AFRL-RH-WP-TR-2012-0129

Multi-UAV Supervisory Control Interface Technology (MUSCIT)

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September 2012

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NOTICE AND SIGNATURE PAGE

AFRL-RH-WP-TR-2012-0129 HAS BEEN REVIEWED AND IS APPROVED FOR PUBLICATION IN ACCORDANCE WITH ASSIGNED DISTRIBUTION STATEMENT.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
01-09-2012

2. REPORT TYPE
Other

3. DATES COVERED *(From - To)*
1 Jun 2012 – 31 Aug 2012

4. TITLE AND SUBTITLE
Multi-UAV Supervisory Control Interface Technology (MUSCIT)

5a. CONTRACT NUMBER
IN-HOUSE

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
63231F

6. AUTHOR(S)
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5d. PROJECT NUMBER
2830

5e. TASK NUMBER
02

5f. WORK UNIT NUMBER
28302923

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Materiel Command
Air Force Research Laboratory
711 Human Performance Wing
Human Effectiveness Directorate
Warfighter Interface Division
Supervisory Control Interfaces Branch
Wright-Patterson AFB OH 45433-7511

10. SPONSOR/MONITOR'S ACRONYM(S)
711 HPW/RHCI

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
AFRL-RH-WP-TR-2012-0129

12. DISTRIBUTION / AVAILABILITY STATEMENT
Distribution A: Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES
88 ABW/PA Cleared 01/25/2013; 88ABW-2013-0334.

14.
The tremendous success of UAVs has seen the role of unmanned systems expand well beyond the mission for which they were originally intended. One can hardly imagine a role which unmanned systems will not eventually be applied. The future use of UAVs secure, the challenge for unmanned air systems (UAS) developers has shifted from one of demonstrating their value on the battlefield to one of increasing the efficiency of their use. The Multi-UAV Supervisory Control Interface Technology (MUSCIT) program, a research initiative sponsored by the Air Force's Supervisory Control Interface Branch of the Human Effectiveness Directorate (711HPW/RHCI), was tasked to investigate operator interface control issues associated with multi-UAV control. The focus of this effort was to investigate automation and interface technologies that will reverse the status quo to move from multiple operators per vehicle to multiple vehicles per single operator.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Douglas J. Zimmer
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**	SAR	58	**19b. TELEPHONE NUMBER** *(include area code)*
Unclassified	Unclassified	Unclassified			

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1.0 INTRODUCTION

The military utility of unmanned air vehicles (UAV) is no longer in doubt (Hq USAF, 2009, OSD, 2007). The ability to provide persistent surveillance over the battlespace has been cited on several occasions as the critical capability that led to the capture and/or termination of numerous high value targets (HVTs) in ongoing conflicts in Iraq and Afghanistan (Cullen, 2011). The tremendous success of UAVs has seen the role of unmanned systems expand well beyond the mission for which they were originally intended. One can hardly imagine a role which unmanned systems will not eventually be applied. The future use of UAVs secure, the challenge for unmanned air systems (UAS) developers has shifted from one of demonstrating their value on the battlefield to one of increasing the efficiency of their use. Given the increased demand for such assets, the using community must find ways to reverse the manning ratio for their use. Current concepts of operations require multiple operators for every unmanned system, a ratio that cannot be sustained if the projected increase in use is to be believed. If the anticipated expanded use of UAVs is to be realized, a more desirable manning concept must be identified.

The Multi-UAV Supervisory Control Interface Technology (MUSCIT) program, a research initiative sponsored by the Air Force's Supervisory Control Interface Branch of the Human Effectiveness Directorate (711HPW/RHCI), was tasked to investigate operator interface control issues associated with multi-UAV control. The focus of this effort was to investigate automation and interface technologies that will reverse the status quo to move from multiple operators per vehicle to multiple vehicles per single operator.

Given this charge, the dominant question became, 'How many UAVs can a single operator effectively control?' We quickly discovered that, like all such questions, it depends on the context and the demands associated with particular situations. In responding to this question, the MUSCIT program executed a series of developmental spirals, each spiral consisting of a simulation and flight test phase; and each phase expanding on the complexity of situations associated with multi-UAV operations. Early spirals focused exclusively on static tasking, emphasizing point surveillance and the demands associated with providing persistent surveillance across multiple locations (Hughes et.al, 2009, Hughes, et.al, 2011). The second spiral extended the emphasis from merely point surveillance to route surveillance and area search. The idea being that in addition to the sensor control and monitoring activities associated with route surveillance and area search, these tasks would also require operators to attend to vehicle control and mission management functions as well (Hughes et.al., In Press). In each of these spirals the primary research question centered on the impact on operator performance as the number of vehicles increased. In each case, the addition of a vehicle coincided with an increase in tasking as each vehicle was assigned a point surveillance location, a route segment or an area to be searched. Ultimately, the measure of success was the ability to demonstrate that one operator (equipped with an advanced control station and associated automated systems) could perform as well as two operators performing comparable tasks.

Findings from both Spirals 1 and 2 were relatively predictable. Under certain conditions, a single operator controlling multiple vehicles executing multiple tasks could perform as well as a single operator performing a single task (or multiple operators performing multiple tasks).

However, like all finite systems, there exists a limit to their capacity. We learned a great deal about many of the issues that limit capacity and operator interface concepts that can expand that capacity. We also, to some extent, demonstrated the feasibility of multi-UAV control, at least within the context of the mission tasks and scenarios we investigated. What we didn't learn was how operators truly responded to the dynamics of operational situations and how they adapted their strategies to compensate for limits in the capacities of their systems. The full-mission scenario conducted as a demonstration during the Spiral 2 simulation provided some insight into how operators really think about their task. We were able to observe how they adaptively reacted to situations that posed significant problems to task execution and challenged their ability to successfully perform a mission. Such situations force the competent operator to move beyond standard protocols and engage in true problem solving behavior. Given their inability to effectively perform all tasks, they were forced to prioritize their activities and focus on what they believed to be most important given their ongoing assessment of the situation. These demonstrations were enlightening in that they provided a means to gain a view into how operators "think" about their work, how they assess situations, which aspects of a given situation are important, and what actions are appropriate. In many cases, these priorities differed significantly from our own. Our surprise in their responses to the situations we placed them in was, to say the least, very educational. This demonstration also illustrated to us that if we are to gain any real insight into how UAVs are to be used, and how operators are going to interact with them, we must create a simulation environment that presents representative problems and situations and allows our operators the freedom to respond to these situations naturally. Rather than the controlled experiments that dominated the first two spirals, our third and final spiral would sacrifice experimental control for operational authenticity. Our belief was that we would uncover a much richer understanding of the demands and constraints of UAV operations if we observed operators as they engaged in the process of adapting to situations as they arose and to escalation in activity as the situation evolved. It was important, therefore, that the tasking and the flow of activity be as representative as possible.

It has become our contention that simulations should be designed to capture or "stage" what is believed to be the critical, deeper aspects of the situations of interest from actual field operations. The stronger the control one uses to shape the simulation task, the more confident one must be that the variables being manipulated are indeed the most critical for understanding adaptive control.

During Spirals 1 and 2 we discovered that there lies a natural tension between experimental control and situational authenticity. We find that the closer we move to actual operations, the less control of the sequence of activities and the associated tasks we are able to exercise. In fact, the data we collect and the methods for collection become fundamentally different. The comparisons we make to differentiate and explain variability in the data are often fundamentally different. We look across conditions and situations to develop an understanding of the decisions to be made, the nature of the challenges encountered, the trade-offs to be considered, and the goals to be balanced. From a control station perspective, we make observations targeted at understanding how the available capabilities and features of the control station support those strategies and help to facilitate the development and adoption of alternative strategies as situations dictate. We also note any problems encountered during operations and identify any workarounds developed by operators in response to those problems.

As such, naturalistic studies do not necessarily fall under the category of a traditional experiment where independent variables are controlled and dependent variables are collected, but such naturalistic observation is essential to understanding the dynamics of complex operational domains (Klein, 1998). In fact, it is arguably the form of research that should precede more controlled experimentation. Granted, we are unable to directly observe operators in the field. However, we are able to create a synthetic task environment through simulation that can, to some extent, replicate those task conditions. The challenge is to identify those aspects of operational conditions that are critical to shaping the strategies adopted by operators. In essence, a simulation is a model of the system being simulated (Woods & Hollnagel, 2006). Our understanding of these essential aspects of the field of practice should be reflected in the development of our simulations. If our model is a reasonable representation of these critical aspects, our observations will be valid; if not, we run the risk of inaccuracies. In short, our task environment would be weak in terms of authenticity as it does not capture the demands and constraints of actual operations. Highly controlled experiments can have the same impact as the desire to carefully constrain activity to ensure experimental integrity changes the nature and flow of activity in ways and weaken the authenticity of the task environment. We dictate how tasks should be conducted which guarantees we capture the dependent variables under the specific conditions prescribed by the experimental matrix.

During Spiral 3, we believe we have established a reasonable balance between these two ends of the spectrum (i.e., controlled experimentation through highly constrained simulation and authenticity through natural field observations). It is possible, through simulation, to create interesting situations that drive the demands and constraints in ways that force operators to engage in goal conflict resolution, resource allocation, and value-tradeoffs. Within such a study the comparisons of interest is the design of the situation itself. The data is detailed observations of operators' behaviors in response to these situations, how they assessed the situation, information considered, strategies for dealing with uncertainty, sources of uncertainty, tradeoffs considered, etc. In the current spiral, our focus has not been on attempting to quantify how many vehicles can a single operator control, but rather how might an operator's approach to a task change given the availability of multiple vehicles. Will the overhead associated with vehicle/sensor control outweigh the benefits of additional sensor resources? Or conversely, will the addition of resources increase the capacity of operators to dynamically respond to a series of escalating situations?

In working directly with our counterparts within the operational community, we developed a series of scenarios that we believe accurately reflect the demands and constraints, conflicts and challenges, and uncertainty and ambiguity that are typical of many of the missions currently being performed by operational forces engaged in ongoing combat operations.

Observations during simulation and flight test trials during the past two spirals revealed many of the challenges associated with attention management across multiple platforms and design issues relative to means by which operators selectively control and interact with individual vehicles. In this third spiral, enhancements to the control station baseline have been incorporated that we believe address many of these issues. This third spiral has been initiated with the purpose of assessing the appropriateness of these enhancements, as well as the value-added of specific automation technologies targeted at further supporting operators during multi-UAV operations.

The following sections provide an overview of these enhancements and the rationale for their incorporation.

Mission/Sensor Management. One of the initial focuses of the MUSCIT program was an emphasis on mission and sensor management. The separation of these two functions was precipitated largely due to the configuration prevalent in many of the current UAV ground control stations (i.e., Predator, Reaper, Hunter, Shadow) that include both a pilot and sensor operator. As one would expect, the pilot is primarily responsible for vehicle control and maintaining the viability of the platform to perform the mission. Likewise, the sensor operator is primarily responsible for control of the sensor and ensuring that the system's sensors are providing the necessary imagery and sensor data required for the mission. Typically, when speaking of mission management one often is actually referring to vehicle or flight management; the process of placing and maintaining the vehicle in position where its sensors can provide the imagery necessary to perform its assigned mission. Therefore, we often think of mission management as mission planning; identifying a sequence of appropriate waypoints that one believes will place the vehicle (and sensor) in a position that provides the necessary field of regard at the appropriate time. The response to the inevitable uncertainty and dynamics associated with military operations is to engage in the process of ongoing dynamic replanning.

Conversations with operational SMEs following our Spiral 2 simulation indicated that the attention required to engage in deliberate planning would be prohibitive given the demands on attention during active RSTA operations. Such constraints on attention forced us to reconsider how mission management (i.e., vehicle control) should be attended. It became clear to us that the sensor operators we spoke to cared to pay little attention to the vehicle or vehicle control. As far as they were concerned, the vehicle was a distraction; merely a means of positioning the sensor. All other vehicle considerations were secondary. For them it was all about the sensor. This attitude would seem to lend justification for the separation between vehicle and sensor control. In the Predator/Reaper community the pilot is responsible for vehicle control while the sensor operator is responsible for sensor control. To the extent that these two functions interact, the two operators coordinate their actions to achieve the desired effect, sensor on target.

In our experience however, vehicle and sensor control are so tightly coupled that it would seem reasonable to integrate these control functions into a single operation. In other sensor platforms a sensor guidance mode is often used to help maintain the vehicle in position to maintain sensor coverage. The mode couples the sensor's view angle to the vehicles autopilot or flight director. By coupling the sensor steering to the autopilot/flight director, the system is able to maintain the vehicle in an optimal position both for sensor viewing. As part of the Spiral 3 enhancements we have integrated a similar capability into the Vigilant Spirit Control Station (VSCS). During operations each vehicle is placed in its loiter mode. While in loiter mode, the vehicle will maintain a loiter over its designated loiter position. During pervious spirals, VSCS included a Loiter Slave mode where the sensor would center itself on the center of the current vehicle loiter position. An alternative mode was created (Sensor Slaved) where the center of the vehicle's loiter was constantly updated to correspond to the center of the sensor's field of view. As the sensor operator moved the sensor to various positions on the ground, the vehicle loiter point would update to keep the vehicle in a position to maintain quality sensor coverage. This mode was particularly useful while tracking moving targets.

The risk with such an approach is that the intense focus on the sensor image will result in a failure to maintain awareness of the vehicle and vehicle status. The primary concern from a pilotage perspective is to ensure the airworthiness of the vehicle and its flight path. For the purposes of the current study, we made assumptions regarding the reliability of the air vehicle and its auto-pilot control. In other words, we assumed that the vehicle would remain airborne and it would fly where the control station commanded it to fly. That being said, there remains several issues that need to be addressed to ensure airworthiness. First and foremost is terrain clearance. If one is to give free reign to an air vehicle within an area of operations it is critical that the vehicle flies at an altitude to ensure clearance over terrain in the area. Although it would be possible to integrate some form of terrain following algorithm, this issue was resolved by placing the altitude hold for each vehicle well clear of any terrain in or around the area of operations.

