing air vehicle status in the context of the mission timeline, created at the ideation sessions.

Groundspeed: 128kts Airspeed: 124kts Vertical Airspeed: 0.1kts Altitude (AGL): 1302 ft Heading: 297°

AC is ~ 1 hour 5 min until Notification Point

ASR 1234B Mission En Route; ETA to NP is 2150

Acknowledged; Expecting delivery at 2155 on 8 April

Figure 3. Example of main operating base interface in mission view.

air vehicle–focused left panel and a network-/communications-focused right panel. The interface includes mission timeline and fuel status panels along the bottom of the screen; the design prototype is shown in Figure 3.

The timeline panel below the mission view (enlarged in Figure 4) was intended to depict an overall picture of the plan to the MOB operator. The entire mission is depicted in elevation, with turns removed from the flight path, resulting in a linear representation of the mission. The air vehicle's current position is indicated by a vertical white line on the timeline along with the flight plan elevation and cross-section of terrain directly underneath the flight plan. Flight plan waypoints correspond with waypoints in the map view. Clicking on one of these waypoints will highlight the corresponding waypoint in the map view and display relevant information, such as ETA. The design calls for warnings, cautions, and advisories to be populated on the timeline as red exclamation marks, orange triangles, and

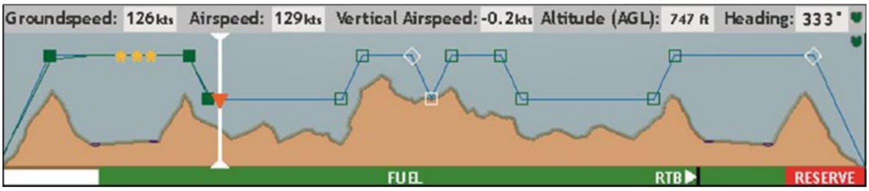

Figure 4. Timeline display and functionality provides a representation of the entire mission and status of the air vehicle.

yellow stars, respectively, as they occur in the mission; these are analyzable with historical detail in the lower left box.

Above the timeline is the air vehicle's current parameter status, intended to give the MOB operator critical information relating to the air vehicle's current movement and location. Below the timeline is a fuel bar indicator. The current amount of fuel is depicted by a green bar that starts out full and is represented by a full green bar across the bottom of the timeline. As the mission progresses, the green bar updates with the percentage of fuel left and reduces in size as fuel is spent. A red portion of the fuel indicator represents the reserve tank. Return-to-base (RTB) fuel is an indication of the amount of fuel required for the air vehicle to make it home from its current position. If the RTB fuel indicator is within the green bar, the air vehicle has enough fuel to return to base.

This timeline design concept aimed to support a number of goals for the operator to have effective and efficient interactions with the AACUS:

1. Allow for visualization for past and present AACUS status as well as projecting into the future through the default view and by clicking on waypoints to access more detailed information (e.g., ETA). The timeline concept allows the operator to project into the future, simulating the outcome of changes to the plan (Wiggins, Dominguez, Long, & Miller, 2006).
2. Intuitively represent constraints and restraints. The timeline intuitively represents constraints and restraints to sequencing of tasks in a mission (e.g., altitude; elevation; time, such as ETA; resources, such as fuel) in a manner that supports efficient visual search with color and shapes (Treisman, 2006).

Validate

Using the initial MOB design concepts, we conducted several iterative informal validations with design team members and two UAS pilots. For the first iteration, four design team members were sent the file of design concepts with an accompanying description. Each person provided initial review and met to discuss, resulting in design refinement. Next, we sent the MOB designs (in PowerPoint format) along with descriptions to the two UAS pilots who attended the workshop and asked them to critique. We received several comments and suggestions for improvement, which provided the basis for the next design iteration.

Cognitive wall walk. After initial informal assessments, our Navy sponsor offered to host a formal validation workshop. Participants included active-duty marines with relevant experience and a retired marine officer with logistics experience ($n = 4$). Other participants brought experience in marine operations, systems design, and human–robotic interaction research. We employed a cognitive wall walk method, which is a variant of a commercial usability method called the cognitive walkthrough (Wharton, Rieman, Lewis, & Polson, 1994). This method involved stepping through a series of scenarios that were developed to elicit the participants' in-context comments. Scenarios included routine activities as well as situations involving contingencies and replanning. To illustrate the process with respect to the mission timeline portion of the display, we asked the participants to monitor mission, takeoff, and early en route mission phases using the design concept (Figure 3) in the context of an AACUS mission scenario. The context was set with specific timing: "Planned takeoff time is 1700; it is now 1615; please walk us through the steps and thoughts you would have as you prepare to take off, then as you take off, and reach altitude." After this discussion, we asked a similar question for the next mission phase, when the AACUS aircraft would be in stable flight. After this simulation, we asked participants questions, such as the following, in regard to the scenarios:

1. Do the display features shown here support what you need for preparing, taking off, and normal mission monitoring?
2. What else would you like to see in this situation?
3. What actions would you need to take with the interface that you don't see represented here?

Again, this approach yielded comments and suggestions, such as edits to specific features on the interface and in regard to the timeline specifically, for the next iteration.

CONCLUSION AND APPLICATIONS

We have illustrated the integration of CTA and design thinking to understand user needs and generate design concepts by tracing one aspect of the interface, the mission timeline display, across all aspects of an *understand, generate, and validate* process. With this approach, we created a series of design concepts for an operator of an envisioned-world autonomous helicopter. We validated the concepts that resulted from a cross-discipline design workshop via several iterative cycles of seeking feedback and refining designs. There are three significant aspects of this work:

1. We have demonstrated the process and results of a close integration between CTA work and design thinking. Our team included both cognitive engineering and design personnel to ensure tight integration at each step in the process.
2. We have completed a comprehensive effort to design interfaces in an envisioned-world setting of interaction with an autonomous system capable of integration with different helicopter vehicles. Our process and products represent a step forward in design of human–autonomy interfaces to support user cognitive tasks.
3. We have completed a substantial and time-intensive research-and-development effort emphasizing the importance of applying CTA knowledge elicitation methods early in system design to ensure the aircraft systems and autonomy/perception systems are highly collaborative with their human operators.

By conducting CTA interviews and achieving a grounded understanding of the domain, and by involving operators throughout the design and validation process, we were able to achieve designs that are informed by user needs. Feedback from operators during the final validation workshop indicated that this approach enabled us to design intuitive interfaces that make critical information salient to the user. Testing and refinement of the design concepts as implemented in the fielded AACUS will be the next step. Flight test of the first phase of AACUS, including several system aspects but not full implementation of these MOB designs, was carried out in February of 2014. This flight test did include implementation of tablet-hosted interfaces developed using the same process for a COP-based non-aviator who will receive resupply and direct the AACUS aircraft in landing, wave-off, and other functions (Dominguez et al., in press).

ACKNOWLEDGMENTS

This research was funded by the Office of Naval Research (Contract: N00014-12-C-067 [ONR]; Subcontract: AFS12-1643 [Aurora]) under the leadership of Missy Cummings and Max Snell. We appreciate the team leadership and guidance of John Wissler and Jim Paduano of Aurora Flight Sciences. We also thank James Bona and Desare'a Chessar from Kutta Technologies for their help and contributions.

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