Adaptive Distributed Aviation Asset Optimization for Operational Effectiveness (Phase II)

John Merrihew
JohnMerrihew@VELOXITI.com
Program Manager
VELOXITI
Alpharetta, Georgia

Larry Lafferty
LarryLafferty@VELOXITI.com
Vice President of Engineering
VELOXITI
Alpharetta, Georgia

Charles M. Shepard
CharlesShepard@fVELOXITI.com
Business Development
VELOXITI
Alpharetta, Georgia

Norman Geddes
normgeddes@veloxiti.com
Chairman of the Board
VELOXITI
Alpharetta, Georgia

Steve Toney
SteveToney@veloxiti.com
Software Engineer
VELOXITI
Alpharetta, Georgia

Abstract

The paper describes the use of an Intelligent Decision-aiding Agent (IDA) associate for management of distributed aviation assets during warfighter net-centric operations. VELOXITI, Inc. (formerly Applied Systems Intelligence, Inc.), is collaborating with government personnel to demonstrate and evaluate a Situational Awareness Fusion Enhancement (SAFE) Aid in a man-in-the-loop experimentation environment as part of an Aviation Development Directorate - Applied Aviation Technology Directorate (ADD-AATD) Phase II Small Business Innovative Research (SBIR) project. Last year's Phase I focus was on defining the requirements for integrating a collaborative adaptive tasking system (CATS) into a full mission simulation environment. This year's efforts have grown into the SAFE Aid Intelligent Decision-Aiding Associate (IDA) system which incorporates a platform agnostic Intelligent Associate System for scout/attack/utility helicopters, and which will be integrated, demonstrated and evaluated in an operationally relevant man-in-the-loop simulation environment. SAFE Aid is intended to dramatically increase situational awareness within the cockpit and allow the ability to identify and access multiple Surveillance and Reconnaissance assets with a single bezel button to automatically task manned and unmanned assets. This tasking is based upon prioritization of Area of Operations (AO) events that optimizes all Surveillance and Reconnaissance assets to cover high priority events in the AO. SAFE Aid also enables aircrew safe route planning functionality, collision avoidance, predictive aircraft positioning, over the horizon weather updates, and many other operationally relevant functionality for scout/reconnaissance/attack/utility helicopter missions including MEDEVAC support.

This paper will show the development, integration, demonstration and evaluation of the SAFE Aid technology that reduces aircrew workload and enables aircrews to effectively manage and utilize distributed aviation assets, without impairing their operational performance on other flight tasks. Aircrews will fly operationally relevant mission vignettes in a laboratory simulation environment with SAFE Aid operating and without SAFE Aid operating. Data collection and analysis of aircrew responsiveness will assess the aircrew's ability to optimize interaction between manned and unmanned aircraft within a relevant mission context environment. Mission safety will be demonstrated using the ability for the system to incorporate additional knowledge bases adapted to accommodate evolving Tactics, Techniques and Procedures (TTPs). Mission demonstrations will involve multiple aircrews operating in two simultaneous mission simulation environments. Operational effectiveness and situational awareness requirements will consider data and user interfaces, real-time performance and human interaction issues. These defined requirements will aid in documenting the evaluation criteria for the SAFE Aid IDA. Evaluation criteria consider collection and analysis of the measurements for both a simulator-based environment and for full flight environments. The ultimate goal is to identify IDA benefits for aircrew members when the SAFE Aid system is operating, as compared to when the system is not operating, and the impact this has on operationally relevant mission scenario success.

Notations and Acronyms

- Advanced Tactical Combat Model (ATCOM)
- Air Maneuver Battle Lab (AMBL)
- Area of Operations (AO)
- Brigade Combat Team (BCT)
- Co-Pilot Gunner (CPG)
- Cognitive Decision Aiding (CDA)
- Cognitive Associate System (CAS)
- Computer Generated Forces (CGF)
- Concept of Operations (CONOPS)
- Decide Act Graph (DAG)
- Data Analysis Tool (DAT)
- Data Distribution Service (DDS)
- Fragmentary Order (FRAGO)
- Gray Eagle (GE)
- Generic Unmanned Supervisory Segment (GUSS)
- Improved Data Modem/Joint Variable Message Format (IDM/JVMF)
- Intelligent Decision-Aiding Associate (IDA)
- Landing Zone (LZ)
- Manned Evaluation Plan (MEP)
- Multi-Function Display (MFD)
- Manned Simulation Test (MST)
- Manned-Unmanned (MUM)
- Manned-Unmanned Teaming (MUM-T)
- Medical Evacuation (MEDEVAC)
- Observe-Orient-Decide-Act Loop (OODA Loop)
- Observe-Orient Graph (OOG)
- Reconnaissance and Surveillance (RS)
- Restricted Operations Zone (ROZ)
- Situational Awareness Fusion Enhancement Aid (SAFE Aid)
- Synergistic Unmanned Manned Intelligent Teaming (SUMIT)
- Tactical Operations Center (TOC)
- Unmanned Aerial System (UAS)
- Unmanned Aerial Vehicle (UAV)

Introduction

Motivation behind SAFE Aid was driven by the full Observe-Orient-Decide-Act Loop (OODA Loop) first defined by the legendary Col. John Boyd (Figure 1). The SAFE Aid system software suite provides integrated, intelligent pilot aiding by focusing, interpreting and acting upon the following four key elements:

- Situation Assessment - Observe, and Orient: Combining and understanding data from systems, sensors, and network messages into a unified situation model that is automatically monitored for relevant events.

- Dynamic Planning - Decide: ISR Asset recommendation is presented to the co-pilot (CP) with option to accepting or rejecting the request.
- Procedure Execution Assistance - Act: Assist the aircrew with the performance of procedures if pre-authorized by the CP; allows the pilot to perform any task deemed.
- Information Management: Presents information that the CP needs to the proper display surface at the right time, minimizing head-down time and bezel button presses.

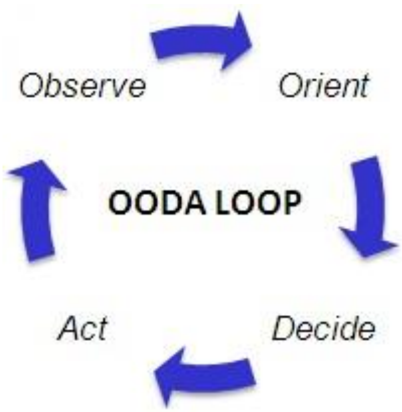


Figure 1. The OODA Loop

Key stakeholders and partners during the development, integration and evaluation of SAFE Aid include: the funding sponsor, the Army Applied Aviation Technology Directorate, Fort Eustis, Virginia; the Army Concepts and Requirements Directorate (CRD), (formerly the Concepts, Experimentation and Analysis Directorate (CEAD)) Air Maneuver Battle Laboratory (AMBL), Fort Rucker, Alabama; the Army Research Laboratory; and the 2-17 Cavalry Squadron (2-17 CAV) at Fort Campbell, Kentucky.