Second, one must also be concerned with deconfliction of ownship aircraft. Given that vehicles will likely fly in close proximity to one another, the risk of potential midair collision with other aircraft is always present. Ownship deconfliction was achieved through altitude separation. Placing each of the vehicles at different altitudes eliminated the possibility of a mid-air collision, even if both aircraft were flying in the identical loiter pattern. For the purposes of the current study a separation of 100 ft was deemed sufficient to assure altitude separation. While intruder aircraft were not included in the current study, an effective sense and avoid capability would be required to prove the viability of this concept. And while sense and avoid capability is an ongoing subject of research (Tadema, 2011), it was not included as part of the current effort.

Finally, one must ensure that each vehicle under one's control must remain within the confines of assigned airspace. In the current simulation it was assumed that the vehicles were assigned a block of airspace in which they were free to maneuver. However, given focus on the sensor image, it is not unreasonable to assume that it would be easy for an operator to lose awareness of these boundaries and allow a vehicle to stray outside the assigned airspace. To ensure that vehicles did not violate airspace constraints while in the Sensor Slave mode it was necessary that operators create a "Keep In Box" that corresponded to the assigned airspace for the mission. The creation and activation of a "Keep In Box" was a prerequisite to the activation of the Sensor Slave mode. If an operator would attempt to place a vehicle in Sensor Slave mode without an active Keep In Box a warning would be presented indicating that Sensor Slave mode is not available. Once in Sensor Slave mode, the vehicle's loiter point would update to correspond to the center of the sensor's field of view. In the event that the sensor FOV went outside the Keep In Box boundaries, the positioning of the vehicle loiter would be limited such that a minimum of a two radii distance was maintained between the center of the loiter and the edge of the Keep In Box boundary. This ensured that the vehicle remained well within established safe airspace constraints. Once the loiter position became limited due to movement of the sensor FOV toward the airspace boundary, the operator was given an advisory indicating that the loiter position was being limited by the Keep In Box. While we recognize that refinements to such an approach may be required, we felt the current implementation was sufficient for the current simulation and flight test effort.

Automatic Target Tracking. As part of previous spirals the impact of automation on operator performance has been a central theme. One of the primary assumptions behind multi-UAV control has been the assumed dependence on automation for the viability of the multi-UAV concept. While automation was a central focus of our investigation, the limited availability of viable automation capability required that we simulate these automated features. In Spiral 2 we implemented an auto-detect feature to support the point surveillance, route surveillance and area search tasks. In each case we relied on ground truth of targets and distracter objects to simulate the auto-detect capability. While such an approach can provide useful insights into the potential impact of such automation, given the inability to accurately represent the specific behavior of these systems, we often gain very little insight into the human-automation coordination issues associated with operating at the competency boundaries of the automated system. Since such coordination issues are a primary concern of multi-UAV control station design, we believed it was important that during our final spiral we consider incorporating a viable auto tracking capability as part of the available control station features. Prior to Spiral 3 simulation, VSCS developers had been working with Real Time Video Systems (RTVS) and had integrated a real-time image processing system that provided both a mosaicing and an auto-tracking capability. The implementation of each of these features will be described in more detail later in the report. While the incorporation of this system potentially introduces an additional source of variability in the performance data, its inclusion provided an opportunity to observe how operators deploy such capabilities, the conditions under which they tend to rely on its performance or conversely their tolerance for sub-optimal automation performance. The extent to which operators used the features of this system was totally dependent upon their confidence that the capability would help rather than hinder their ability to perform their assigned mission. It was the variability in the performance of the auto-tracking that ultimately provides the desired insight into operator attitudes and behaviors relative to its use.

VSCS Familiarization System. One of the most insightful discoveries during Spiral 2 was that the quality of our data and the insights gained from the data runs was critically dependent upon the specific backgrounds, qualifications and familiarization of the participants with the control station itself. The ability of operators to effectively use the full complement of features available via the control station was critically dependent upon their level of competence with the implementation of those features. During the previous two spirals, participants were given an instructional presentation on the capabilities of the control station to include the specific mechanisms and mechanics of those features that would likely be required to execute the tasks planned for the data collection trials for those simulation trials. Following the instructional briefing, participants were given a full demonstration of the control station and then offered the opportunity to "experiment" with the control station.

Once participants indicated they felt reasonably comfortable with the workings of the interface, they were exposed to a series of training trials. These training trials were similar in tasking to the data collection trials they were to perform during the course of the simulation study. Training trials were performed for each configuration to be encountered during data collection trials. Participants were required to demonstrate a minimum level of competence on the training trials and indicate their confidence in the ability to adequately perform each of the tasks. In each case the total training time, to include the instructional presentation, was approximately 3-4 hours. While this level of training appeared sufficient for the part task elements of the previous spirals, it was evident that during the full mission trials performed during the Spiral 2 simulation the lack of intimate familiarity with many of the nuances of the control station limited the participants' ability to adequately exploit its capabilities during the trials. They often reported that while they wanted to adopt a certain strategy, they weren't sure how that might be accomplished within the current control station implementation.

Based on these observations, it was evident that if we expected participants to effectively perform a representative full-mission scenario and use the control station in a manner that would be expected under operational conditions, the level of competence with the mechanics of control station was essential. In short, we need to create qualified VSCS operators. With the assistance of our sponsor, the MUSCIT team prepared and delivered a full VSCS system to support a more robust control station training program. Our sponsor developed a control station training program fashioned after the training program currently being used to qualify other small UAV operators (e.g., Raven). Each participant was given several hours of instruction on the operation of the VSCS, its features, and implementation.

OBJECTIVE

The objective of this study was to investigate the demands associated with the use of multiple unmanned aerial vehicles (UAV) within the context of representative RSTA and counter-proliferation set of scenarios and establish a performance benchmark for the control of multiple UAVs using advanced control station designs. Supplemental study objectives included:

- Investigating the value of control station interface enhancements to operator performance during representative operational tasks.

- Assessing the ability of operators to use the control station in response to unanticipated and unexpected events.
- Evaluating the ability of the control station to support the development of adaptive strategies in response to increasing levels of mission complexity and uncertainty.
- Investigating the performance effects and behavioral adaptations operators adopt as the number of UAVs available and video image streams being monitored increases.
- Investigating the means and mechanisms of coordination and collaboration as the number of operators transition from a single operator to two operator crew. Assess the ability of the control station to support cooperative strategies in response to dynamic events within the mission scenario.
- Increasing our understanding of operational missions, operational task demands and constraints, and coordination requirements both inside and outside of immediate UAV support teams.
- Identifying opportunities via automation, visualizations, control mechanization, concepts of operations, etc. that would enhance the feasibility usefulness of multiple UAVs.
- Assessing the quality and fidelity capabilities of our simulation environment and identify specific feature and capability candidates for future incorporation in subsequent simulation spirals.

2.0 METHOD

2.1 Apparatus

The following section describes how the software and hardware components functioned in support of the Spiral 3 program.

2.1.1 MUSCIT Spiral 3 Simulation Architecture

The simulation architecture implemented for the Spiral 3 simulation study is presented in Figure 1. The simulation included two and four digital simulations of small UAVs, each equipped with a gimbaled electro-optical (EO)/infrared (IR) sensor. Vehicle simulations were modeled after the MLB Company's Bat 3 UAV platform, while sensor simulation was based on Cloud Cap Technology's TASE Duo gimbaled EO/IR sensor system. Simulation of ground entities was created using the FLexible Analysis Modeling and Exercise System (FLAMES®), while the sensor simulation visualization was created using the Virtual Reality Scene Generator™ (VRSG™) by MetaVR, Inc. The Vigilant Spirit Control Station (VSCS) served as the framework for creating the control station configuration used in the current study. Details regarding the features and capabilities of each of these components are provided in the sections that follow.

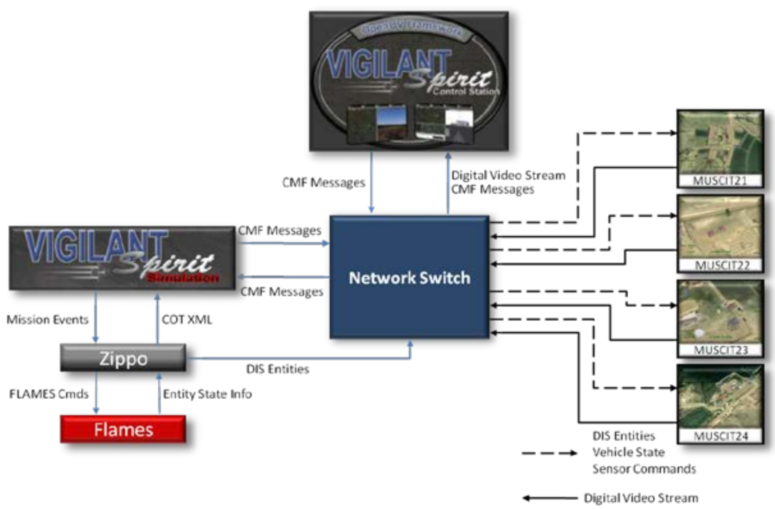


Figure 1. Illustrated architecture for the MUSCIT Spiral 3 Simulation

2.1.1.1 VSCS (One and Two Operator Configurations)

The control station interface (see Figure 2) has four main parts; vehicle status, tactical situation display (TSD), vehicle and payload management, and sensor exploitation. The vehicle status area allows the operator to maintain situation awareness of the UAV(s) the operator is controlling. The TSD allows the operator to maintain battlespace awareness. The vehicle payload and sensor management area allow the operator to control the aircraft and the payloads they are carrying. Finally, the sensor exploitation area allows the operator to view and interpret the sensor information coming from the UAVs. The control station interface was displayed on two side by side 24" widescreen Dell LCD monitors with a combined resolution of 3840 x 1200 or 1920 x 1200 per monitor. Under the default set up, the vehicle status area, TSD, and vehicle and payload management area are shown on the left monitor and the sensor exploitation area is shown on the right monitor.

Figure 2. Sample layout of the control station

The VSCS interface runs on a single Dell Precision PWS690 with dual 2.66 GHz Intel Xeon X5355 processors and 2.75 GB of RAM, with Windows 7 as the operating system for the PC. The PC also uses Nvidia Quadro FX 4600 Video Card.

For the Spiral 3 simulation, VSCS also incorporated a commercial off the shelf product from Real Time Video Systems (RTVS) that included a pixel tracking system as well as an image mosaic capability. The pixel tracking system would allow an operator to "designate" an object within an image and the system would control sensor steering in an attempt to maintain that object within the center of the sensor field of view. In order to use the pixel tracking system, the user would have to switch into the mosaic image mode in the video tool. The user would select the object they would like to track (CTRL-Left Mouse), a red tracking box would be drawn, and the automation would try and center the object in the middle of the screen. A problem occurred while trying to center the object; when the sensor moved too fast the object would "break lock" from the tracking system. In order to correct this, a dampening algorithm was added to slow the movement of the camera. One of the side effects to using the RTVS system was the inability to draw an overlay during the mosaic mode. The user would lose their sensor overlay when the mode was switched on.

The Spiral 3 configuration of VSCS also included the Dynaspeak Voice Recognition in conjunction with a Push-To-Talk switch as its voice recognition system. The vocabulary was expanded from Spiral 2. In this spiral, the mission became much more complex, so the vocabulary was tailored with that in mind. The vocabulary contained more commands that enabled the operator to switch automation modes and command the movement of the aircraft. The goal continued to allow the user to complete tasks without the operator having to draw his/her attention away from the sensor imagery.

Finally, to assist operators in positioning the vehicle to maintain the sensor within an acceptable viewing range, a sensor guidance feature was incorporated into the vehicle guidance control mechanisms of the VSCS. While in the Loiter Slave mode, the operator was given the option to place the vehicle within a Sensor Slave mode. The Sensor Slave mode synchronized sensor steering to vehicle loiter position. As the operator, or auto tracking system, updated the position of the sensor's field of view, the center of the loiter position for the vehicle was simultaneously adjusted to correspond to the center of the sensor's field of view. In this manner the sensor would continuously maintain a constant slant range to the object(s) of interest.

One caveat to the use of the Sensor Slave mode was that prior to entering this mode it was necessary that the operator create a "Keep-In" box. The box created an area in which the vehicle was free to move in response to sensor position updates. In the event that the sensor position moved outside the confines of the Keep-In box, an alert was presented to the operator indicating that the system was commanding a loiter update outside established constraints. As a result, the vehicle's loiter position could not be placed any closer than a distance equal to 2 radii of the current orbit. This constraint was included to reduce the potential for vehicles to stray outside established safe flying zones and protect against the possibility that operators become fixated on sensor imagery to the extent that they lost situational awareness on current airspace constraints. The alert upon sensor movements outside the defined boundaries is intended to cue the operator that further excursion in the current direction will require an expansion of the Keep-In box and associated coordination with appropriate airspace control authorities.

2.1.1.2 Vigilant Spirit Simulation

The Vigilant Spirit Simulation (VSSim) is responsible for simulating both the vehicles as well any other system that the control station may receive information from. For the vehicles, configuration files are read in with the vehicle real world specifications (weight, max speeds, etc.) and the VSSim publishes CMF 4586 messages to the control station with telemetry and other status information (gas, power, etc.) just as real UAVs would. One of the other major systems modeled is the Cursor On Target XML routing system. It streams information to the control station about all of the blue forces that exist in the current theater. One of the main goals of VSSim is to represent, as closely as possible, the capability of a real world system as it would work with the control station.

2.1.1.3 FLAMES®

FLAMES® is a family of computer software products that provide a framework for computer programs simulating physical and cognitive behaviors of complex entities that act and interact in time and space. This study used FLAMES® version 8.0.1 to develop individual entities and script their movements, saving the resulting scenarios for the experimental trials. The FLAMES® interface was run on a single Dell Precision PWS690 with a 3.2 GHz processor and 2 GB of RAM. During scenario generation, entities and their movements were displayed using a VRSG™ image generation tool, as discussed in the next section. Information passes from FLAMES® to VRSG™ via a distributed interactive simulation (DIS) interface.

2.1.1.4 VRSG™ by MetaVR, Inc.

VRSG™ is a real-time computer image generator designed to visualize geographically expansive and detailed worlds on PCs. VRSG™-generated images display in the sensor management area of the VSCS. Directing of mobile elements (e.g., personnel, vehicles) in the scene occurred using FLAMES® scripts. Each VSCS video window required an instance of VRSG™ to be running. For the current simulation, VRSG™ software ran on a Dell XPS 720 with 3.0 GHz Intel Core Duo 2 with 3 GB of RAM.

