OPERATOR VEHICLE INTERFACE LABORATORY:

UNMANNED COMBAT AIR VEHICLE CONTROLS & DISPLAYS FOR SUPPRESSION OF ENEMY AIR DEFENSES

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As part of its transformation, the U. S. Air Force of the future will conduct military operations with a mix of manned and unmanned aircraft. Indeed, today's Air Force has an array of unmanned air vehicles (UAVs) at its disposal, which provide particular advantages – such as cost or endurance – over manned craft. For the most part however, these vehicles are either cruise missiles or reconnaissance vehicles. Even when unmanned aircraft are used for weapon delivery and other combat missions, they are first and foremost reconnaissance vehicles that have been "retrofitted" to carry and launch weapons. Soon, new unmanned aircraft, enabled by new technologies, will come on-line. These new UAVs will be technologically sophisticated, high performance aircraft that will be significantly more effective for conducting specific combat missions than their current-day unmanned counterparts. The new UAVs will also heavily rely on information technologies and will allow the use of aircraft/weapon technologies that are not suitable for manned aircraft. In addition, removal of the pilot from the aircraft will greatly increase the odds of combat personnel survivability and make possible more options for air vehicle signature suppression and overall system affordability. In short, there will be missions during the next 20 years that will continue to require that a human be present, but for many missions, unmanned aircraft will provide capabilities far superior to vehicles that have a human on-board.

Suppression of Enemy Air Defenses

One operational concept receiving much attention within the Department of Defense (DoD), and especially within the Air Force, is the employment of UAVs for the Suppression of Enemy Air Defenses (SEAD) mission. "The SEAD mission is an activity that neutralizes, destroys, or temporarily degrades surfaced-based enemy air defenses by destructive and/or disruptive means. It requires detailed mission planning, extensive coordination, and rapid tactical responses to successfully attack an enemy's Integrated Air Defense System (IADS) in support of friendly forces" (Joint Chiefs of Staff Publication 3-01.4). The UAV Operator Vehicle Interface (OVI) Laboratory, located in the Air Force Research Laboratory Human Effectiveness Directorate, facilitates research for issues associated with developing effective operator interfaces for UAV control stations to accomplish SEAD and other combat missions. Programs conducted within the UAV OVI lab generally have two objectives. First, they quantify UAV control station requirements within the context of the projected year 2015 SEAD mission in order to evaluate automatic- versus manual-function tradeoffs that will enable a single operator to manage multiple UAVs simultaneously. Second, they conceptualize and design operator vehicle interfaces that integrate control/display technologies and decision-aiding features so that the system (the operator plus the UAVs) can successfully accomplish all mission requirements.

Background

Future UAVs will be highly automated systems with the operator's role primarily being that of system manager and supervisory controller. As such, the role of human factors design in the overall UAV system architecture is critical. The operator will be responsible for establishing goals and priorities for the system, monitoring and directing automated subsystems, and ensuring the overall success of the mission. However, automation can have both desirable and undesirable effects. Among the desirable effects, automation can greatly improve the performance of the system by taking over tasks that are performed poorly by a human operator or by reducing operator workload during high task-loading conditions. On the undesirable side, high levels of automation may cause human performance decrements often associated with long term monitoring (the operator enters into a state of reverie) or the loss of situation awareness from reduced human involvement with the automated functions. If there is no feedback loop (or a poor feedback loop) to the operator about what the automatic systems are doing and why, the operator may be surprised by the behavior of an automatic system. This often leads to unanticipated, and sometimes undesirable, outcomes. Providing the operator with "insight" into automated processes might prevent operator reverie or at least mitigate some undesirable effects of automation.

Phase 1

As an initial goal, the UAV OVI program set out to develop a set of design guidelines for applying automation and human-computer interface (HCI) technologies to the UAV control station. These guidelines would be the result of OVI analyses, design, redesign, and evaluation activities. With a nearly infinite problem set (a new platform, a new operational concept, an intricate/difficult mission, just to name a few), the problem needed "bounding". This bounding took the form of a design requirements scenario (very similar to a concept of operations). This scenario was decomposed and analyzed by subject matter experts—former Air Force pilots who have flown SEAD missions and current unmanned air vehicle operators—to identify functional and information requirements for the control station design. The requirements and analyses then served as the basis for developing conceptual OVI designs and for evaluating their usefulness for multiple UAV control within the SEAD context.