This paper describes the development and evaluation activities behind Adaptive Distributed Aviation Asset Optimization for Operational Effectiveness with the use of an IDA for management of distributed aviation assets during man-in-the-loop experimentation and evaluation for warfighter net-centric operations funded under a SBIR phase II program. VELOXITI, Inc., with support and assistance from the US Army's CRD AMBL, integrated the SAFE Aid system into a mature man-in-the-loop mission simulation environment located within the AMBL at Fort Rucker, Alabama.

The SAFE Aid system serves to validate development and test activities which enable aviators to effectively manage distributed aviation assets, in this example - unmanned aircraft, without impairing their performance on other flight tasks. The SAFE Aid system enables enhanced aviator performance and mission safety and demonstrates the ability for the system to incorporate additional knowledge bases adapted to accommodate evolving Tactics Techniques and Procedures (TTPs).

The development of SAFE Aid did not occurred in isolation, but instead in the context of a rich technology base that has evolved over many projects and products over a 24 year period. VELOXITI has been a leader in the evolution of this cognitive decision-aiding technology base, participating in the design and development of most of the human-centered IDA systems made in that period. The development of human-centered IDA systems began with the DARPA Pilot's Associate program in the 1987 to 1993 timeframe. This visionary program enabled the launch of VELOXITI as a company in 1990. Since then, VELOXITI has played a central role in the evolution of this technology base. The Rotorcraft Pilot's Associate (RPA) conducted during the 1993 to 1998 timeframe took much of what was learned in the DARPA Pilot's Associate program and applied it to rotorcraft systems. The U.S. Army subsequently assessed the functionality of the RPA capabilities and found that although the improved situational awareness provided by the UAS sensor reduced the time required to detect and engage targets, it also added more tasks to complete the engagement because of the additional sensor access. SAFE Aid enables the aircrew to now expand target identification and engagement by evaluating available information within an area of operations, providing the aircrews with a prioritized list of available aviation assets available to engage, and proposes optimization of asset utilization that minimizes the amount of heads down time within the cockpit.

SAFE Aid provides a Soldier-Centric Approach with aviator and multiple airborne reconnaissance and surveillance assets supporting ground forces. Army Aviation operates in direct support to ground forces usually at the Brigade Combat Team (BCT) level. Timeliness and accuracy of information to the Aviation aircrew has always been and continues to be a challenge. An asymmetric enemy is not cooperative to either ground or aircrew. The soldier's contextual world is complex and uncertainty is high, as is the rotorcraft aircrew environment. Aviation aircrews and their ground counterpart operate in a bandwidth restricted environment. The network at the BCT level and above holds a tremendous amount of data that requires analysis, interpretation and assessment.

Discussion

Under the Army's Aviation Applied Technology Directorate, the Manned-Unmanned (MUM) System Technology program is addressing the challenges of teaming Unmanned Aerial Vehicles (UAVs) and manned helicopters. To perform MUM operations safely and effectively, the Army needs an innovative and effective way to dynamically task distributed unmanned assets without overloading the aviator. Typical Unmanned Aerial System (UAS) control implementations require intensive user inputs to specify the desired mission behaviors. In the cockpit, this presents a high cognitive demand that pulls attention away from the flight situation and is inherently error prone.

As Army Aviation transitions to enhanced and highly advanced cockpits and aviation systems for future vertical lift, the Army is spearheading the opportunity to control UAS from the cockpit of its manned aircraft for synergistic MUM intelligent teaming. The combined MUM team has the potential to provide the Army aviator with more situational awareness of the combat environment and to multiply his effectiveness. This new initiative brings more challenges and demands on the aircrew, specifically MUM operations between aircrew, UAS operators and UAVs. To meet this challenge, VELOXITI developed an IDA system technology for use in aircraft that is platform agnostic and independent of aircraft type. An IDA system has an architecture built on a knowledge base that includes procedural information, operational data, and a current picture of the world state. The IDA cannot model the world, which is too complex, but it can deal with varying uncertainty. This is accomplished using Bayesian probability analysis which determines the probability likelihoods from uncertain data in the AO, and with Machine Learning that escalates the probability likelihoods based on prior experience in the AO.

The SAFE Aid IDA enables an air crew to leverage and task individual UAVs, multiple UAVs, or other airborne sensor assets to enhance MUM Teaming (MUM-T) Operations by analyzing events and ISR asset availability throughout the AO, by recommending the best reconnaissance and surveillance asset to the aircrew, and by automatically tasking reconnaissance and surveillance assets to stream video feeds to the cockpit. SAFE Aid enables Safe Route Planning by analyzing threats along the aircraft's route on ingress and egress and generating a new route to minimize the risk to the aircraft. SAFE Aid provides for Severe Weather Analysis by determining severe weather risks to the mission and aircraft, alerting the aircrew to mission impact, and generating new route(s) for the aircrew to choose in order to avoid the severe weather. Combining these IDA capabilities enhances many mission aspects; using the example of a MEDEVAC support mission, SAFE Aid can generate a safe route to and from the Landing Zone (LZ) and assist in tasking surveillance and reconnaissance assets to stream live video feeds at the LZ for maximized situational awareness.

Critical development challenges being addressed include: 1) Maintaining aviator awareness of distributed manned and unmanned aviation asset mission status in flight; 2) Supporting the coordination of multiple unmanned assets and manned reconnaissance and surveillance assets in a variety of simultaneous activities; 3) Providing efficient control capabilities to the Army Aviator while minimizing the impact on workload.; and 4) Identifying known threats, events, status, and conditions occurring in the AO.