A major challenge in creating the simulation was the correlation of FLAMES® and VRSG™. Entities built and scripted in FLAMES® display in VRSG™, but FLAMES® is not cognizant of terrain and cultural items placed in VRSG™. Examples of these items are the buildings and roads placed in VRSG™ to create the compounds used for this study. FLAMES® has no idea as to the location of buildings and roads. To keep people from walking into buildings and to keep cars on the roads, these cultural features had to be represented in FLAMES®. Accordingly, experimenters very carefully mapped the latitude/longitude locations of cultural features residing in VRSG™ into FLAMES®. Experimenters accomplished this intricate mapping using airspaces, depicted in Figure 3. Roads were represented by black lines and buildings by green polygons. In addition to mapping building corners, the experimenters mapped the doors of certain buildings in order to enable the appearance of entities entering and exiting those buildings.

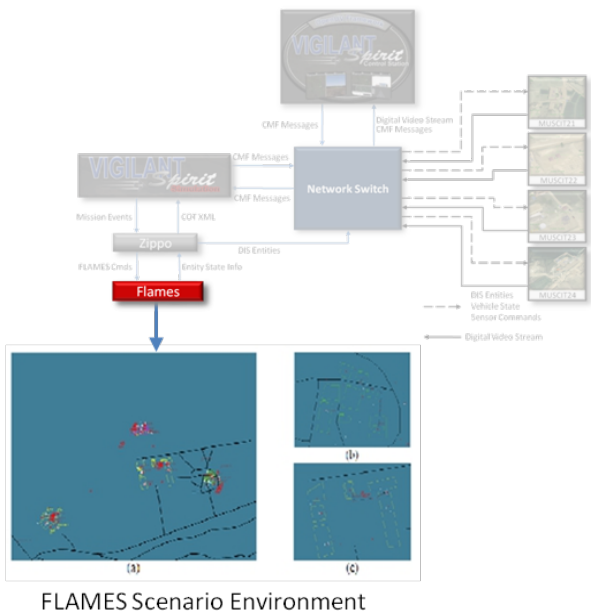


Figure 3. FLAMES® scenario development environment

A second challenge of scripting scenarios in FLAMES® is that scenario events must occur at specifically prescribed times. The movement of entities in FLAMES® is based on routes, start times, and speeds, rather than on a given entity's appointment to a specific location at a specific time. Therefore, to ensure that entities arrived at desired locations at desired times, experimenters timed how long specific routes took to complete and then varied entity start times to accommodate proper event times. To expedite this process, experimenters created only a handful of routes for the entities at each area of interest (AOI). After recording route travel times for the entities, experimenters were able to prescribe appropriate entity start times.

2.1.1.5 Scenario Generation/Scenario Control (Zippo Tool)

Per discussions with sponsor representatives, the scenario for Spiral 3 simulation was designed to be flexible and dynamic. In order to keep participants from gaming the scenario, we wanted the ability to inject various events into the scenario. These events included sensor noise, GPS failures, communication failures, additional unanticipated enemy forces, IEDs hitting convoys, and many others. This desire to inject unexpected events into a scenario during runtime forced us to design a new method to create simulation scenarios. In the past, these scenario events were rigidly scripted. Once the scenario started, the test operator had no way to control or alter any of the events.

In creating scenarios for the Spiral 3 simulation, rather than following a scripted list of events, we created a flexible and dynamic timeline of events. The test operator could indicate what events would happen when at the start of the mission. At any time, the test operator could inject system failures, weather conditions, detonations, or entity behavior events by adding them to a running timeline. A log of these events was then recorded so that our approach to simulation design could be both flexible and repeatable for the purposes of data collection.

The events that were sent out from the Scenario Generation tool were sent directly to MetaVR or used by the Zippo tool. The Zippo tool was the "bridge" between our scenario generation tool and FLAMES. Zippo would connect into the FLAMES constructive simulation and command which entities to load based off the messages received from the Scenario Generation tool. The test operator no longer had to adhere to a rigid timeline and the order of the events no longer needed to be carefully constructed because Zippo allowed for the "on-the-fly" scenario construction.

2.1.2 Communications

Voice Net. The UAV crew communicated to other entities via Voice Net. These communications took the form of either mission coordination, mission tasking, or surveillance reports based on UAV imagery. The study employed a commercial Voice-over Internet Protocol (VoIP) communication system, TeamSpeak, to provide the communication capability.

2.2 Data Collection Layout

To provide a more representative environment for multi-UAV operations, participants were isolated from the test administrators, much like they would be in many existing ground control stations (i.e., Predator/Reaper, Hunter, Shadow, etc.). The configuration of participant control stations and test operator/test administrator stations is presented in Figure 4. The separation of the participants from the test administration team afforded the opportunity for the administration team to "role play" many of the entities incorporated into each of the scenarios. Given the dynamic nature of the scenarios and the uncertainty associated with how participants would respond to mission events, it was both impractical and unwise to script all communications between these entities and the MUSCIT participants. For the most part, communications initiated by directing elements (i.e., EAGLE15) or communications that did not include MUSCIT, were scripted and implemented via a scripted playback of recording radio messages. When an active dialog between MUSCIT participants and another party was necessary, members of the test administration team assumed those roles, engaging in real-time radio communications via the Teamspeak VoIP communication system.

To ensure test administration personnel were able to monitor MUSCIT participant activities, dual-monitor workstations were included in each of the test administrator stations that were running the MORAE screen capture software. MORAE provided a real-time video capture of each of the MUSCIT control station screens, highlighting cursor position and mouse selections. The MORAE application also afforded the opportunity for the test administrator(s) to "bookmark" any event or activity during the course of the scenario that could be subsequently used to collate specific operator performance metrics (e.g., target detections, track initiations, vehicle movements, etc.). One issue associated with the MORAE screen recordings was the constraint of a 1Hz update rate for the recording. The selection of a 1 Hz update rate was established as a tradeoff between data collection requirements and control station performance constraints. Since the recording is accomplished on the VSCS machine it was important to ensure that the processing required to support the rate of recording did not adversely impact the performance of the control station. Pre-data collection trials indicated that a 1Hz update rate would not put at risk the operation of VSCS.

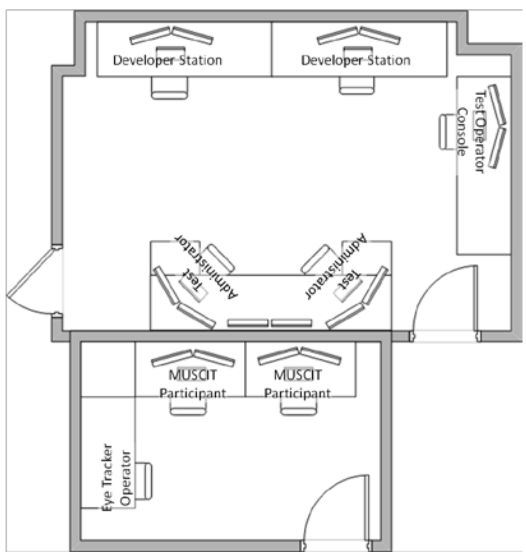


Figure 4. MUSCIT Spiral 3 Data Collection Configuration

2.3 Experimental Design

3.3.1 Participants

For MUSCIT Spiral 3 simulation, eight individuals were recruited to participate in the data collection.

2.3.2 Design

The MUSCIT Spiral 3 simulation investigated operator performance during a typical mission involving a range of RSTA tasks to include point surveillance, route surveillance, area search, and target tracking. This simulation was conducted using a 2 x 2 within-subjects design. Participants performed trials using a 1 or 2 operator VSCS configuration and with two or four UAVs. For the four trials within this experiment, data collection across control station configuration levels was blocked. Operators performed the mission with two and four UAVs at one level of control station configuration before moving on to the other level. The order of presentation of control station configuration blocks was counter balanced. The order of number of UAVs available within each block was also counter balanced. Each trial lasted approximately 45 minutes. Conditions for each of the Spiral 3 simulation trials are presented in Table 1.

Total session time per participant was approximately 8 hours (including 2 hours for familiarization training on the use of controls and displays, completion of post-trial ratings, post-session debriefs and breaks).

Table 1. MUSCIT Spiral 3 Experiment Trials

Trial	Task	Number of UAVs	# of Operators
1	Mission	2	1
2	Mission	4	1
3	Mission	2	2
4	Mission	4	2

Control Station Configuration:

1-Operator Control Station. The study participants performed both pilot and sensor operator activities. For 1-operator control station configuration, the participant marked and reported all surveillance events, responded to and executed any re-tasking requests, and responded to any information request via voice. This condition provided the operator with full functionality of the control station.

2-Operator Control Station. The Dual Operator control station configuration assumed a distribution of work across two operators. As such, the features and capabilities available in both control station were identical. Participants were given the flexibility to assign responsibilities as they deemed appropriate. Participants coordinated during the mission as necessary to effectively perform the assigned tasks in support of mission objectives. Participants needed to coordinate their response to unanticipated events, and manage the allocation of resources to meet evolving demands.

Note: While operators could monitor vehicle state information and sensor imagery from vehicles they did not control, any attempt to direct the vehicle or steer the sensor would result in a message indicating that the vehicle/sensor the operator was attempting to control was not under his control. To attain control, the operator must first request and then be granted control of the vehicle, the sensor, or both.

2.3.3 Experimental Trials

Each participant completed a total of 4 trials, and while each scenario was different, the primary tasks included in each trial were fundamentally the same. The primary difference across scenarios was the sequencing and locations at which various events within the scenario occurred. This variability in the scenario design was included to ensure that participants were not able to completely anticipate the onset of an event prior to its presentation. The following sections provide a detailed description of the various scenario events that were included in each scenario, the relevant cuing mechanisms, radio communications and red and blue ground force behaviors which constituted each of the scenario trials. We felt it was also important to set a context to the execution of the present scenario as a basis for operator decision making. During trial debriefs following previous spiral sessions it became evident that operator decision making behavior was fundamentally dependent on their interpretation of the operational context, goals, and objectives. In lieu of such a context, a participant might feel free to assume or create a context upon which to base high order decisions such as resource allocation and task prioritization. Therefore, we felt it essential that we, as experimenters, set the context to the extent possible, at least it terms of outlining the order of battle and the overall commander's intent for this mission.

The intelligence briefing for Operation LOOKOUT presented to each participant provided the following background information:

> *Recent intelligence indicates that a meeting between two High Value Targets is to be conducted within the next several hours. Willie Britches, a suspected IED manufacturer and know member of the Dunbar Underboss Mob Brigade (DUMB), and Ali Rod, also a reputed member of DUMB, are reportedly scheduled to meet at a Chemical Plant located on the east side of their local village. Both parties are considered by coalition leadership as highly dangerous. Britches' DUMB recently claimed responsibility for the May 25th bombing of a government building that resulted in the deaths of 14 multi-national tourists. Rod is responsible for IED proliferation throughout the town of Gridironstan. The meeting at the Chemical Plant to take possession of a suspected WMD represents an escalation in the level of violence they are planning within the region against local and foreign forces.*
>
> *Both Britches and Rod have been under constant surveillance at their respective compounds by Surveillance-Reconnaissance Teams (SRT) for the past several days. Britches (HVT1) is currently located at Objective Steelers and Rod (HVT2) is currently located at Objective Cowboys. It is believed that both HVTs will be leaving their respective compounds within the next hour, enroute to their meeting at the Chemical Plant (Objective Giants). MUSCIT vehicles are to be assigned to provide support. Of primary importance is that upon confirmation of departure from their respective compounds by the SRTs on the ground, MUSCIT assets must maintain positive contact on HVT and confirm arrival at Objective Giants. Upon HVT arrivals MUSCIT assets will continue to support overwatch of Objective Giant providing situation updates as appropriate and provide convoy escort support to the assault team as they move from FOB Freedom to the preplanned blocking positions around Objective Giants. MUSCIT would also provide tracking support throughout the assault, tracking any personnel attempting escape from the compound until the WMD and the HVTs had been positively secured.*

A Small Unmanned Aerial System (SUAS) will be assigned to provide available overwatch of the area of operations, providing the JTAC assigned to the assault team real-time visual imagery of HVTs, their compounds, and the assault location (Objective Giants)

The Request for support as presented to the participants during the mission brief is as follows:

> **REQUEST MQ-1 (SUAS CAPABLE)** CONDUCT OVERWATCH ON CAOC APPROVED TGTS. SONIC21 WILL TRANSFER CHAIN OF CUSTODY OF HVT1 TO MUSCIT21. SONIC22 WILL TRANSFER CHAIN OF CUSTODY TO MUSCIT 22 WITH APPROVAL THROUGH LOAF 44. ONCE EYES ON LOAF44 WILL LOITER OBJ GIANTS TO ANTICIPATE HVT1/2 ARRIVAL AT GIANTS. SONIC21 REMAINS ON OBJ STEELERS. SONIC 22 REMAINS ON OBJ COWBOYS. SONIC23 IVO OBJ GIANTS. HVTS ARE EXPECTED TO RENDEZVOUS AT GIANTS TO COLLECT SUSPECTED WMD FOR FURTHER PROLIFERATION. CHAOS43 WILL PROVIDE ON CALL CAS/OVERWATCH AS EAGLE ELEMENTS DEPART FOB FREEDOM ENROUTE TO OBJ GIANTS. EXPECT VDO/CORDON OF OBJ GIANT. ONCE HVT1/2 DETAINED/WMD SECURED CHAOS43 WILL PROVIDE ARMED RECCE/CONVOY ESCORT TO FOB FREEDOM.

A listing of all the BLUE players included in the scenario is presented in Table 2 and a map of the Area of Operations, including the ingress and egress routes of the assault team from FOB Freedom is presented in Figure 5.