Phase 1 Description

Phase 1 OVI Design. The Phase 1 evaluation used an initial "point design" OVI control station consisting of three 20-inch (diagonal measurement) liquid crystal displays (LCDs) placed in a side-by-side, wrap-around arrangement (Figure 1). The field-of-view for this arrangement was approximately 100 degrees. During the evaluation, a computer mouse and keyboard comprised the primary input devices, however, a voice recognition interface was also demonstrated to the participants after the formal data sessions for subjective impressions and critique.

The evaluation participants primarily used three display formats: Situation Awareness (SA), UAV status, and a multifunction format. The SA format (Figure 2) was a dynamic, large-scale presentation of the combat area of interest with all relevant friendly and hostile players overlaid on a north-up map depicting relevant terrain and cultural features. Key components represented on the SA format included the UAVs and their flight routes, the strike aircraft and their flight routes, combat area threats, and the strike package targets. The SA format had several operator-selectable options, including data filtering, zoom, and pan capabilities. The format was presented full time on the left LCD to facilitate operator situation awareness regarding mission progress and the overall combat situation.

Figure 1: Phase 1 UAV OVI Configuration

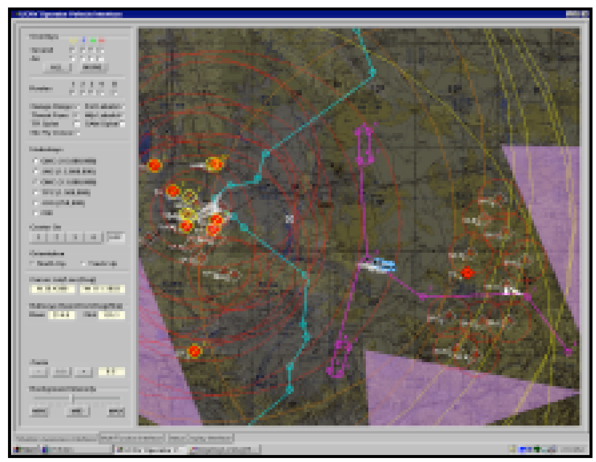

Figure 2: Phase 1 SA Display Format

The UAV Status format (presented full time on the right LCD) provided health and status of the four UAVs: a pictorial indication of selected flight parameters, flight performance, system malfunctions, weapon inventory and status, data link status, and radar warnings.

The center LCD was used exclusively for the Multifunction format, which provided the primary interface for managing most of the mission events. A multifunction control panel on the right side of the format was used to select navigation, weapons or communications modes and a map control panel on the left side of the format enabled map zooming, scaling and map features selections, thus duplicating some of the capabilities of the SA format.

Phase 1 Evaluation Method. Nine participants, acting as UAV operators, used the control station to manage a flight of four UAVs within a part-task (ingress and attack) SEAD mission. Each operator monitored the progress of the pre-planned mission, adjusted the UAV package route as required to avoid unanticipated threats and to achieve desired weapon release times, monitored changes in the threat environment, and adjusted target assignments in response to those changes. The two experimental variables were: 1) route replanning autonomy, and 2) time stress, and each of those had two levels of difficulty. Route replanning autonomy included manual versus semi-automatic in-flight route planning and target assigning. In half of the evaluation conditions, the operator manually accomplished several route replanning and target assignment tasks. In the other half (semi-automatic), the operator used simulated decision aids to accomplish these tasks by assessing system decision-aid recommendations and selecting one solution from among several produced. Under the time stress variable, as the operator updated the route plan or re-assigned targets, the amount of time available to accomplish the task before some consequence occurred was varied (e.g., two minutes versus five minutes available before the UAV package entered into a threat envelope). These variables provided a method of manipulating task difficulty during critical mission phases and enabled the assessment of operator interaction with the manual and semi-automatic conditions under varying time-constraints. The session also included a voice recognition interface demonstration and a detailed evaluation debriefing.

Phase 1 Scenario Overview. A detailed script was used to describe the flow of mission events, provide the "triggers" for variable mission events, and to simulate communications requirements. Operators were instructed that "…intelligence has discovered the location of a hardened and deeply buried command bunker. A flight of three bombers is tasked to make a night attack on the bunker, however, the enemy has deployed a variety of surface-to-air (SAM) batteries and numerous anti-aircraft artillery (AAA) units around the bunker for protection. To support the bomber strike package, a flight of four low-observable UAVs have been tasked to accomplish a SEAD mission to suppress the SAMs long enough for the bombers to ingress, attack the bunker, and egress safely." The UAVs were described as carrying standoff, highly lethal munitions capable of autonomous attack and destruction of specific targets.