The SAFE Aid reasoning engine as configured for the Phase II development effort handles the more commonly occurring battlefield events: MEDEVAC Support, Troops in Contact, Downed Aircraft, Probable IED, Confirmed IED, Insurgent Leader, Zone Recon, Route Recon, LZ Recon, and Demonstration. Some of these events are more important than others; for example, Downed Aircraft events almost always have priority over Demonstrations. The SAFE Aid knowledge base associates an importance value with each event type. These include all normal doctrinal operations related to the elements listed in Table 1 below:

Table 1. Doctrinal Operational Elements

Troops in Contact Personnel Recovery/Downed Aircraft MEDEVAC (Medical Evacuation) IED (Improvised Explosive Device) VBIED (Vehicle Borne IED) SVIED (Suicide Vest IED) P-IED (Possible IED) Using Predictive Analysis CASEVAC (Casualty Evacuation) POO/POI (Point of Origin / Point of Impact)	Airspace ROZ (Restricted Operating Zone) HVT (High Value Target) RS (Reconnaissance and Surveillance) asset & management Unit boundaries Joint and coalition coordination Minefield Demonstrations Air Threats

Based on the nature of an event and currently available assets, SAFE Aid analyzes and recommends the most suitable reconnaissance and surveillance (RS) assets. The resource allocation algorithm considers both the nature of the event and the characteristics of available RS assets.

The agent considers many different platform attributes including those listed below in Table 2 below:

Table 2. Aviation Platform Attributes

Average speed Coverage radius Current altitude Current location (latitude, longitude) Echelon Equipment can travel to event IMINT capable (Imagery Intelligence) Is asset manned or unmanned MASINT capable (Measure &Signature Intelligence) Max seconds until arrival	Max wind speed NTISR capable (Non-traditional ISR) Required offset from target Sensor fidelity rating max Sensor fidelity rating min SIGINT capable (Signals Intelligence) Stealth rating Survivability rating Task org to Battalion

An advantage of an IDA system is that it can interact with and task individual and/or multiple types of UAVs and other air assets to complete the mission. UAVs can provide video surveillance and reconnaissance, target laser designation, battle damage indication, communications relays, and even alternative weapons platforms - all under the watch of the aircrew while safely under cover or out of contact. Teaming UAVs with manned vehicles has the potential to greatly increase the mission effectiveness and the survivability of the manned assets. UAVs can act as an extended sensor network for the manned vehicles, allowing them to extend their influence over a much larger battle space. Whether the manned helicopter is executing an attack sequence or conducting a reconnaissance mission, the IDA will have the knowledge necessary to construct an appropriate plan for crew support with UAVs. Another advantage of associate systems is the efficiency of the knowledge structures. Because VELOXITI's SAFE Aid technology is a knowledge-driven system versus data, our footprint is small compared to traditional database systems. VELOXITI has demonstrated, in a desktop prototype, which IDA technology can provide the necessary functionality to the Scout, Reconnaissance, Attack and Utility rotorcraft for commanding and tasking multiple UAVs based on IDA knowledge.

Planning for insertion into current and emerging aviation platforms is being accomplished by use of an agile man-in-the-loop simulation-driven development process that validates current and emerging requirements for aircrew cognitive decision aiding. This enables validating stated requirements for a SAFE Aid IDA while refining the design and implementation near real time. At the completion of Phase II, SAFE Aid system will have demonstrated its robustness and mission value in a mature man-in-the-loop flight simulation environment.

At the completion of Phase II, SAFE Aid will be a well-defined and deliverable functioning prototype ready for technology insertion and flight evaluation, production readiness and system certification in Phase III. The methodology proposed for Phase II was divided into five main development spirals, each with several small sprints within them. The first four of the major spirals culminate in manned simulation test (MST) periods in mission flight simulators development and provided by the AMBL. The final spiral applies the results of the MST 4 to the final requirements, design, and implementation in other Army high fidelity flight simulation facilities. Each sprint within a spiral is typically 30 days long and includes refinements of requirements, test cases, design, and implementation, all focused on the goals of the major spiral and the tests defined for the MST event. Our work for Phase II involved the use of active duty aircrews from the 2-17 CAVALRY Squadron during the major MST events. While VELOXITI and the AMBL both have employees with Army rotorcraft flight experience, we strongly desired to include Army flight personnel in the MST process to obtain the most recent and relevant operational experience with manned unmanned operations. The collective SAFE Aid evaluation and demonstration Team has extensive experience in planning, conducting, and analyzing manned simulation environment testing and flight tests.

SAFE Aid Technology Description and Functionality

The SAFE Aid system for this Phase II experiment was a component of a federated avionics system. SAFE Aid receives data from multiple avionics subsystems over one or more data buses and issues data over these buses to other components in the federated architecture. An important feature of this design is that SAFE Aid is a component whose failure is isolated from the rest of the aircraft's mission and vehicle systems.

A key aspect of the SAFE Aid system is the MUM-T functionality. The SAFE Aid system easily allows the aircrew pilot or co-pilot the ability to task a single UAV or multiple UAVs with providing reconnaissance video feed of an event back to the cockpit. Figure 2 is representative of the path an event takes that is detected by ground forces, who enter the information into the system network, as it flows to the aircrews. The event information passes to the IDA, which then analyzes and presents the best recommended plan of action and assets for reconnaissance to the aircrew. The aircrew then selected an asset for recon, which is then automatically tasked by SAFE Aid, resulting in video feed of the event being shown in the cockpit for the aircrews. Degraded video feed or loss of video feed, due to communications jamming, interference, or loss of asset, is also easily managed by the aircrew. The aircrew can simply untask the asset whose video feed has degraded and task another asset to relocate and provide video coverage of that area.

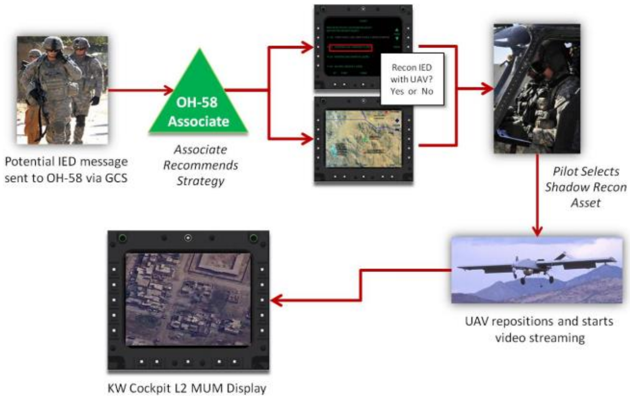


Figure 2. From Event Occurrence to Cockpit Video Feed

The software applications developed specifically for the SAFE Aid Phase II system consisted of the following two aircraft/cockpit components:

- SAFE Aid Intelligent Decision-aiding Associate
- SAFE Aid Display Manager

The system also leveraged software applications from previous government-sponsored work for emulating the ground-based subsystems with the following applications:

- Event Generator
- Receive Chat Service

SAFE Aid is the intelligent agent behind the cognitive decision-aiding system. It accepts the raw input data from the avionics, blue force tracker, and ground subsystems, performs analysis on the data, establishes its own situational understanding, and recommends actions to the pilot. Leveraging the OODA Loop concept, the system has a knowledge base for assessing the situation (Observe-Orient) and for generating responses to events of interest (Decide-Act). The graph structures used for capturing Observe-Orient knowledge and Decide-Act knowledge were extended to accommodate new events of interest and to allow for more complete decision aiding. The knowledge base enhancements also included manned-unmanned (MUM) teaming efforts and MEDEVAC mission support from previous projects involving Apache Longbow and Black Hawk helicopters.