Table 2. Operation LOOKOUT Blue Forces

NAME	LOCATION	REMARKS
/SONIC 21/	/OBJ STEELERS/	/SR TM 1//
/SONIC 22/	/OBJ COWBOYS/	/SR TM 2//
/SONIC 23/	/OBJ GIANTS/	/SR TM 3//
/EAGLE 15/	/FOB FREEDOM/	/JTAC/ASSAULT FORCE//
/FALCON25/	/FOB FREEDOM/	/QRF//

AIRCRAFT INFORMATION

TYPE//	//CALLSIGN//	//ARMAMENT//	//REQUEST//
Direct fire sup	//CHAOS 43//	//105,40, 25,	//ON CALL CAS/ ISO GAF//
1XMQ-1//	//LOAF 44//	//SPECTER FINDER/MUSCIT 21/22//	// ISO GAF//
2XF-16CJ//	//VIPER 41/42//	//HARM/AAMRAM/AIM-9//	//SEAD REQUESTS//
1XAWACS//	//SHOGUN//	//NA//	//COMMAND AND CONTROL//

Figure 5. Operation LOOKOUT Area of Operations

In creating the individual scenarios, the MUSCIT team designed a series of mission events. Each event was designed to exercise a specific feature or capability within the control station and create specific demands on operators to exercise these capabilities. The blending and sequencing of these tasks into an integrated scenario provided an opportunity to observe the changes in adaptive strategies adopted by operators as 1) the number of vehicles available to support this tasking was varied and 2) how crews would coordinate the distribution and negotiation of tasking as the demands on available resources were increased.

Objective Overwatch. As per the mission brief, each trial began with two of the MUSCIT vehicles positioned in a loiter over Objective Steelers (current location of HVT1) and Objective Cowboys (current location of HVT2). The primary purpose of positioning these vehicles at these locations was to ensure the sensors were in a position to assume custody (i.e., visual contract) of the HVTs as they departed their respective compounds enroute to the chemical plant (Objective Giants). While providing overwatch, a secondary objective of operators during point surveillance was to identify and describe "pattern of life" behaviors. While the term *pattern of life* is broadly defined from an operational perspective, its meaning in the current mission context required operators to report the presence of any armed individuals in and around the compound and indicate which buildings these individuals were entering and exiting. As mentioned earlier, MUSCIT vehicles have been assigned to these locations in anticipation of the need to establish and maintain chain of custody of the HVTs as they move from their respective compounds to the chemical plant (Objective Giants) for their meeting. The desire to collect pattern of life data for each objective is motivated by the possibility that at some point, it may become necessary as part of the current mission to execute an assault on one or both of these compounds. In that case, information regarding the level of potential resistance and the likely concentration of that resistance would be useful during assault planning and execution.

As part of the mission brief, operators were provided as series of photo intelligence images of the objective areas (Figure 6)

(a) (b) (c)

Figure 6. Annotated photo imagery of (a) Objective Steelers, (b) Objective Cowboys and (c) Objective Giants

As mentioned in the mission brief, SRTs are collocated at each of the objective points (SONIC21 at Steelers, SONIC22 at Cowboys and SONIC23 at Giants) observing these compounds for several hours. Within the context of the current mission, the SRTs are responsible for providing positive identification of the HVTs as they depart the compound area. Upon confirmation of the HVT's eminent departure, the SRT will provide a contact report to the JTAC attached to the assault team (EAGLE15). EAGLE15 will then radio MUSCIT to confirm visual contact of HVT by the MUSCIT vehicle, thus establishing chain of custody.

HVT Dynamic Tracking. At predetermined times within each scenario the SRT would contact EAGLE15 and report the departure of the HVT from a specific building within the compound. EAGLE15 would then report the departure and building to MUSCIT, cuing MUSCIT to establish visual contact of the HVT. An example of the exchange follows:

SONIC21: EAGLE15 – SONIC21 reports HVT1 is departing building 9

EAGLE15: 15 copies … Break Break … MUSCIT – EAGLE15, report contract HVT departing building 9

MUSCIT: MUSCIT is contact on HVT1 departing building 9

EAGLE15: 15 copies, maintain contact

MUSCIT: MUSCIT Wilco

The pervious exchange reflects SONIC's initial positive identification of the HVT and provides a location (exiting building 9) to cue MUSCIT to the appropriate individual. EAGLE instructs MUSCIT to confirm contact on HVT. Upon MUSCIT's report of contact, EAGLE acknowledges and instructs MUSCIT to maintain visual contact on HVT. MUSCIT acknowledges request and indicates that he will comply.

Upon departure of the building the HVT would proceed to a structure outside the compound perimeter, mount a motorcycle and begin the route toward Objective GIANTS. Again, SONIC would report the departure of the HVT from the compound area on a motorcycle, indicate the direction of departure, and the road on which the HVT was traveling. MUSCIT would confirm contact and indicate his intention to maintain visual contact on target.

The participant was given the option of deploying an automatic target tracking capability. The tracker was a feature included in a third-party application, Real Time Visual System (RTVS) that had been integrated in the VSCS. To initiate the tracker, it was necessary that the operator activate the RTVS, which placed the video image into its mosaicing mode. Once in mosaic mode, the operator could initiate the auto tracker by placing the cursor over the object to be tracked (i.e. HVT) and simultaneously pressed the Shift Key and the left mouse button. A red box was presented within the sensor image indicating the object the auto-tracker was currently tracking (Figure 7). The RTVS would attempt to steer the sensor such that the tracked object remained within the center of the sensor's field of view. An indication that the quality of the tracking solution was degrading was noted when the red box drifted from the object being tracked. To re-establish track the operator would re-engage the tracker by placing the cursor over the object to be tracked and again simultaneously press Shift-left mouse button. If the vehicle was placed in Sensor Slaved mode and the RTVS auto-tracker was engaged, it was possible for the operator to remain "hands off" while the system continued to track the HVT and continue to update the vehicle position to maintain the HVT within the sensor's field of view.

(a) *(b)*

Figure 7. RTVS automatic target tracker (a) indication that target tracker is actively tracking HVT, HVT is centered within red box and red box centered within sensor field of view, (b) target tracker may be losing positive track on HVT as HVT is outside red box. Operator may need to reacquire target by selecting the HVT object to realign tracking algorithm.

At a predetermined time following the departure of the first HVT from his compound, the second HVT would depart the other compound. Cueing of the HVT departure was the same for both HVTs (i.e., SONIC reports). The timing of the departures was scheduled such that operators were required to track a single HVT for at least 3 min prior to the second HVT's departure. This allowed analysts to collect performance data during periods of single and dual target tracking.

Improvised Explosive Device (IED) Event. During the course of each trial operators were presented with an IED event. Operators were initially cued to the event via a radio call from CHAOS43 to EAGLE15 reporting that a friendly convoy was taking fire in the center of town. EAGLE15 immediately requested and received location coordinates for the besieged convoy. Upon receipt of these coordinates, EAGLE15 instructed MUSCIT to immediately move one vehicle to the IED location and provided the coordinates. MUSCIT was also instructed to contact the Quick Reaction Force (QRF) that was preparing their departure from FOB Freedom enroute to support friendly forces at the point of the IED attack.

When contacted by MUSCIT, the QRF unit commander instructed MUSCIT to provide situation report of the IED location and move a second vehicle overhead their location to provide convoy escort as they moved from FOB Freedom to the location of the IED attack. As the QRF moved from FOB Freedom to the IED location, multiple areas of interest that posed potential threats to the QRF were present. (e.g., armed pickup trucks (technicals), armed roadblocks, mobs of civilian personnel, etc.). It was the responsibility of the MUSCIT operator to establish contact with these areas, assess the level of potential threat, and inform the QRF unit commander of the potential threat. At that time the unit commander would determine whether a change in course was appropriate. While the QRF was enroute, red forces in armed technicals arrived at the IED location creating a more immediate threat to friendly ground forces. As part of their ongoing situation report the MUSCIT crew would provide updates on the evolving IED event, reporting the arrival of the hostile forces. As the QRF approached, they engaged hostile forces and destroyed the red technicals. The IED event ended when the QRF radioed that the location was secure and that MUSCIT vehicles were released to contact EAGLE15 for further tasking.

Search for Hostile Activity. During each trial MUSCIT was also instructed to move one of the vehicles to a specified location and provide a situation report on what was believed to be potentially hostile activity in and around the area. The instruction came in the form of a radio transmission from EAGLE15 requesting MUSCIT move a vehicle to a predefined MacroGrid location. The MacroGrid is a grid overlay of the area of operations used to help coordinate the location of sectors within the operational area. Specific grid location, designated by two letters and two numbers, specified a particular grid location corresponding to a location on the ground. The MacroGrid used by participants in the current simulation is presented in Figure 8. The request from EAGLE15 to MUSCIT was as follows:

EAGLE15: MUSCIT – EAGLE15 we have reports of potential hostile activity in the area of MacroGrid GOLF GOLF One One. Move MUSCIT vehicle to that location and provide sit rep

MUSCIT: Wilco Suspicious activity in vicinity of GOLF GOLF One One. Moving MUSCIT21 to that location, will report when overhead.

EAGLE15: 15 copies

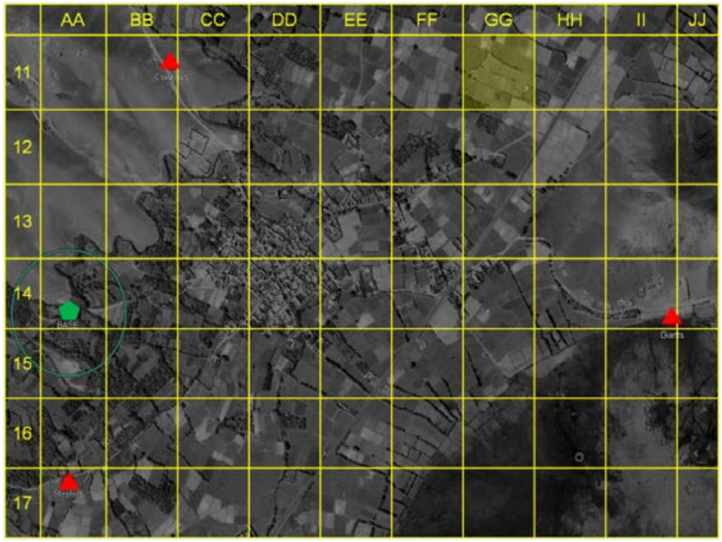


Figure 8. MacroGrid Overlay of Area of Operations for Operation OVERLOOK. (Note: The shaded area would indicate the approximate location of the reported suspicious activity referred to in the previous radio message)

Upon receipt of the request the operator would reference the MacroGrid and identify the appropriate grid location (in this case Golf Golf One One) and correlate the MacroGrid location to a specific area within the TSD. Moving a vehicle and sensor footprint to that location the operator would begin a wide area search of the area, looking for any objects meeting the description of the reported activity. Upon location of the activity the operator provided an initial situation report. At that time the operator may request additional information regarding the suspicious activity. In response to such requests, EAGLE15 would indicate that ground forces had reported that they had seen what they believed to be a large collection of technicals in a compound as well as what appeared to be potential IED activity. The operator would then indicate whether he could confirm either the presence of armed technicals or any potential IED activity. Upon completing this report EAGLE15 would either retask MUSCIT or have the vehicle resume previous tasking. If the suspicious activity was not located prior to a new tasking being received from EAGLE15, it was assumed that the new tasking was given precedence and the search was discontinued.

Assault on GIANTS. In preparation for the assault on the GIANTS compound, it was necessary for the assault force to travel from FOB Freedom to their respective blocking position located at tactical positions surrounding the chemical plant. Prior to the assault team's departure, EAGLE15 would contact MUSCIT requesting that one of the MUSCIT vehicles be moved to a position overhead FOB Freedom to be available for convoy escort. Upon the assault team's departure from FOB Freedom EAGLE15 would again contact MUSCIT to confirm visual contact with the convoy and to establish convoy look ahead. Specifically, MUSCIT was responsible for identifying any potential threats to the safe passage of the convoy as they moved from Freedom to the blocking positions.

Once blocking positions were established, EAGLE15 would direct CHAOS43 (Direct fire support) to move into position to initiate the assault on GIANTS. On EAGLE's command, CHAOS would release rounds to take out the two guard towers located within the GIANTS compound. MUSCIT's primary responsibility during the assault was to provide visual oversight as the assault team approached and entered the compound and track any ground personnel attempting to escape (squirters). Of particular interest was tracking of the HVTs; it was assumed that HVTs attempting escape would travel via the motorcycles they used enroute to GIANTS. As personnel departed the compound MUSCIT operators were to maintain track, giving priority to fast moving personnel, and report their approach to any of the established blocking positions. If squirters moved away from blocking positions, MUSCIT operators were to maintain contact until they stopped movement, at which time the operators were to maintain visual contact and provide EAGLE15 with the coordinates of the stationary squirter to direct ground forces to intercept and take into custody. MUSCIT was to maintain contact until ground forces arrived and confirmed personnel were secured or the trial was terminated. The various scenario events, dependent measures, descriptions are displayed in Table 3.

A total of four separate scenarios were generated combining the variations of the above mission events in various sequences. Four scenarios ensured that no participant would experience the identical mission events or the same sequence of events more than once during data collection trials. Detailed descriptions of each of the scenarios are presented in Appendix D. of this report.

2.3.4 Dependent Variables

2.3.4.1 Objective Data Collection

Table 3. Performance measures collected during MUSCIT Spiral 3 simulation

Scenario Event	Dependent Measure	Operational Definition
Objective Overwatch	– Detection Rate	Measured as the percentage of armed personnel entering and exiting buildings within the Steelers and Cowboys compounds that were positively reported by MUSCIT operators
HVT Dynamic Tracking	– Percentage of time HVT positively tracked	Measured in terms of the percentage of time from when the HVT departed the compound to entry into the chemical plant that the HVT was within the FOV of the MUSCIT sensor tracking the target
	– Single track performance	Measured the percentage of time HVT was within the sensor field of view when a single HVT was being tracked
	– Dual track performance	Measured the percentage of time both HVTs were within the sensor fields of view when a two HVTs were being tracked simultaneously
IED Event	– Time to IED event within FOV of MUSCIT sensor	Measured in terms of the time elapsed between when the IED event occurred and when the convoy entities engaged by the IED were within the FOV of the MUSCIT sensor
	– Time to provide initial situation report of IED event	Measure as the time elapsed between when the IED event occurred and when the test administrator noted the first verbal report of visual contact with IED event
Forced Distracter	– Time to locate activity	Measured as time from when the radio call requesting MUSCIT investigate activity to the time the specific area is within the MUSCIT sensor field of view
	– Time to report activity	Measured as the time from when the radio call requesting MUSCIT support to investigate suspicious activity to the time MUSCIT operator provides a situation report

Compound Assault	– Percentage of time squirters are positively tracked	Measured as the percentage of time personnel squirting from the compound were in the sensor field of view.