Phase 1 Results. Participant ratings using the Subjective Workload Assessment Technique (SWAT) were collected to provide estimates of absolute workload and to identify tasks where excessive operator workload existed. Questionnaires and interviews were used to collect operator narrative comments and subjective ratings for situation awareness and interface usability.

1. Manual versus semi-automatic route replanning. Participants identified both required and unwanted functional capabilities for a real-time route replanner. Required capabilities included: a) feedback about what the replanner was doing, i.e. its intent; b) an ability to assess the "goodness" of the new route; and, c) ability to display the original flight route or allow recalling it regardless of what had been "accepted" as a reroute. Unwanted replanner items included: a) "non-intuitive" reroute options (operators are reluctant to use them), and b) manual reroute generation without a "figure of merit" for assessing the "quality" of the options.

2. Mission accomplishment. The participants successfully accomplished this "low fidelity" SEAD mission using destructive means, but other IADS suppression tactics are essential to this type of warfare. Several participants pointed out that there are significant variations within the SEAD mission that warrant UAV capabilities that are broad and flexible. Thus, the UAV operator needs the ability to creatively manage IADS suppression via a range of disruptive and/or destructive tactics (a combination of electronic countermeasures and weapons use) to attack critical IADS nodes. Without broad solutions, UAV operators will not be able to manage a SEAD mission containing an array of IADS dimensions.

3. Mission management. A single person could manage four UAVs flying as a formation within an environment where a single, unexpected, ingress event was a pop-up threat. Participant comments also verified that a single person could manage four UAVs for SEAD as long as the original plan unfolded with little or no variation. Participants with operational flying experience emphasized that missions rarely go according to plan and that it is the creative, adaptive nature of the crew that enables mission success. As modern IADS threats and tactics proliferate, adaptive crew behaviors will become increasingly important counter-tactics and automation will be a critical part of crew/system integration.

4. Situation awareness. Rating scale data and debriefing comments indicated that the OVI provided adequate situation awareness, but these data must be placed in context: there were limited external events and no system malfunctions in the scenario. Also, the participants with operational experience kept the situation awareness and UAV status display formats in their cross-check because their training and combat experience dictated that "if something isn't happening now, it's only a matter of time before it does". Participants with operational experience universally judged these formats as "must haves". Notable however, were numerous instances of operator fixation on the Multifunction (center) display format, which often resulted in degraded performance during reroute and weapon assignment, particularly for participants without operational experience.

5. *Automated target assignment.* Participants reacted favorably to the automated target assignment function. Ratings, comments, and experimenter observations confirmed that automated target assignment was easier and more effective than manual assignment. This is significant in that the scenario target laydown was not as complex as many real world cases and the UAV weapon loadout was uniform: essentially, this was an ideal mission situation. But, when target reassignment occurred manually, retargeting took excessive time and resulted in numerous situations where the UAVs had passed their preprogrammed launch point. Furthermore, this occurred without multi-tasking (where the operator was distracted with radio calls, checking on system failures, etc). This would be much more characteristic of a combat environment.

Phase 2 Description

The first phase helped educate the OVI team on UAV operations as well as interface requirements. In phase 2, researchers extensively renovated the OVI lab, refined the display formats and information control logic (e.g., by using "split screen" formats and small picture insets as in Figure 3), and conducted a system demonstration using these new features. Now, eight state-of-the-art personal computer (PC) workstations provide a low-cost, high-fidelity simulation environment. The workstations (Figure 4) are Dell 530 computers with Wildcat 5110 graphics cards and 1 gigabyte of memory. Each can drive two 1280 x 1024 displays at two operator consoles. Not only does the PC-based environment drastically reduce graphics development costs (OVI is using graphics capabilities that would have cost hundreds of thousands of dollars on UNIX-based workstations only a few years ago), but software development also benefits. Numerous low-cost, commercial-off-the-shelf, software development tools and components are available for PCs.