SAFE Aid is platform agnostic, meaning that it is a general cognitive decision-aiding system that is not tied to any one type of helicopter but can be used with any Display Manager representing any number of different rotorcraft air vehicles.

The complex knowledge-based system that is the fundamental working engine of the associate does not model the entire world, but rather a subset specifically designed for the modern warfighter, and more specially, the rotorcraft pilot. The information used for this knowledge was partly obtained from the following documentation listed in Table 3 below:

Table 3. Operational Guidance Documentation

- BRIGADE COMBAT TEAM AND BATTALION DRILLS FROM OPERATION IRAQI FREEDOM / OEF
- FIELD MANUAL 3.0 OPERATIONS FEB 2008
- FIELD MANUAL 5.0 THE OPERATIONS PROCESS MAR 2010
- FIELD MANUAL 7-15 THE ARMY UNIVERSAL TASK LIST MAR 2005
- JOINT PUBLICATION 3.0 JOINT OPERATIONS FEB 2008
- FIELD MANUAL 6.0 MISSION COMMAND AUG 2003
- FIELD MANUAL INTERIM 3.24-2 (FM 90-8, FM 7-98) TACTICS IN COUNTERINSURGENCY MAR 2009
- 4IBCT 3ID KM_SOP FINAL 071630APR10
- 2009 ARMY CAPSTONE CONCEPT
- ARTEP 3-91-MTP BCT BATTLE CMD STAFF 200507
- FM 3-24.2 TACTICS INCOUNTERINSURGENCY(FM 90-8, FM 7-98)APRIL 2009
- TC 1-611 SMALL UNMANNED AIRCRAFT SYSTEM AIRCREW TRAINING MANUAL
- TC 2-01 INTELLIGENCE, SURVEILLANCE, AND RECONNAISSANCE SYNCHRONIZATION
- 1ST AIR CAVALRY BRIGADE TACSOP 01 JUL 08
- DOD MIL-STD-2525C INTERFACE STANDARD COMMON WARFIGHTING SYMBOLOGY 17 NOVEMBER 2008
- GTA 21-08-002 BASIC COMBAT TRAINING SMART CARD APRIL 2008
- TC 1-251 AIRCREW TRAINING MANUAL ATTACK HELICOPTER AH-64D (INCL CHG 1)
- TC 1-400 BRIGADE AVIATION ELEMENT HANDBOOK
- UNMANNED AIRCRAFT SYSTEMS COMMANDER'S GUIDE AND AIRCREW TRAINING MANUAL

- Subject Matter Expert (SME) interviews with combat-experienced rotorcraft pilots

SAFE Aid Display Description and Operation

The SAFE Aid Display Manager is the graphical user input (GUI) part of the system and is a separate application from the SAFE Aid and is platform specific. For this application, the Display Manager was configured to represent the multi-function display (MFD) panel of an OH-58D Kiowa Warrior helicopter. The Display Manager receives information from SAFE Aid, such as events, Fragmentary Orders (FRAGOs), weather reports, etc., and displays this information to the operator (in this case, the Co-Pilot Gunner (CPG) member of the aircrew), formatting the information in relationship to the hardware bezel buttons surrounding the MFD panel. The user can select the bezel buttons to initiate changes to the Display Manager running in the MFD panel.

The Display Manager also accepts blue force vehicle information updates from the avionics bus (for this experiment, the simulator bus) and displays this information as vehicle position reports on the SAFE Aid Display Manager map. The map consists of satellite imagery supplied by the National Geospatial Intelligence Agency for use with this system and is powered by a licensed ArcGis Server Manager.

The SAFE Aid Event Generator is a separate application that emulates a ground subsystem for generating the chat messages created at the Tactical Operations Center (TOC) and other networked field locations. The Event Generator allows the user to select predefined events, FRAGOs, and weather reports and send them to the cockpit SAFE Aid system by way of the SAFE Aid Receive Chat Service.

The SAFE Aid Receive Chat Service is a separate application that receives raw chat messages from the ground subsystems, analyzes these messages through Natural Language Processing, and sends a corresponding formatted message on to SAFE Aid in the cockpit. It understands events, FRAGOs, weather reports, ROZs, etc. This software is intended to reside at the TOC and would have a communications link to the aircraft. For this experiment, the Receive Chat Service was sending messages to SAFE Aid through a Data Distribution Service (DDS) message protocol system.

The user interface of the SAFE Aid Display Manager was purposely kept simple and consists of three screens that can be selected by the operator by selecting one of the bottom bezel buttons on the MFD panel. These screens consist of the Situation screen, the Events screen, and the Map.

Figure 3 shows the main Situation screen on the MFD panel. The Situation screen consists of all incoming messages from the SAFE Aid listed in chronological order. These messages consist of events, FRAGOs, weather reports, route generation messages, etc. The operator can select any message by pressing the corresponding bezel button and see more information about that message. If the message pertains to an untasked event, then the additional information may contain a prioritized list of reconnaissance assets that can be selected by the operator and tasked to move to that location, adjust its sensors to look at the stare-point position, and stream its video feed back to the cockpit of the aircraft. For the SAFE Aid evaluation experiment missions, the reconnaissance assets consisted of only Gray Eagle and Shadow unmanned aerial vehicles (UAVs); any available manned or unmanned air vehicle may be chosen as a reconnaissance asset. Any closed messages in the Situation screen will be displayed as gray text so the operator can easily distinguish between the active and closed events. The operator can scroll up and down to see additional messages.

Figure 3. SAFE Aid Situation Screen

Accepting a FRAGO will result in a new route to the destination and the assignment of the ownship to that FRAGO. FRAGOS that the system currently supports includes:

- Medevac Support
- Zone Recon
- Route Recon
- Transport
- Observation
- Movement

Figure 4 shows a selected untasked event with a prioritized list of reconnaissance assets that can be selected and tasked to look at that event. The reconnaissance assets are listed in order of score based on the previously discussed 17 variables of the manned or unmanned asset. The exception to this priority list is that the ownship will always be listed first if the system determines that it can be a viable reconnaissance asset. If an asset is already tasked, then it will still be available for selection; however, it will displayed in gray text to indicate easily to the operator that it is tasked, and its current task and task priority will be displayed. The operator can select a tasked asset and retask it to an event. If the operator does select a tasked asset, then the event to which the asset was previously tasked will become untasked. The operator can also close the event from this screen or generator a spot report.