2.3.4.2 Subjective Data Collection

During the course of the experimental session a series of subjective assessment techniques were administered. After each trial, participants were asked to provide a workload assessment based on the NASA TLX rating scale (Hart & Staveland, 1988), a situational awareness rating based on a modified China Lake Rating Scale, and a series of ratings related to the unique characteristics of the trial and control configuration. Following the completion of all experimental trials, the participant was asked to complete a short end of exercise (ENDEX) satisfaction survey to provide comments and opinions regarding the operator interface. Following the completion of all the experimental trials, a final debriefing was conducted which allowed the participant to comment on various aspects of the experimental trials, the features and capabilities of the control station, and opportunities for enhancing the control station design, the simulation environment, and employment concepts and mission scenarios.

2.4 Procedure

Up to 8 hours per participant was required to process through the entire training and test sequence, including scheduled breaks. Procedures were standardized such that each participant received the same information and opportunity for familiarization with the simulation throughout the briefing and training phases of the experiment. The sequence of events was the same for all participants, except that the order of the treatment conditions was determined by the experimental design.

Participant Screening/Consent. Participants reviewed material summarizing the nature of their involvement. Also administered was a brief background questionnaire, which included questions on operational background and sensor operator/image analyst experience.

Mission Briefing. In addition to a mission brief that was made available to participants prior to arrival, participants received an intelligence and mission brief outlining the specific operational situation and mission objectives. The mission scenario was described in detail, including a review of relevant concepts of operation and rules of engagement. Call signs of those with whom the UAV crew would be communicating were identified, and the communication plan reviewed.

Upon arrival to the lab, each participant received refresher training in all procedures to be employed during the entire experiment. First, participants were given an introductory briefing on the VSCS, to include a description of its features, displays, and control mechanism. The voice commands were also emphasized, as it was determined that participants did not receive sufficient instruction or opportunity with the voice system. Training continued until the test director judged the participant competent on all aspects of task performance (e.g., mission management, sensor management, and communications).

Experimental Trials. Each run lasted approximately 45 minutes. Participants wore headsets for all experimental trials. Task order and time into the trial was randomized within the constraints listed in Table 1.

Debriefing Questionnaires. Subjective data was collected by having participants complete a series of short rating scales after each trial (NASA TLX, modified China Lake Rating Scale). Following the completion of all experimental trials, a final debrief was conducted that included questions asking participants to comment on various aspects of the experimental trials; the features, capabilities, and potential enhancements of VSCS; the simulation environment; and alternative mission scenarios. If time permitted, discussion extended to solicit feedback on current systems and envisioned challenges associated with multi-UAV control.

3.0 DATA ANALYSIS & RESULTS

3.1 Inferential Analyses

As part of the MUSCIT Spiral 3 simulation, various measures of statistical inference investigated the effect of two treatment variables: Number of UAVs (2 and 4) and Number of Operators (1 and 2). Many dependent measures discussed in a previous section and abbreviated here as HVT 1, HVT 2, Forced Dis, IED (Sec To in FOV, and Sec to Report), and Squirter, were included in the analyses. Information on other dependent variables was collected, but not included in this analysis. Data for these variables can be found in Appendix C. For these measures, experimenters used a 2 x 2 repeated-measures Multivariate Analysis of Variance (MANOVA). Results of this analysis yielded no significant main effects for the treatment conditions nor a significant interaction between conditions. Summary statistics for the dependent variables included in the analysis are presented in Table 4 and Figure 9.

Table 4. Descriptive statistics for dependent measure collected during MUSCIT Spiral 3 Sim

	HVT 1 % Coverage	HVT 2 % Coverage	Forced Dis Sec to Report	IED Sec To in FOV	IED Sec To Report	Squirters % Coverage
1-Op 2-Air	87%	91%	162.00	46.57	117.29	62%
1-Op 4-Air	93%	96%	226.63	62.88	158.38	75%
2-Op 2-Air	99%	99%	113.50	10.75	104.50	60%
2-Op 4-Air	82%	84%	204.25	-6.25	24.25	74%

Plots of the data included in the analysis are presented in Figure 9 (a) – (e). As Figure 9(a) shows, there is little difference in the HVT coverage across conditions, with the 2-Op 2-Air condition showing the best performance, and the 2-Op 4-Air condition showing the worst performance. For the Forced Distracter task, the number of aircraft seems to affect performance. It appears that the more aircraft the operators had to deal with, the longer it took them to complete this task. The operators were also able to complete this task slightly faster in the 2 operator condition. These trends can be seen in Figure 9(b). There are two scores reported for the IED task, Time from the IED explosion to when the operators put the IED location into the field of view (FOV) and time from the explosion to when the operators reported on the scene. This data is displayed in Figures 9 (c) and (d). In each case, the operators were able to perform faster in the 2 operator, 4 Aircraft condition. In the case of the IED Call to in FOV (Figure 9 (c)), operators were actually able to put the sensor on the convoy before the attack. This explains the negative time. And finally for the task of tracking squirters it seems that the number of aircraft accounted for the difference in coverage. The two 4 aircraft conditions performed similarly, and better than the two 2 aircraft conditions. This trend is displayed in Figure 9 (e).

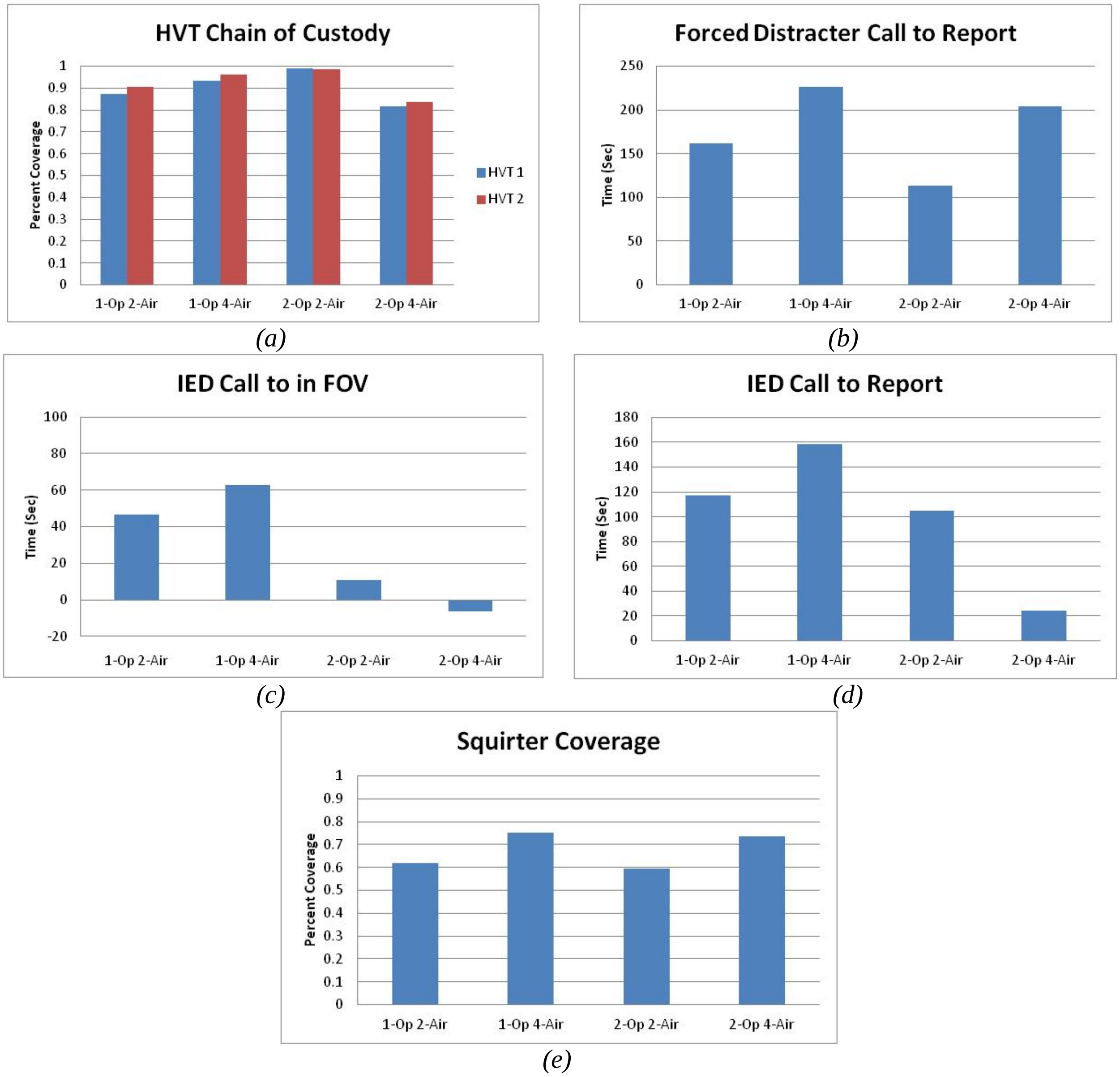
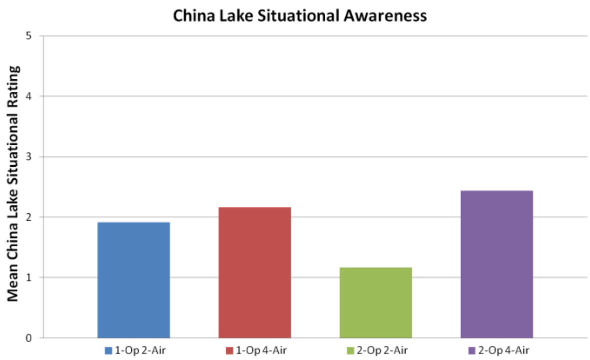


Figure 9 Summary plots for (a) Coverage of HVTs 1 and 2, (b) Time to Report on Forced Distractor Task, (c) Time from IED Explosion to when it was in FOV, (d) Time from IED Explosion to when it was reported on, and (e) Coverage of Squirters

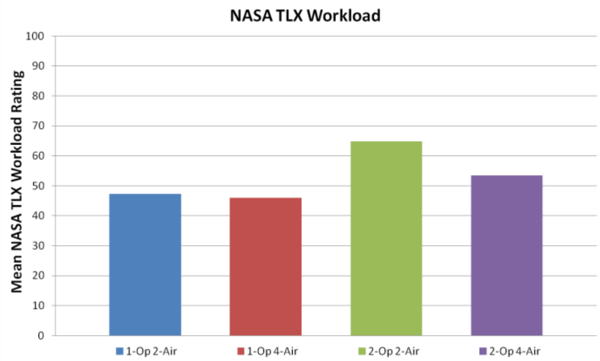
Operators also provided subjective feedback at the end of each trial. This feedback summarized in Table 5 and Figure 10. As mentioned previously, operators were asked to provide a number on the China Lake scale to correspond with his or her perceived situation awareness (SA). It is important to note that for the China Lake scale, a lower number indicates better SA. Figure 10(a) shows mean China Lake scores for the different conditions. The NASA TLX was collected as a measure of reported workload. Figure 10 (b) shows the 2-Op 2-Air condition having the highest reported workload. Experimenters also administered a post trial survey that focused on the feasibility, reasonability, and timeliness of the mission considering this control station, as well as scoring the usefulness of a number of features of the control station. As Figure 10 (c) shows, operators rated the mission to be at least moderately feasibly, reasonable, and timely, with this control station. The figure also shows that all 4 features in question were rated to be useful, with the Sensor guidance, and POI tracking rated to be the most useful.

Table 5. Descriptive statistics for Subjective Data collected during MUSCIT Spiral 3 Sim

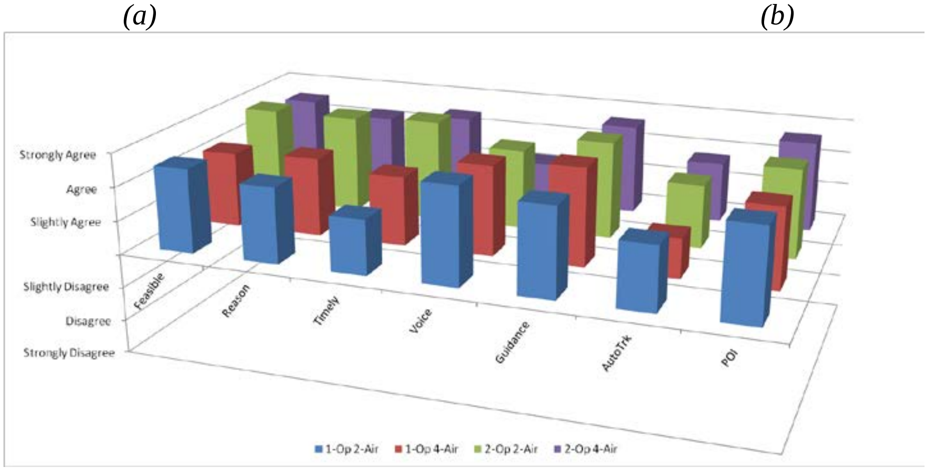
	Feasible	Reason	Timely	Voice	Guidance	AutoTrk	POI	RTVS	TLX	CLSA
1-Op 2-Air	2.500	2.250	1.625	2.875	2.625	1.875	2.714	-0.857	47.259	1.917
1-Op 4-Air	2.222	2.333	2.056	2.667	2.889	1.167	2.375	-0.143	45.926	2.167
2-Op 2-Air	2.875	2.875	3.000	2.375	2.875	1.875	2.625	0.167	64.852	1.167
2-Op 4-Air	2.556	2.222	2.444	1.222	2.667	1.778	2.667	-0.714	53.481	2.438



(a)



(b)



(c)

Figure 10. Participant subjective ratings for (a) China Lake Situational Awareness, (b) NASA TLX Workload Rating, and Summary of Participant response to post trial

4.0 SPIRAL 3 FLIGHT TEST

Although the fundamental testing occurred within a rigid lab environment, it was decided to compliment the lab simulation with a subset of capabilities as a flight test. The flight test was conducted with surrogate UAVs to exercise the mission functionality and tasks. Activities consisted of data collection while one or two operators managed 2 small UAVs during representative RSTA scenarios.

Our team of 18 personnel, military, civilian, and contractors, travelled to Camp Atterbury, Indiana for two weeks in August 2011 to conduct the flight test.