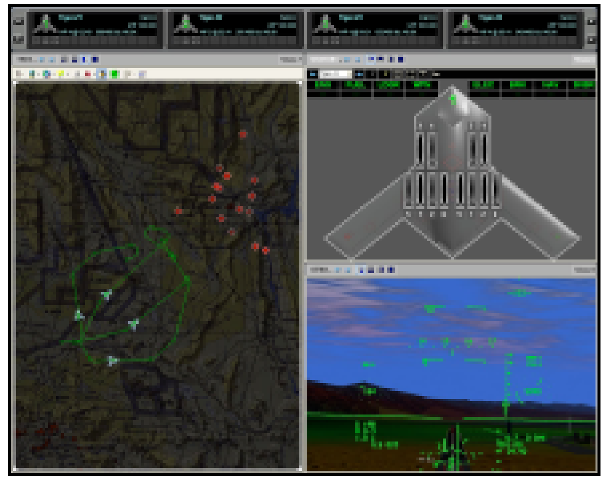

Figure 3: Phase 2 Split Screen Format Example

Figure 4: Phase 2 UAV OVI Workstations

Phase 2 OVI Software Architecture

Researchers are building OVI phase 2 simulation software using Microsoft's Visual Studio product line, third party component libraries, and OpenGL graphics language. They are also using industry standard software interface techniques whenever possible so operators "start out" familiar with most of the new interface concepts, thus making operator training more efficient. Finally on the software architecture side, researchers are exploiting many techniques and tools used on the Internet today with emphasis on meeting requirements, affordability, rapid prototyping, and using industry standards and software services whenever possible. The services can be interface-specific or can support the general simulation environment. For example, if researchers need to simulate a Synthetic Aperture Radar (SAR) capability for a UAV, they can utilize a simple, low-fidelity service that maintains a database of images corresponding to the areas where a SAR image will be taken in lieu of having a complex and expensive radar model attached to the simulation. Additionally, for more detailed interface performance testing, where a higher fidelity physics-based model residing on a remote computer system running a different operating system might be required, the service provided to the OVI interface is transparent to the operator. In either case, the method the operator uses to command the SAR to take the image and the way the images are shown on the interface will be identical. This technique enables researchers to scale OVI simulations based on system resource capabilities and testing requirements and provides an easy way to upgrade services as new capabilities or requirements emerge.

Phase 2 OVI Facility Enhancements

In addition to the computer workstation upgrades mentioned previously, the facility now also contains a mock-up of a mission control station van (shelter) that provides a realistic setting for testing concepts (Figure 5). This shelter mock-up can accommodate up to four operators at one time and the display monitors used by each of those operators can be configured in either a horizontal or vertical arrangement, providing flexibility dependent upon evaluation requirements and customer needs. Test controllers monitor operator activities using projectors and repeat monitors outside the shelter mock-up.

Phase 2 Demonstration Objectives. Unlike Phase 1, there were no experimental variables or “treatment” conditions. As a result, Phase 2 testing activities were limited to laboratory demonstrations of system conceptual capabilities. The Phase 2 demonstrations had four objectives: 1) solicit operator insight into potential strategies for dealing with UAV/SEAD complexities, 2) determine which new OVI features were most useful for SEAD and to maintain SA, 3) discuss operator decision-aiding requirements, and 4) identify alternative interface options that support the strategies for dealing with the envisioned complexity, that will prove robust against uncertain and dynamic mission environments, and that enable operators to effectively adapt to situations as they arise.

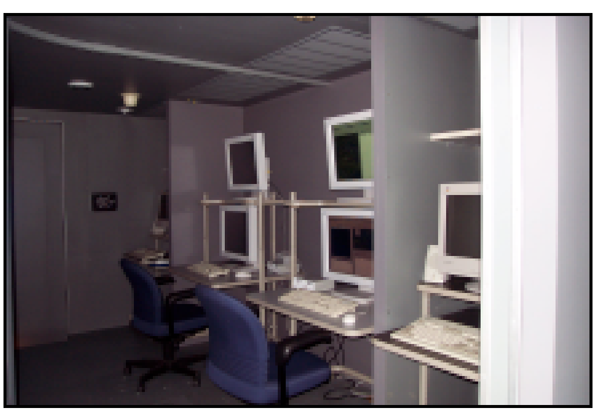

Figure 5: Mission Control Station (MCS) Mock-up

Phase 2 Demonstration Method. In order to understand the potential interactions and tradeoffs that existed among a variety of operator perspectives, the research team drew as many perspectives into the assessment as possible. Nine individuals with at least one of the following backgrounds were included:

- UAV ops experience (e.g., Global Hawk, Predator)
- Combat UAV concepts development experience
- IADS operations experience
- Air combat/fighter aircraft operations experience

Phase 2 Scenario. The notional UAV SEAD mission for Phase 2 was based on the DARPA/Air Force-approved concept-of-operations. The mission scenario was initiated at a point following the handoff from the Forward Air Operations (FAO) controller to the Area of Responsibility (AOR) controller, with the operator participants acting as AOR. To avoid unnecessary lulls in scenario execution, the mission pace increased during extremely low activity portions. Unlike Phase 1, this mission had no vehicle malfunctions, no pop-up threats, nor any other unexpected occurrences. The threat laydown consisted of SA-10, 11, and 12 SAM sites with their associated Flap Lid, Fire Dome, and Grill Pan fire control radars. The sites included command vehicles and transporter-erector-launchers for missiles.

The UAV mission objective was to attack four of the SAM sites to destroy the fire control radars and the associated equipment. The UAVs used onboard electronic support systems to locate the fire control radars and maneuvered into position to take SAR images of the SAM sites. After downloading the SAR images to the mission control station (MCS), the operator determined the exact points to attack (called Desired Mean Point of Impact (DMPI)) from the SAR images and sent the coordinate information to the UAVs. The UAVs then maneuvered to release the small diameter bombs (SDBs) on the DMPIs with the operator’s consent. After weapons delivery, the UAVs recovered as single aircraft (non-formation).

As scenario tasks, the operators monitored the health and status of the flight of four UAVs, downloaded SAR images, selected the DMPIs, prepared the weapons for release, and authorized weapon releases.

Phase 2 Procedures. While performing the mission tasks, participants used a “think-aloud” technique in which they verbalized their thought processes. This provided insight into how the participants were conceptualizing the tasks, the strategies they were using, and their understanding of the control/display concepts. Participants also commented about specific features of the interface, mission, and simulation environment while performing the tasks. Comments and verbalizations were noted during the demonstration and were reviewed in more detail during post-mission discussions.

The participants represented differing stakeholder perspectives, so the research team tailored its questions, apriori, to the specific information it hoped to derive. For example, from an operational SEAD specialist, the discussions focused on how a flight of SEAD aircraft might coordinate an attack or how the system might need to adapt to a dynamic IADS environment. From an IADS operator, the discussion focused on how IADS operators might react to UAV engagements.

Phase 2 Results. In the context of this evaluation, the procedures performed by participants included:

- Set up/configure the displays and formats for target engagement
- Set up/configure desired features on the Tactical Situation Display (TSD)
- Capture a SAR image
- Designation of DMPIs
- Target weaponeering

Overall the feedback received was extremely positive, suggesting that the current developmental philosophy is “on the right track”. As one example, the dominant feature of the interface was the quad display concept, which attempts to balance the need for multiple views of the UAV domain while minimizing problems associated with “windowing”. Related to the quadrant concept was the method for tailoring the format views using an “active quadrant” icon (Figure 6). Operators could command either split-screen or full-screen views, and found the feature very easy to use. They did not think that quadrant, vertical half screen, horizontal half screen, or full screen views would be too limiting; the ability to manually select view size by “expanding” the windows was not judged to be a requirement.

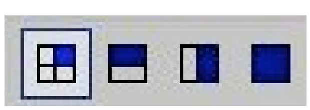

Figure 6: Quadrant Selection Icons

Summary. Space limitations for this paper preclude a complete discourse on the results of Phase 2. The preceding quadrant selection excerpt provides an example of the type of information gathered from the participants. A “Combat UAV Design Review Report” (see references) is in its final stage of editing. It includes: 1) results/recommendations for MCS/OVI set-up and configuration, 2) TSD set-up and configuration control recommendations, 3) SAR imaging and DMPI selection results, and 4) results/recommendations for information display, the use of text-based drop-down windows, and the use of icons for making selections and setting up display and format preferences.

Acknowledgment

Mr. Allen Rowe, Veridian Inc., wrote much of the software code and provided invaluable expertise in developing the software architecture that is used by the current UAV OVI mission control station. His contributions to OVI’s success were immeasurable.

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