Figure 4. SAFE Aid Untasked Event Selection

Figure 5 shows the main Events screen on the MFD panel. The Events screen consists of only active events and lists the events in priority order, with the highest priority events always shown at the top. The operator can select an event to task a UAV, untask a UAV, generate an Optimization Plan, close the event, or generate a Spot Report. The operator can scroll up and down to see additional events.

Figure 5. SAFE Aid Events Screen

Figure 6 shows the SAFE Aid Optimization Plan. The Optimization Plan is generated by SAFE Aid upon request by the operator. This plan consists of the highest priority events optimally matched with the best RS assets that are available in the Area of Operations (AO). This plan is generally requested when too many events have occurred in the AO for the CPG to evaluate and task RS assets to handle them. The associate will generate the plan and present it to the operator with a choice to accept or reject. If the operator accepts the plan, the associate will automatically task each of the RS assets with the corresponding event.

Figure 6. SAFE Aid Optimization Plan

Figure 7 shows the SAFE Aid Map screen. The Map screen consists of satellite data imagery overlaid with graphics representing blue force air and ground vehicles, point and checkpoint locations, Forward Operating Base (FOB) locations, Named Area of Interest (NAI) zones, reconnaissance zones, Restricted Operating Zones (ROZs), route reconnaissance start and end points, ownship routes, events, enemy locations, air threats, and weather zones. The Map also allows the operator select Center to always focus the centerpoint of the map on the position of the ownship or select Pan to remove focus from the ownship for the operator to use the arrows buttons to view a certain location. The operator can also zoom in and out on the map to see more detailed or less detailed images. The cockpit version of this map used satellite data imagery obtained from the National Geospatial Intelligence Agency.

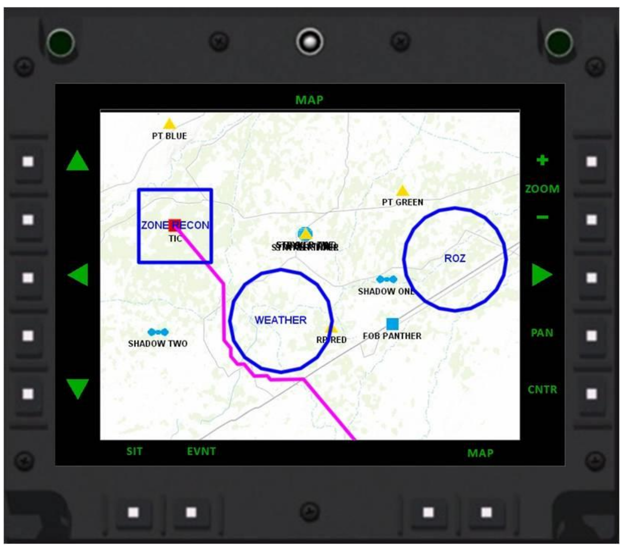


Figure 7. SAFE Aid Map

The SAFE Aid software components were integrated into the AMBL simulation environment. Messages were sent between the simulation system and the SAFE Aid IDA through the DDS system. SAFE Aid receives messages directly from the simulator (blue force vehicle position updates), from the Receive Chat Service (new events, FRAGOs, weather reports, etc.), and the SAFE Aid Display Manager (operator actions). Because STANAG 4586 messages could not be used for this experiment, SAFE Aid communicated with the UAV Ground Control Stations, represented by the Generic Unmanned Supervisory Segment (GUSS), by sending a chat message to the stations indicating a FRAGO to task a UAV to reposition and look at a starepoint location corresponding to an event or to untask a UAV to return to its original loiter position.

The SAFE Aid Display Manager only ran in the CPG MFD panel and was not part of the avionics system. The CPG could toggle between the cockpit avionics and SAFE Aid by flipping a switch up and down. The toggle switch was located directly under the CPG MFD panel. Any bezel button selections that were made while the switch was flipped to the "SAFE Aid" mode were sent from the simulation to the SAFE Aid Display Manager. Bezel button selections were not sent to SAFE Aid when the switch was set to the avionics.

The L2 MUM system was displayed on the additional center display panel and was an external system to SAFE Aid. The video feed that was displayed on this panel came directly from the UAV simulations. The CPG could select one of four video feeds by selecting a corresponding radio button directly above the center panel. Any information from this panel was not sent to the SAFE Aid system.

Man-in-the-Loop Experimentation Environment for Evaluation and Testing

The Air Maneuver Battle Laboratory located at Fort Rucker, Alabama, provided the facilities needed to conduct the SAFE Aid man-in-the-loop immersive simulation environment. The AMBL personnel, with support from their subcontractor teams from SAIC, ZedaSoft, and Lockheed Martin, worked with the VELOXITI team to integrate and demonstrate the SAFE Aid functionality. The AMBL provided two functioning manned helicopter cockpits simulators (OH-58D) side-by-side to enable evaluation of SAFE Aid between a non-SAFE Aid and a SAFE Aid enabled cockpit. Figure 8 shows the layout of the SAFE Aid enabled cockpit.

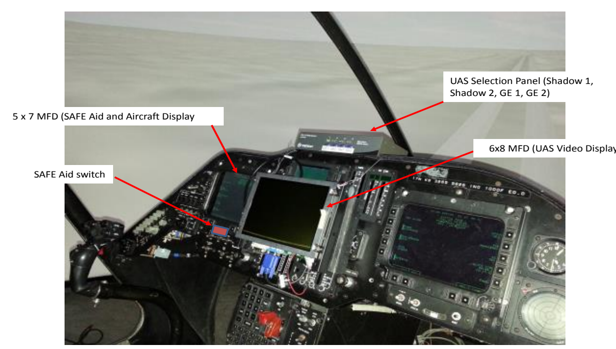


Figure 8. SAFE Aid Enabled Cockpit

The Advanced Tactical Combat Model (ATCOM) is a Boeing-developed constructive and virtual simulation environment used extensively by the Army. ATCOM provide a 6-degree-of-freedom flight performance environment that emulates both static and dynamic entities. ATCOM can be used for current, emerging, and future aviation combat systems analysis. For the SAFE Aid evaluations, ATCOM provided the immersive simulation environment in which the AMBL simulated aviation assets flew. The simulation provided interoperability within the simulated battle-space to create a force-on-force construct that enabled enemy combatants movement, interaction, and engagement.