The Flight Test Plan and testing scenarios were vetted and submitted for all required safety and technical review boards through AFRL, 711th HPW. In addition, Test Cards were submitted for approval to the appropriate Test Approval Authority. Test Hazard Analysis forms were also completed and approved before testing began.

4.1 Flight Test Objectives

The objective of this study was to investigate the demands associated with the use of multiple unmanned aerial vehicles (UAV) within the context of representative RSTA and counter-proliferation set of scenarios and to establish a performance benchmark for the control of multiple UAVs using advanced control station designs within a flight test environment. Supplemental study objectives included:

- Investigate the value of control station interface enhancements to operator performance during RSTA tasks.
- Assess the ability of operators to use the control station in response to unanticipated and unexpected events.
- Evaluate the ability of the control station to support the development of adaptive strategies in response to increasing levels of mission complexity and uncertainty.
- Investigate the means and mechanisms of coordination and collaboration as the number of operators increase from a single operator to dual operators.
- Assess the ability of the control station to support cooperative strategies in response to dynamic events within the mission scenario.
- Increase our understanding of operational missions, operational task demands and constraints, and coordination requirements both inside and outside of immediate UAV support teams.
- Identify opportunities via automation, visualizations, control mechanization, concepts of operations, etc. that would enhance the feasibility of multi-UAV control.
- Assess the quality and fidelity capabilities of our flight test environment and identify specific feature and capability candidates for future incorporation in subsequent iterations of the control station design.

4.2 Method

4.2.1 Apparatus

The following section describes the flight test facilities as well as how the software and hardware components functioned in support of the Spiral 3 flight test.

4.2.1.1 Flight Test Tools, Equipment, Location

The test was conducted using 2 MLB CC Bat 3 UAVs, as seen in Figure 11. The MLB Bat 3 is a commercial off the shelf small, unmanned aerial vehicle that operates 5 hours autonomously while delivering high quality video imagery. The BAT 3 was launched autonomously using a car-top, bungee-powered catapult and landed autonomously on its wheels.

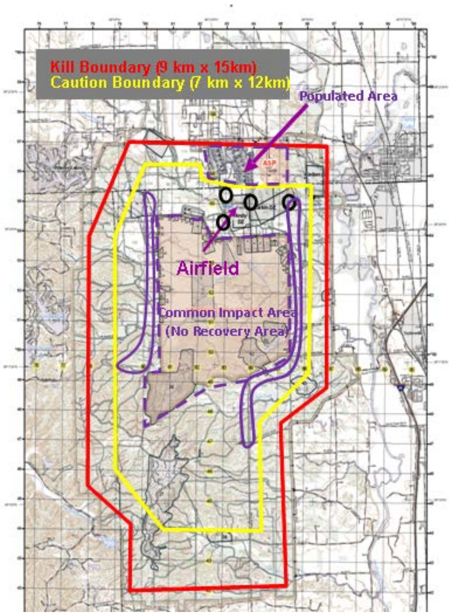
Figure 11. MLB CC BAT 3 UAV

The UAV weighs 31 lbs fueled with payload with a range of 6-10 mile radius. Other specifications of the BAT 3 include:

- Maximum ceiling range of 10,000 ft
- Data Link of 900 MHz C2, 2.4 GHz video
- Launch Platform is a bungee, catapult system
- Operations include PCC Autonomous flight, left and right manual control
- Flight wind limits of 35 knots

The BAT 3 used a TASE gimbaled camera system from Cloud Cap Technology which allowed the operator to manipulate the camera for specific location viewing. The operators were able to deploy, steer, and zoom the gimbaled camera from the ground station.

The flight test was conducted at Camp Atterbury, Indiana in which we utilized a 7km X 12km restricted airspace flight box. The flight test relief map with kill and caution boundaries is show in Figure 12. Our Team was located in two mobile trailers at the south end of the Camp Atterbury runway (as indicated in the satellite view of Camp Atterbury, Figure 12).



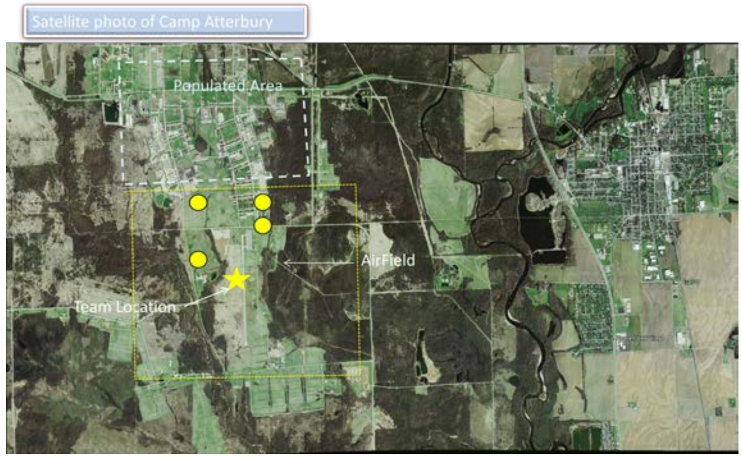


Figure 12. Relief Map and Satellite view of Camp Atterbury

4.2.1.2 MUSCIT Spiral 3 Flight Test Architecture

The Flight Test portion, similar to the laboratory testing, utilized the VSCS as the control station. The VSCS station simultaneously presented planned and real-time routing flight information for the BAT 3s while they were performing their RSTA tasks. The VSCS displayed planned routes, real-time positional information on a map, and simultaneous video from the UAVs.

For the MUSCIT Spiral 3 flight test, the workstation configuration consisted of two side by side 1920x1200 pixel LCD monitors, with four main parts; vehicle status, tactical situation display (TSD), vehicle and payload management, and sensor exploitation. The vehicle status area allowed the operator to maintain situation awareness of the UAV(s). The TSD allowed the operator to maintain battlespace awareness. The vehicle payload and sensor management area allowed the operator to control the aircraft and payloads. Finally, the sensor exploitation area allowed the operator to view and interpret the sensor feeds coming from the UAVs. Figure 13 shows the flight test ground station architecture.

A key enabler for allowing VSCS to be easily connected to the BAT 3 vehicles is the Vigilant Spirit 4586 Common Message Framework (CMF) Toolkit. The VS 4586 CMF Toolkit is an implementation of the NATO STANAG 4586 data link interface standard. It provided a standard set of messages for communicating between the control stations and the BAT 3. This concept was successfully demonstrated during several flight tests (e.g, MUSCIT Spiral 1, ICE-T).

The flight test setup allowed for redundant data recording. Each Piccolo Command Center (PCC) ground station recorded the telemetry data in the Piccolo format. Additionally, all of the CMF data sent to and from the Vigilant Spirit Control Station was recorded.

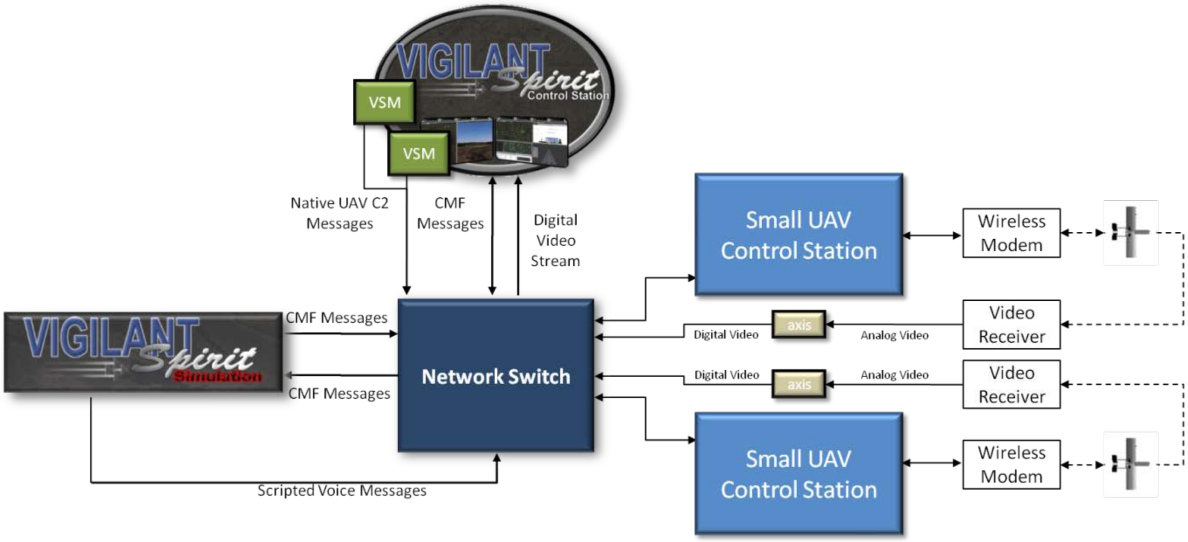


Figure 13. Illustrated architecture for the flight test ground stations

4.2.1.2.1 Vigilant Spirit Control Station

4.2.1.2.2 Vigilant Spirit Simulation

During MUSCIT Spiral 3 flight test the Vigilant Spirit Simulation (VSSim) component provided the means by which the test administrator was able to manage and control flight test data collection trials.

4.2.1.2.3 Small UAV Control Station

Cloud Cap's Piccolo Command Center (PCC) and Portable Ground Station (PGS) served as the small UAV Control System for this flight test. The PCC provided the interface for safety pilots to send command and control inputs to and receive telemetry data from the aircraft through the PGS, via a 900 MHz antenna. The aircraft was also sending back video that was collected by a separate 2.4 GHz patch antenna, piped into an AXIS video encoder and distributed over the network. This video was available to anyone on the network.

4.2.2 Communications

Voice Net. The UAV crew communicated to other entities via Voice Net. These communications took the form of either mission coordination, mission tasking, or surveillance reports based on UAV imagery. The study employed a commercial Voice-over Internet Protocol (VoIP) communication system, TeamSpeak, to provide the communication capability. In addition to the TeamSpeak VoIP communication net the flight test team also used hand held 2-way radios. These radios were used primarily to coordinate between the PCC operators, the test administrator, the MUSCIT operators, the Safety Officer, the Safety Pilot, and the scenario actors to coordinate the initiation and termination of each trial.

4.2.3 Data Collection Layout

To provide a more representative environment for multi-UAV operations, participants were isolated from the test administrators, much like they were during the Spiral 3 simulation. Data collection for the participants was conducted in a trailer provided by Camp Atterbury for UAV flight test, flight demonstration and training purposes. The configuration of participant control stations and test operator/test administrator stations is presented in Figure 14. The separation of the participants from the test administration team afforded the opportunity for the administrator to "role play" many of the entities incorporated into each of the scenarios.

Again, to ensure that the test administrator was able to monitor MUSCIT participant activities, dual monitor workstations were included at the test administrator workstation running the MORAE screen capture software. As during simulation, the MORAE application provided a real-time video capture of the MUSCIT control stations, highlighting cursor position and mouse selections. Due to space constraints in the shelter being used only one MORAE system was used and was attached to the number 1 control station. As a result, only screen captures were available from one of the operator control stations. Trials were conducted such that the number 1 control station was used for both single and dual operator trials. Repeater displays of the MUSCIT control were presented in a common area in the center of the shelter to allow visitors and other interested parties to observe operations without disrupting the flow of activity of the MUSCIT participants.

Figure 14. MUSCIT Spiral 3 Flight Test Data Collection Configuration

4.2.4 Flight Test Design

4.2.4.1 Participants

To the extent possible the MUSCIT team wanted to include those operators that had participated in the MUSCIT Spiral 3 simulation. Due to operational constraints, only 2 sensor operators were able to participate in the flight test effort. To supplement these participants, we also recruited individuals from within the AFRL community who either had piloting experience and/or were actively engaged in UAV and/or UAV control station development research. These individual were given the same opportunities for familiarization training afforded their counterparts prior to their participation in the flight test data trials. In all, a total of six individuals were included as participants in the MUSCIT Spiral 3 flight test effort.

4.2.4.2 Design

The flight test investigated operator performance during a representative mission involving a range of RSTA tasks to include aspects of point surveillance, route surveillance, area search, and target tracking. During flight test trials participants conducted the flight test scenario within the context of a single operator and as a member of a two operator crew. As in the MUSCIT Spiral 3 simulation crews were free to distribute tasking across the crew as they saw fit. Participants were brought to the flight test as two member crews. The order in which conditions (i.e., single operator versus dual operators) were presented to the participants was such that the first participant completed a single operator trial after which the second participant joined the first to complete the two operator trial. Following the two operator trial, the first participant was excused for a post trial debrief and the second participant completed a single operator trial. The experimental matrix for the flight test is in Table 6.Total session time, per participant, was approximately 6 hours (including 2 hours for training on the use of controls and display, completion of post-trial ratings, post-session debriefs, repositioning of air vehicles, and breaks).

Table 6. MUSCIT Spiral 3 Experiment Trials

Trial	Task	# of Operators	# of UAVs
1	Mission	1	2
2	Mission	2	2

4.2.4.2.1 Independent Variables

Control Station Configuration

1-Operator Control Station. Utilizing the 1-Operator control station configuration the participant was responsible for the management and control of all UAVs assigned. The participant was given the flexibility to allocate resources as they deemed appropriate. The participant was responsible for all vehicle and sensor management functions as well as coordination with any and all external entities to include simulated C2 elements, ground forces, etc.

2-Operator Control Station. The 2-Operator control station configuration assumed a distribution of work across two operators. Participants were given the flexibility to assign responsibilities as they deemed appropriate. Participants coordinated during the mission as necessary to effectively perform the assigned tasks in support of mission objectives. Participants needed to coordinate their response to unanticipated events, and managed the allocation of resources to meet evolving demands.

4.2.4.3 Flight Test Trials

For the flight test, each participant completed a total of 2 trials, one as a single operator and the other as a member of a two operator crew. The mission brief presented to participants was essentially the same as the brief presented during the MUSCIT Spiral 3 simulation (3.5.1.1 of this report). The fundamental differences between the flight test scenario and the simulation scenario was the layout of Objectives Steelers, Cowboys, Giants and FOB Freedom. The area of operations for the MUSCIT Spiral 3 flight test is presented in Figure 15. More detailed images of each of the objective locations is presented in Figure 16. The flight test scenarios included all the same players the simulation scenarios did and all the same tasks were incorporated with the exception of the IED Event. While the tasks were designed to be as similar as possible, there were some notable differences between the flight test versions of these tasks relative to their simulation counterparts. These variations are noted in the following sections.