The GUSS was used by the AMBL Team to emulate multiple UAS control functions. During the SAFE Aid man-in-the-loop experimentation, the GUSS emulated 4 UAS systems based upon the SHADOW UAV and the GREY EAGLE UAV.

The 2-17 CAV out of Fort Campbell, Kentucky, provided experienced aircrews and UAS operators. The aircrews had a combined total average of 5+ years of aviation experience, 350+ operational missions, and 130+ MUM-T missions experience in multiple theaters of operation. The UAS operators operated the GUSS for the Non-SAFE Aid cockpit and communicated with the Non-SAFE Aid aircrews. The SAFE Aid enabled cockpit also utilized the GUSS station operator, who was only allowed to respond to the message and event traffic being generated by SAFE Aid.

SAFE Aid Data Analysis

SAFE Aid brings valuable information from to the crew from off board sources such as: Blue Force Tracker, IDM/JVMF, Chat, Link 16, etc. As stated earlier, previous SAFE Aid demonstration versions have been developed and demonstrated for Apache and Black Hawk helicopters. The current SAFE Aid IDA evaluation and test was focused on the MUM-T mission and the associated operations routinely conducted by OH-58D Kiowa Warrior helicopters. The intent was to aid aircrews in responding to FRAGOS and using multiple UAV assets in a highly dynamic and fast paced battlefield environment. SAFE Aid delivers filtered information to the cockpit and reports important information for the mission being performed (examples include: weather and restricted operating zones (ROZ)).

The SAFE Aid system displays events with information about activity within the aircraft's mission tasks and associated purposes (examples include: Movements of unknowns or threats can be used to task assets). The SAFE Aid system also has a Map function that enables events and objectives to be automatically added to the Map with routes to way points for navigation and objective movement. The SAFE Aid system delivers FRAGOS, changes in mission tasks, and changes in purposes that can be accepted, used to task other assets, and closed. The SAFE Aid IDA assists in tasking UAS assets by providing an optimized recommendation to the aircrew that identifies which UAS asset is best positioned for accomplishing the mission. Other assets can be tasked and untasked for events and FRAGOS with messages automatically sent to the assets to ensure assets can be optimized across a set of varying events.

VELOXITI has developed and demonstrated a Data Analysis Tool (DAT) for visualizing the IDA processing on multiple levels. With the DAT, SAFE Aid output and recommendations can be visualized and understood on a step-by-step basis and therefore increase understanding and confidence in the SAFE Aid decision making process. The DAT measures, evaluates, and acts upon four distinct variables. Figure 9 shows a representative screen capture of the DAT outputs which includes the following variables:

- Workload: number of instantiated nodes
- Performance: number of satisfied goals
- Task Completion Time: duration of instantiated plans and goals
- Force Synchronization: number of common instances across users

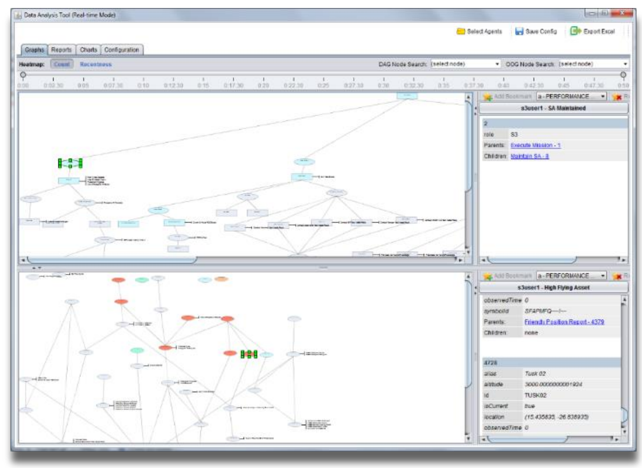


Figure 9. Data Analysis Tool

As new data enters the OOG and "triggers" plans and goals in the DAG significant events are visualized within the DAT. Anytime during the process events and recommended actions can be viewed. With the DAT, intelligent agent output and recommendations can be visualized and understood on a step-by-step basis and therefore increase understanding and confidence of SAFE Aid capabilities and functionality.

Evaluation Activity

SAFE Aid evaluation used several missions as the settings for training and study vignettes. More than one mission was flown in the same Area of Operations, each with different objectives and flight routes. Each mission started in flight and ended by returning to the approach point of a Forward Operating Base. Two missions were conducted in and around a large Urban AO, and two missions were conducted in a Mountainous AO. The missions were focused on close combat attack support and recon using MUM-T and included weapons employment and calls for fire. The missions did not include defeat of threat weapon systems by maneuver or countermeasures.

During the course of a mission, many events occurred in the AO around the mission. Some were directly involved in the study vignettes, while other events were part of the background of activities and information that did not impact the mission itself. Simulation objectives were used to evaluate the increase in situational awareness, to identify and access multiple Surveillance and Reconnaissance assets at any given time, to prioritize AO events, and to generate an AO event driven route.

The four distinct mission types were created for evaluation of the SAFE Aid IDA. Each mission had multiple vignettes that replicated planned and unplanned events and tasks normally experienced in a battlefield environment. Examples of the various vignettes include apprehension of a high value target, medevac support, troops in contact, IED detection and surveillance, route recon, zone recon, etc.

Evaluation Scope

The Manned Evaluation Plan (MEP) provided for assessment of the SAFE Aid system. SAFE Aid is expected to be used by the aircrew Not-Flying in the cockpit of a two-piloted helicopter engaged in MUM-T operations utilizing at least one or more UAS platforms. SAFE Aid is designed to be integrated into existing cockpits and utilizes existing cockpit avionic subsystem driven visual displays and bezel buttons for its operation.

The MEP describes activities to integrate SAFE Aid with a manned combat helicopter mission simulation, validate its successful integration, and perform one or more formal manned evaluation exercises using Army supplied flight crews.

SAFE Aid is expected to contribute to achieving the following benefits compared to the unequipped baseline cockpit:

- Reduced crew procedural errors
- Increased situation awareness by the Non-Flying aircrew member
- Increased coordination between the aircrew flying and the aircrew not-flying
- Reduced time to perform tasking and assignment activities for the UAS

The goal of the manned evaluation is to validate the performance benefits of the SAFE Aid technology in support of the development of requirements and system functionality to be implemented under a later program of record.