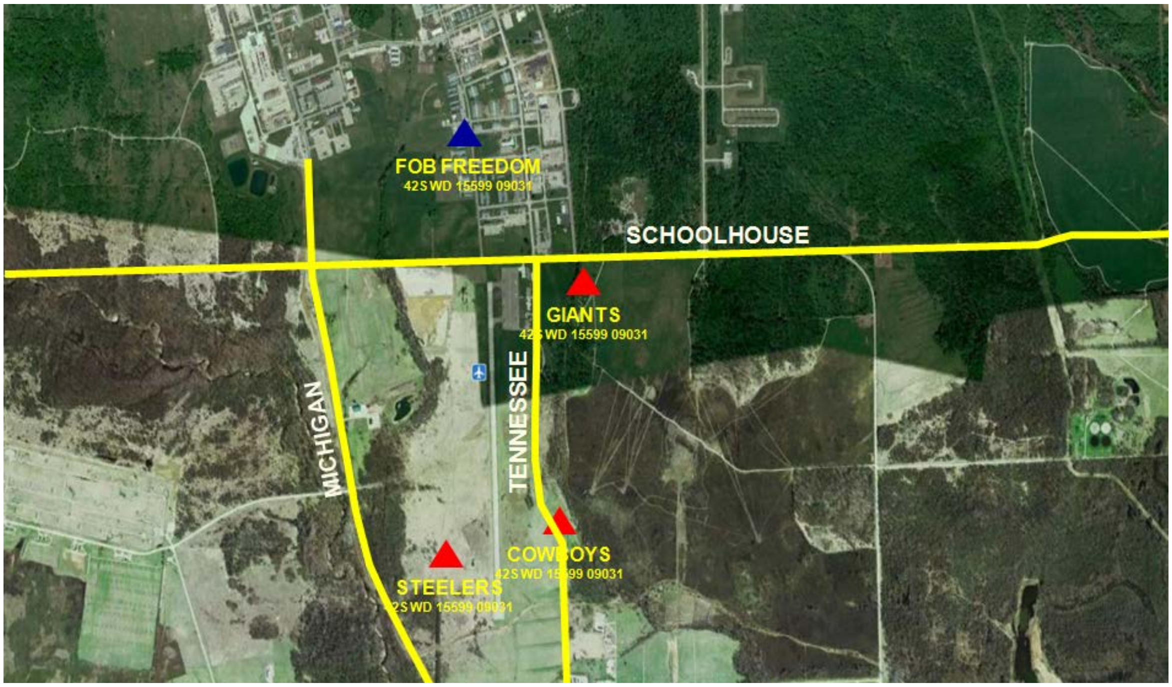
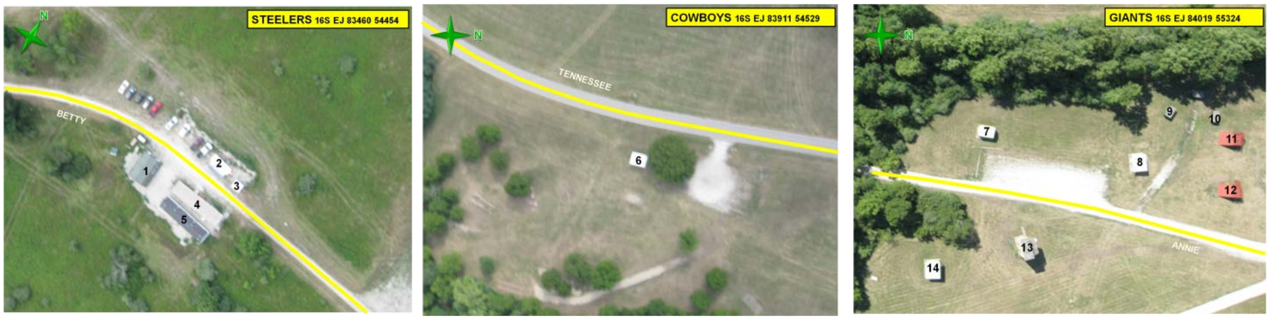


Figure 15. Operation Overlook Area of Operations (Flight Test)

<u>*Objective Overwatch.*</u> As during the Spiral 3 simulation, each trial began with the two MUSCIT vehicles positioned in a loiter over Objective Steelers (current location of HVT1) and Objective Cowboys (current location of HVT2). MUSCIT operators were to monitor activity at each location while waiting for confirmation from the SR teams that the HVT had departed that position. Rather than report the entry and exit of armed personnel in and out of buildings at each objective, participants were instructed to report the presence of any target objects in the area of each objective. Each objective area was populated with several "objects of interest". For the flight test, objects of interest were 4'x3' blue and yellow cloth sheets, each presenting a black symbol (e.g.,○ Δ × □). Prior to each trial the test administrator would indicate to participants the color (blue or yellow) and symbol (○, Δ, ×, or □) that represented a target object for that trial. Upon detection of a target object anywhere around any of the objective areas, participants were to report the presence of the target and create a track designating the position of the target.



(a) (b) (c)

Figure 16. Annotated photo imagery of (a) Objective Steelers, (b) Objective Cowboys and (c) Objective Giants

<u>HVT Dynamic Tracking.</u> The HVT tracking task was functionally equivalent to that performed during simulation trials. At scripted times that depend upon the specific scenario being run, the HVTs would depart from their respective objective areas. Upon receipt of positive identification of the HVT departing the objective area, participants were to maintain positive contact of the HVT as he travelled to Objective GIANTS. For the flight test, actors portraying the HVTs rode bicycles from their original positions at Steelers and Cowboys to the destination at Giants. At some point during their trip to Giants each HVT would stop along their route, dismount their bicycle, and place an object of interest along the road. The participants were to note this event and report whether the object of interest was indeed a target object. Once the HVT arrived at Giants the participants were to continue monitoring HVT activity at Giants and report the presence of any target objects in that area. In addition they were to respond to any additional tasking directed at them by EAGLE15.

<u>Search for Hostile Activity</u>. During simulation trials participants were directed by EAGLE15 to a specific MacroGrid location to investigate what was believed to be suspicious activity within the area. Likewise during flight test, participants were again directed to a specific MacroGrid location. However, in these cases, participants were to report the presence of a target object (i.e., color sheet with specific symbol). At each of the two MacroGrid locations used during the flight test, two *objects of interest* were placed within the area of interest, one of each color. As the participant approached the designated location he would have to first detect the location of the objects of interest. Upon detection, the operator could attempt to identify both the color of the object and the specific symbol present on the object to determine whether it was indeed a target. Upon confirmation of a target object, the participant was to report the presence of the target and create a track to designate its specific location. Upon confirming that no target object was present at the location (i.e., the objects of interest) were not of the proper color and symbol the operator would report such to EAGLE15 who would then direct MUSCIT to resume pervious tasking.

<u>Assault on Giants</u>. Similar to simulation trials, the assault event was initiated with a call from EAGLE15 to come overhead FOB Freedom to provide convoy escort for the assault team enroute to Objective Giants. MUSCIT would establish positive contact on the lead assault vehicle (Note: during flight test trials the assault convoy included a single red pickup truck, the truck was easily identifiable to participants and would depart FOB Freedom at a predefined time

following the call for MUSCIT to come overhead FOB Freedom). The assault convoy would travel from FOB Freedom to Objective Giants at which time the HVT located at Giants would mount their vehicles (i.e., bicycles) and attempt escape from capture by the assault team. While the assault team did not actively pursue the HVTs, MUSCIT was instructed to maintain visual contact on HVTs so assault ground forces could subsequently intercept. MUSCIT would maintain contact on HVTs until such time that either the trial was terminated or the HVT became stationary. At that time, MUSCIT would create a track on the TSD and report the exact coordinates for the location of the HVT for assault force intercept.

4.2.5 Dependent Variables

4.2.5.1 Objective Data Collection

Several performance metrics were captured during each of the simulation trials. Table 7 provides an operational definition of each dependent measure for each of the scenario events included in each trial.

Table 7. Performance measures collected during MUSCIT Spiral 3 Flight Test

Scenario Event	Dependent Measure	Operational Definition
Objective Overwatch	– Detection Rate	Measured as the percentage of Target Objects within the Steelers and Cowboys compounds that were positively reported by MUSCIT operators
HVT Dynamic Tracking	– Percentage of time HVT positively tracked	Measured in terms of the percentage of time from when the HVT departed the compound to entry into the meeting location that the HVT was within the FOV of the MUSCIT sensor tracking the target
	– Single track performance	Measured the percentage of time HVT was within the sensor field of view when a single HVT was being tracked
	– Dual track performance	Measured the percentage of time both HVTs were within the sensor fields of view when a two HVTs were being tracked simultaneously
Forced Distracter	– Time to report activity	Measured as the time from when the radio call requesting MUSCIT support to investigate suspicious activity to the time MUSCIT operator provides a situation report
Compound Assault	– Percentage of time squirters are positively tracked	Measured as the percentage of time personnel squirting from the compound following the initiation of the assault to the End of the scenario

4.2.5.2 Subjective Data Collection

During the course of the flight test trials, a series of subjective assessment techniques were administered. After each trial, participants were asked to provide a workload assessment based on the NASA TLX rating scale (Hart & Staveland, 1988), a situational awareness rating based on a modified China Lake Rating Scale, and a series of ratings related to the unique characteristics of the trial and control configuration. Following the completion of all the flight test trials, a final debriefing was conducted which allowed the participants to comment on various aspects of the flight test trials, the features and capabilities of the control station, and opportunities for enhancing the control station design, the flight environment, and employment concepts and mission scenarios.

4.2.6 Flight Test Operations

4.2.6.1 Flight Coordination/Approach

The Safety Officer and Flight Test Director coordinated the flight tests at Camp Atterbury with Atterbury Airfield Operations. Camp Atterbury UNICOM deconflicted and coordinated all air traffic and ground vehicles on and around the airfield and drop zones. The test Safety Officer notified Camp Atterbury Range Control of the flight test plans and pertinent safety issues. The minimum vehicle altitude was no lower than 500' AGL, except during the takeoff and landing phases of operations.

4.2.6.2 Flight Conditions

The following environmental conditions set the limits for conducting the test. These ensured acceptable equipment performance and appropriate visual contact with the platform. Weather conditions were always confirmed with Camp Atterbury tower and from available ground instrumentation. Weather conditions were evaluated at the beginning of each test day for a go/no-go test decision. With the possibility of rapidly changing weather, the Test Director and Safety Officer monitored conditions throughout the test day. The following wind limits are well within the Bat 3's operational envelope as established by the manufacturer, but there was no need to operate the MUSCIT Bat 3s in more severe conditions.

- Daylight Operations
- Temperature: Greater than 40^{o}F
- Maximum Wind: 30 knots (35 knot maximum gust)
- Precipitation: No more than light rain (only if outdoor equipment is covered/protected)
- Visibility: at least 3 nm
- Ceiling: 500 ft above operating altitude, no lower than 1000 ft AGL

4.2.6.3 Flight Test Procedure

The Spiral 3 flight test occurred over a 7 day period beginning on 7 August, 2011. The first four days of flights served as a "dry-run" of the experimental trials as well as training for the flight test team. While several members of the test team had participated in UAV flight tests, these four days were an opportunity to reorient to the procedures and protocol of the flight test environment and the coordination demands associated with live-fly operations. The first part of the week was also used to train and certify/recertify four members of the MUSCIT team as Piccolo Ground Control Station (PGCS) operators in accordance with AFRL guidelines. Each test team member that was to serve as a PGCS operator was required to complete ground and simulation training as well as perform at least two successful flight sorties. These flights afforded the opportunity to verify communication between the PGCS and the VSCS as well as demonstrate the capabilities of the sensor relative to the planned flight test tasks.

Following the required flight to upgrade and certify/recertify the cadre of PGCS operators, the test team began rehearsals of the scenarios that were to be utilized during data collection trials. This included the determination of target locations and travel routes to be used by "actors" within the mission scenarios. Force distractor areas were also located for inclusion in testing.

When participants arrived to the flight test area they were given a brief tour of the facilities and were able to watch and ask questions during the ground preparation of the UAVs. Experimenters then brought the participants into the data collection trailer. Experimenters briefed the participants on the VSCS flight test interface and highlighted any new features. All of the flight test participants had had some prior experience with VSCS, so more in-depth training was not needed. After the differences training was completed, participants were given the opportunity to interact with the control station during actual flight operations. Participants were encouraged to interact with the interface as if they were conduct actual data trials, engaging the sensor and auto tracker capability. This was a chance for the participants to experience and adapt to the real world aspects of UAV and sensor control. Prior to data collection trials it was important that participants became familiar with the unique aspects of vehicle and sensor control in actual flight operations in comparison to the simulation environment in which they had previously trained. This practice session continued until the test administrator judged the participant to be ready to continue with the experimental trials.

The experimental trials began as shown in Table 6. Since participants were run in pairs, one of the participants would begin with a one operator trial, while the other observed from another room. After completion of the first one operator trial, the second participant would join the first in a two operator trial. Finally, the second participant would complete the final, one operator trial while the first participant observed from another room. Individual and team debriefs occurred after each trial as well as at the end of all three trials. This process was repeated for all pairs of participants.

4.3 Flight Test Results

Given the limited number of data runs available as part of the flight test effort and the degree of uncontrolled variability across data collection trials, the MUSCIT team felt it would be inappropriate to conduct formal statistical analysis on the available flight test data. Summary statistics for some of the key dependent variables captured across the treatment condition (i.e., crew composition) is presented in Table 8 and Figure 17. Information on other dependent variables was collected can be found in Appendix C.

Table 8. Descriptive statistics for dependent measure collected during MUSCIT Spiral 3 flight test

	HVT Cowboys	HVT Steelers	Forced Dis	Squirter Coverage
1-Op	47%	42%	305	64%
2-Op	93%	64%	125	83%

Plots of the data included in the analysis are presented in Figure 17 (a) – (c). As figure 17 (a) shows, HVT coverage was better in the 2 operator case. It is interesting to note though that even in the 2 operator case, coverage was much lower for the HVT leaving Steelers. Figure 17 (b) shows that it took 80 seconds longer to respond to the forced distracter task with 1 operator than it did to respond to the task with 2 operators. Participants also performed better in the squirter task with 2 operators. This is evident in Figure 17 (c).