Evaluation Test Resources

The resources to conduct this evaluation were supplied as a joint activity between VELOXITI and the US Army. The following support resources are discussed in this section:

- Manned combat helicopter mission simulator (AMBL)
- Aircrew subjects and UAS Operators (2-17 CAV)
- Evaluation staff (VELOXITI)
- SAFE Aid IDA (VELOXITI)
- ATCOM Computer Generated Forces (CGF)

Manned Combat Helicopter Mission Simulation\

To conduct the evaluation, SAFE Aid was integrated into an existing manned combat helicopter mission simulator available to the Army. The preferred platform for this evaluation utilized was the OH-58D simulators at the AMBL at Fort Rucker, AL. The simulation had the following capabilities:

- Cockpit for two crew members that closely represents a current Army combat helicopter
- Visual scene environment for helicopter flight
- Representative helicopter flight dynamics
- Simulation of current Army digital data link systems
- UAS Ground command and control station emulation
- Means to pass digital data between the helicopter and the UAS ground station emulation
- Simulation of multiple UAS with representative flight dynamics and sensor payloads including Full Motion Video (FMV) feeds from Shadow and Grey Eagle UAS
- Means to pass digital UAS commands and status reports between the simulator Cockpit and the simulated UAS assets
- Simulation of the data link between the UAS and the simulator Cockpit

Flight Crew Subjects

The SAFE Aid evaluation required six two-person aircrews and six one-person UAS operator per mission simulator. Because the MUM-T mission scenarios selected for the SAFE Aid evaluation were consider to have a high degree of complexity, aircrews were requested to have the following experience level:

- A minimum of 50 flight hours in the OH-58D
- Training in the MUM-T mission

However, an analysis of the aircrews provided by the 2-17 CAV found that they had a much higher experience level both with the OH-58D and with MUM-T operations due to recent deployments within the Southwest Asia area of operations. Aircrew and UAS Operator combined average experience was determined to be:

- Combined average total years of active duty service: 9+
- Combined average years of aviation assignments (after flight training): 5+
- Combined average approximate number of mission in an operational theatre: 350+
- Combined average approximate number of MUM-T UAS missions (including training): 130+

The aircrews were not asked to perform duties other than their current responsibilities as Army aviators and were not be subjected to any unusual physical or emotional conditions beyond the normal environment of a full mission combat flight simulator. All aircrew and UAS operator subject identification was suppressed to provide anonymous data analysis and reporting.

Evaluation Staff

Staff from VELOXITI managed the evaluation, with support from AMBL staff and simulation system contractor personnel. The following roles are required to execute the MEP. These roles include:

- Evaluation Coordination (VELOXITI). Responsible for the overall success of the evaluation, including scheduling and accepting simulation integration, validation, test conduct, data collection and system disassembly at the conclusion.
- Simulation Facility Management (AMBL). Responsible for all aspects of the host facility operations and support for the evaluation. Direct Point of Contact for the Evaluation Coordinator.
- Aircrew Liaison (VELOXITI). Responsible for defining the desired MUM scenarios, training the flight crew subjects, briefing missions and debriefing after missions.
- Data Collection Analysis (VELOXITI). Responsible for defining the data collection and performing the data analysis
- Simulation Technical Support (AMBL contractor). Responsible for assisting the Crew Liaison and Data Collection Analyst with SAFE Aid integration and simulator operation to support the desired test scenarios, data collection processes, and GUSS operations.

Test Design

The test design consisted of two two-person aircrew and two UAS operators for each week of SAFE Aid evaluation. Each two-person aircrew and UAS operator flew four missions which included four separate vignettes. One two-man aircrew and one UAS operator flew the Non-SAFE Aid equipped simulation cockpit, and one two-man aircrew and one UAS operator flew the SAFE Aid equipped simulation cockpit. Each vignette constructed in ATCOM was between 20 and 30 minutes each. Evaluation missions were flown at night under night-vision goggle conditions to increase cognitive workload of both aircrews.

Evaluation configurations

The evaluation used two helicopter configurations:

- OH-58D with MUM-T equipped capability. This configuration will represent the current tasks and crew behaviors for operation of a UAS while in flight or tactical hover.
- OH-58D with SAFE Aid equipped capability. This configuration adds the SAFE Aid capability to the baseline for the OH-58D.

This metric approach was used to assess the effectiveness of prototyped technology. In this case, the experimental design requires two conditions - one with and one without the prototype SAFE Aid technology. Used in this way, SAFE Aid would simply run in the background and not contribute decision-support. Instead, SAFE Aid would provide the metrics framework for assessing staff performance with and without the prototype technology. For the acquisition community, these metrics are anticipated to provide solid benchmarks of performance to assess the effectiveness of any prototype technologies, such as a new mission command system, across the development cycle on a range of dimensional metric parameters.

Evaluation Scenarios

The evaluation examined three separate aircrew performance cycles over a set of identical mission vignettes. The mission vignettes were grouped into three types:

- MUM Route recon while contour flying. (four vignettes)
- MUM zone recon while deployed to cover at a planned observation point with movement to a new observation point. (two vignettes)

- MUM operation with an unexpected defensive deploy to cover and movement to an observation position. (two vignettes)

It was highly desirable that the complexity of the vignettes was high and the vignettes may not be always successfully completed in the baseline case. The SAFE Aid IDA behaviors that were explored across in the mission vignettes and evaluated against variables included:

- Bayesian Reasoning: Determine probability likelihoods from uncertain data in the AO
- Machine Learning: Escalate probability likelihoods based on prior experience in the AO
- Manned-Unmanned Teaming Operations: Analyze events and ISR asset availability throughout AO; Recommend best RS assets to the pilot; Automatically task ISR assets to stream video feeds to the cockpit
- MEDEVAC Support: Generate a safe route to the LZ; Task an RS asset to stream video feeds from the LZ
- Safe Route Planning: Analyze threats along the aircraft's route; Generate a new route to minimize the risk to the aircraft
- Severe Weather Analysis: Determine severe weather risks to the mission; Alert the pilot to mission impact and generation of new routes

Flight Crew Subject Briefing and Training

The flight crews were trained on SAFE Aid prior to flying the four missions and 16 vignettes. SAFE Aid training consisted of the following:

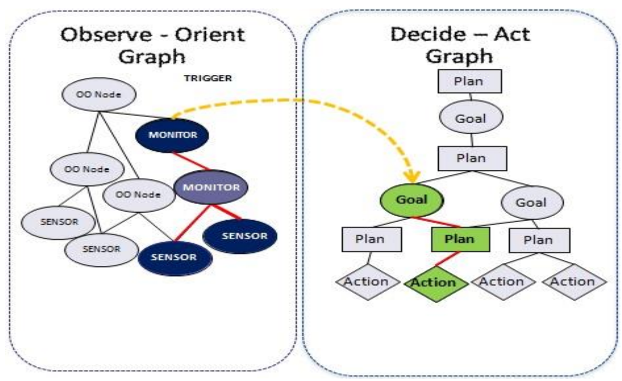
- Instructor led overview of SAFE Aid using slides and hands-on cockpit training
- Overview of mission objectives and CONOPS without revealing the details of each mission vignette
- A training run in each OH-58D simulation cockpit for aircrew visual recognition of targets, visual features and scenes, etc.

Prior to each mission evaluation run, the aircrews were briefed on the operational situation and mission tasks to be expected. The mission vignettes included multiple events not briefed to the aircrew. After each mission was completed, the aircrew completed a brief questionnaire and provided a verbal debrief of their experience during the missions for both the Non-SAFE Aid and the SAFE Aid equipped cockpits.

Evaluation Data Collection

Evaluation data was collected through the knowledge base of the SAFE Aid IDA. The metrics for data collection can be derived from the pattern of node activations from the OODA Loop knowledge-base Observe-Orient (O-O) and Decide-Act (D-A) graphs and be used to gauge the effectiveness of the aircrews during each mission.

Figure 11 illustrates the Observe-Orient Graph and Decide-Act Graph from VELOXITI's Velox.engine implementation of the OODA loop technology. Agents are goal and event driven and must be tailored for the OODA-loop. The Observe-Orient Graph maintains sensor input, combines and aggregates nodes, and provides monitors that fire triggers. The Decide-Act Graph responds to triggers that activate Decide-Act processing to determine which actions should be taken.



Figures 11. The Observe-Orient Decide-Act Graphs

Examples of evaluation data collected included the following:

- Cognitive workload (number of concurrently active goals across time)
- Currently active plans & goals
- Timing to complete tasks
- Necessary collaborations (shared plans & goals)
- Force synchronization (timeliness of distributed sub-goal satisfaction)

Since the knowledge includes a dynamic model of the operational environment and the user interface is updated with appropriate alerts, suggestions, and highlighting of critical information as time progresses, the knowledge representations serve as *state traces.* State traces depict the cognitive work demands on the mission aircrews across the mission scenario runtimes as dynamic events unfold. A suite of data analysis tools (DAT) was developed to look at the underlying node activations in the knowledge structures, which include an instance viewer, a log analyzer, and a shared event analyzer. The Data Analysis Toolset has four primary components that are being utilized to evaluate the results of the aircrew experiences with and without SAFE Aid technology. This data analysis is still underway and is unavailable to report conclusively at this time. However, the DAT components used to evaluate the aircrew experiences enable viewing of node activations and log outputs of moment-by-moment changes in the following activation states:

- Heat Map: Active nodes in the knowledge structure which provides a heat-map for cognitive work analysis
- Cognitive Workload Chart: Time-series figure of activation and deactivation of nodes which shows cognitive workload
- Reports View and Task Completion Timing: The start and stop times for events, e.g., IED, TIC. Events include input data, alerts, recommended COAs, and actual COAs and are anything that triggers node activations and deactivations in the knowledge structures.
- Shared Event Analyzer: Events can be shared across roles, requiring collaboration. For example, an air MEDEVAC requires coordination between the FSO, S2, and S3. The Shared Event Analyzer measures collaboration (team performance) and force synchronization.

Evaluation Test Schedule

The manned subject pilot evaluations took place over three one-week periods on site at the AMBL. An initial on-site internal manned test period was conducted prior to the manned subject aircrew evaluations and provided simulation preparation and SAFE Aid integration and validation. The integration and evaluation periods occurred during the January, February, and March timeframe, 2014.

Conclusions

A continuing challenge for Army Aviation is evaluating, understanding, and predicting enemy movement, friendly situational awareness, and friendly deposition in each AO. Currently this understanding is typically done with the use of radio communications from the ground commander to the lead aircraft in formation. The Army has recognized that cognitive decision aiding tools provide the Army aviator with more situational awareness of the ground combat environment, thereby improving combat effectiveness without degrading the safety of the platform or its occupants.

Intelligent associates are intelligent agent-based decision aids that assist human operators in complex environments requiring high cognitive load. Intelligent associates have been shown to be effective integrating three basic activities: (1) perception, (2) decision making, and (3) performing courses of action. An intelligent associate emulates the behavior and decisions of a human, whether in battlefield operations, a medical diagnosis, or the complex environment of an Army aviator. Intelligent associates obtain their behavior characteristics through knowledge extraction of domain specific plans and goals associated within Army aviation doctrine.

SAFE Aid provided intelligent situation assessment, planning, procedure assistance, and intelligent management of the multi-function cockpit displays through a series of evaluation demonstrations that were based upon realistic working mission scenarios.

The demonstration provided an inside view of the knowledge processing of SAFE Aid that allowed the viewer to see how SAFE Aid recognized signals from the aircraft avionics in terms of its airspace situation and how it produced dynamic plans and procedure execution to fulfill mission responses. The demonstration validated the system's ability to display the automatic route planner that responds correctly to both unexpected missile, AAA threats, and hostile action, as well as aircraft system faults while still completing its mission.

There are several conclusions to be drawn from the current body of work for this effort at VELOXITI:

- Prioritized asset management is critical for both the aircrews and the UAS GCS operator for optimizing and tasking multiple assets within one mission;
- Utilizing SAFE Aid within the TOC could enable rapid battlefield asset management;
- Integrating SAFE Aid into the aircraft's avionics systems is critical and can be considered for future vertical lift mission systems;
- SAFE Aid's ability to show unanticipated pop-up situation development on the aircrew display systems was extremely helpful;
- SAFE Aid's ability to show threats populate on the display map as a situation developed was extremely helpful;
- SAFE Aid's ability to show ROZ graphics on the aircrew map displays as they were activated was extremely helpful;
- Aircrew access to multiple UAS assets, with the ability to task them, provided increased flexibility with a big improvement in situational awareness;
- A definite need exists to enhance the aircrew's operational experience to support management of multiple UAVs and other air assets from the cockpit;
- Current airborne sensors and UAV technologies will expand the capabilities of current and emerging aircraft well beyond present operating limitations.

Future Work

The SAFE Aid knowledge base needs verification from pilots and other subject matter experts. Despite program approval and validation during Phase II, the knowledge should be thoroughly examined and expanded to meet the needs of emerging and future vertical lift aviation programs.

Building the complete SAFE Aid system and integrating it into current and future aviation assets will require close coordination with end users to ensure all functional elements are accessible and operating.

Aircrew and UAS Operator comments, observations and feedback during the evaluation periods will be used to identify growth areas for future SAFE Aid enhancement that will provide increased utility and functionality across a broad range of platforms and ground control elements

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ZedaSoft, Fort Worth, Texas

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