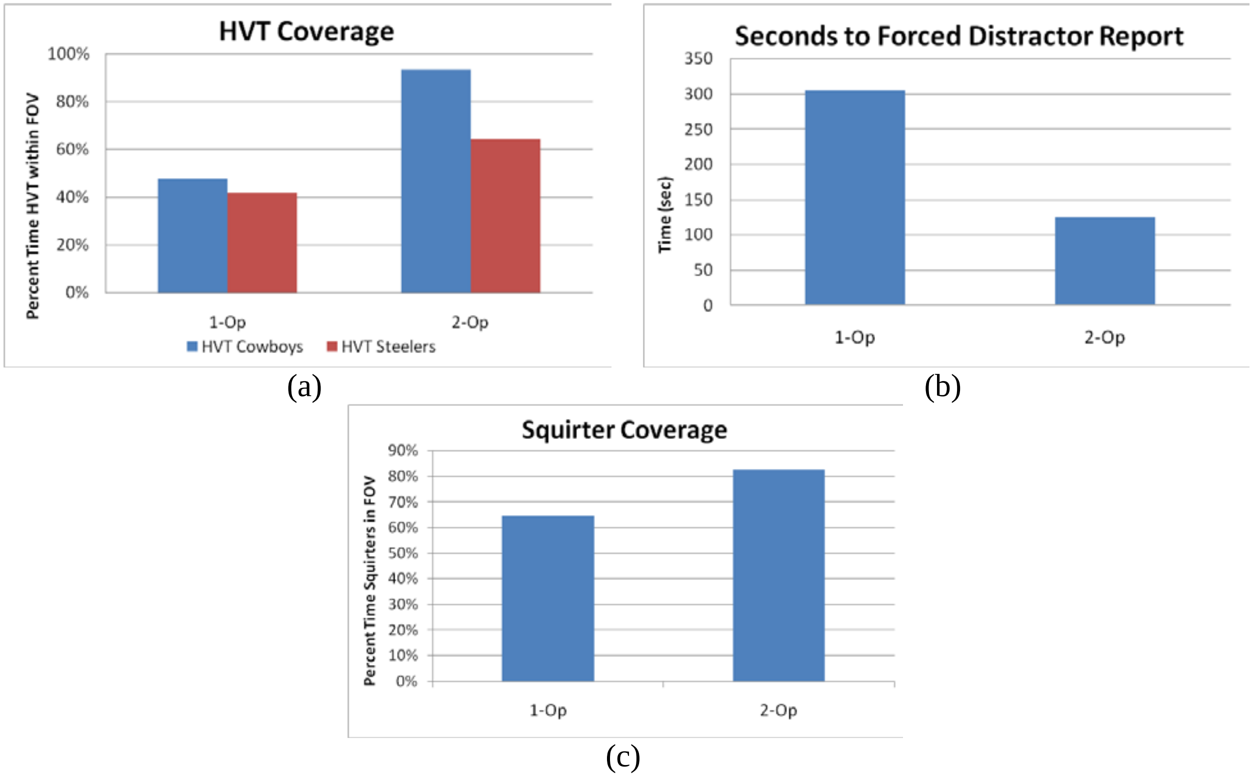


Figure 17. Summary plots for (a) Coverage of HVTs Cowboys and Steelers, (b) Time to Report on Forced Distractor Task, (c) Coverage of Squirters

Operators also provided subjective feedback at the end of each trial. This feedback is summarized in Table 9 and Figure 18. As mentioned previously, operators were asked to provide a number on the modified China Lake scale to correspond with his or her perceived situation awareness (SA). It is important to note that for the China Lake scale, a lower number indicates better SA. Figure 18 (a) shows the mean China Lake scores for the different conditions. The NASA TLX was collected as a measure of reported workload. Figure 18 (b) shows the 1-Op condition having the highest reported workload. Experimenters also administered a post trial survey that focused on the feasibility, reasonability, and timeliness of the mission considering this control station configuration, as well as scoring the usefulness of a number of features of the control station. As Figure 18 (c) shows, operators rated the mission to be at least moderately feasibly, reasonable, and timely, with this control station. The figure also shows that all four features in question were rated to be useful, with the Sensor Guidance, and Voice Control rated to be the most useful.

Table 9. Descriptive statistics for Subjective Data collected during MUSCIT Spiral 3 Flight test

	Feasible	**Reason**	**Timely**	**Voice**	**Guidance**	**AutoTrk**	**KeepIn**	**TLX**	**CLSA**
1-Op	1.80	2.40	1.60	2.80	2.80	1.80	2.20	80.00	1.90
2-Op	2.67	2.83	2.17	2.67	2.50	2.00	2.33	48.05555	1.17

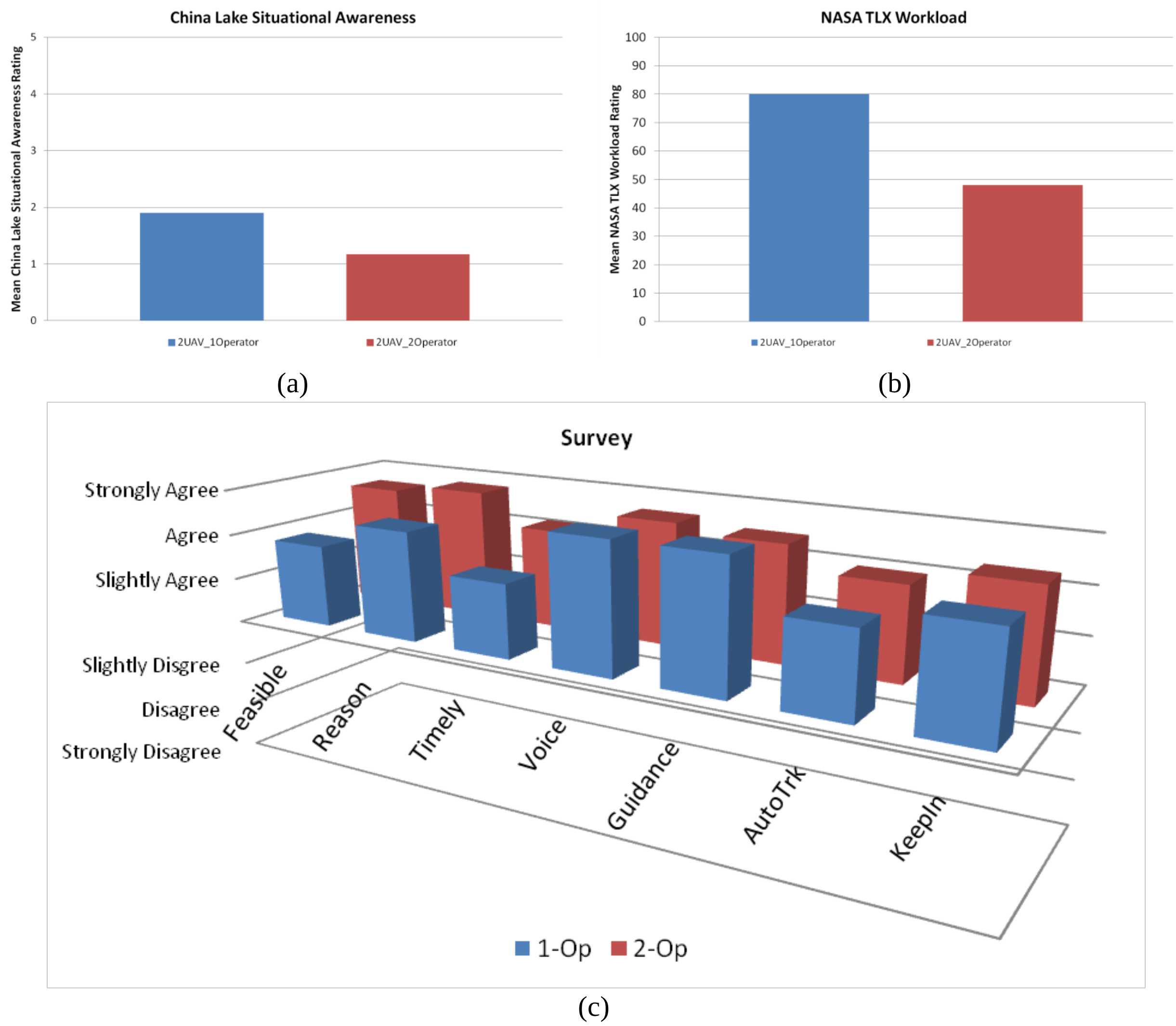


Figure 18. Participant subjective ratings for (a) China Lake Situational Awareness, (b) NASA TLX Workload Rating, and (c) Summary of post trial survey

5.0 Discussion

In the context of MUSCIT's spiraled approach to multi-UAV control station development and empirical demonstration, the current spiral represented a significant departure from previous spiral efforts. During the current spiral, the focus was not directed solely on assessing the capacity of a single operator in controlling and managing multiple UAVs, but rather to more fully understand how multiple UAVs could be used to support envisioned operations during a representative RSTA/counter-proliferation type mission. The question we were asking focused less on "how much" to merely "how" and "why". The hallmark of an experienced operator is that they "make it work". A recurring comment from participants across spirals was that they felt it was their responsibility to make it work. To our participants we insisted that as a technology development program, we were interested in understanding the vulnerabilities in the design, weaknesses in the concept, and flaws in the implementation of the control station. In other words, our hope was that their exposure to the control station in a simulated and flight test environment would expose many of the design flaws in the system and help point us toward enhancements that would improve the system and increase the likelihood that the feasibility of multi-UAV control was indeed achievable. Without fail, however, operators were consistently quick to blame themselves for suboptimum performance. While they might provide some indication of problems they encountered with the system, guiding us toward potential opportunities for design enhancements, they were unrelenting in their insistence to take responsibility for performance.

In making the system work, they remain adamant that they are responsible for identifying and deploying strategies and possible workarounds that will ultimately result in success. While it may seem a bit cliché, for them, *failure is not an option*. During Spiral 3, the MUSCIT team hoped to capitalize on this drive to "make it work". Our focus was on understanding "how" operators make things work in the face of time stress, uncertainty, and conflicting goals. To do this, we created an environment through a series of operational scenarios that challenged their ability to cope; that created time stress, which provided limited and sometimes ambiguous information that forced operators to prioritize objectives in the face of conflicting goals. In doing so, we might catch a glimpse into their thought processes and the adaptive strategies they adopt in managing multiple assets to accomplish a complex task. Looking beyond the "how" of making it work, we were also interested in the "why". What guided the decisions, what tradeoffs were considered, what values were to be considered in selecting between alternative courses of action. We weren't so much interested in quantifying a limit on capacity of a single operator as we were in understanding how and why operators act as they do in the face of difficult and challenging situations and how the capabilities and features of the control system either supported or inhibited their ability to *make it work*.

The following section provides a detailed description of many of the situations encountered during the simulation and flight test trials, some of the specific control station features and capabilities that significantly contributed to the ease with which operators were able to accomplish tasks, as well as those instances that significantly challenged operators and thereby suggest opportunities for either refinement to existing capabilities or the integration of new capabilities. Where possible, specific examples of operator interactions with the control station will be used to illustrate the point.

Sensor Slaved Mode (Sensor Guidance). Probably the most desirable feature of the control station within the context of the current mission was the incorporation of the Sensor Slaved mode. Activation of the Sensor Slaved mode significantly reduced the demands for vehicle control on the operator. As described earlier in the report, once the vehicle was placed in sensor slaved mode the vehicle's loiter point would be continuously updated to correspond with the current look point of the active sensor. As a result, operators were not required to continuously update the loiter point of the vehicle in order to maintain an appropriate slant range to the target, particularly during dynamic target tracking. The Sensor Slaved mode, probably more than any other feature, greatly reduced the attentional demands on operators. Evidence of the value of the sensor slave mode was illustrated when one operator commented that "Operating 4 was tough, operating 4 when you didn't have sensor slaved was nearly impossible". Given we were working with experienced operators, their primary focus was on controlling and monitoring the sensor imagery. The ability to automatically position the sensor to provide the desired image was a monumentally advancement in terms of being able to make use of multiple UAVs.

There were, however, a couple of instances where problems with the sensor slave mode were encountered. During one dual operator trial one of the operators was in the process of actively tracking one of the HVTs from Objective Cowboys to Objective Giants. The second operator had just received confirmation of the departure of the HVT from Objective Steelers and had established contact and was actively tracking the HVT using the auto-tracking capability. As the HVT was being tracked the operator noticed that the slant range of the sensor image was increasing. This cued him that maybe the loiter point of the vehicle was not being properly updated. A glimpse at the TSD to check on the position of the sensor footprint and the current loiter position confirmed that the loiter point was not being updated. Thinking that maybe he had forgotten to place the vehicle in sensor slave he again pressed the sensor slave mode button. Again, the loiter did not update. Coincidentally, the vehicle, in its static loiter, flew directly overtop the moving HVT causing the sensor to enter a Nadir condition. One reason UAV sensor operators try to avoid nadir conditions is that at sensor elevation angles approaching 90^{o}, the sensor steering mechanism has difficulty stabilizing its azimuth control. As a result, the sensor swung wildly away from the HVT location and the operator lost contact on the HVT. Because the sensor slave mode did not seem to be operating as expected the operator was required to manually update the loiter point during the subsequent search to reacquire the HVT. Due to the added demands of vehicle control and the confusion associated with the sensor slave mode operations, the operator was unable to reacquire the HVT prior to its subsequent arrival at Objective Giants, which the first operator reported given that he was on station at Giants providing point surveillance on the compound.

A review of this incident revealed that the unexpected behavior of the sensor slave mode was due to a failure to create a Keep In Box prior to activating the sensor slave mode. The Keep In Box is a safety feature implemented by VSCS developers to ensure that vehicles being controlled under sensor slave mode would not violate their current airspace constraints. Again, while the operator, upon realizing that the Keep In Box was not active was quick to focus blame on himself, this episode also points to an issue of control station feedback and mode awareness. While the control station did provide an annunciator that indicated that the sensor slave mode was not active when the operator attempted to re-engage the mode, it failed to provide any indication as to the source of the fault. While hindsight is perfect, it is not unreasonable to assume that a message reporting that a Keep In Box needs to be established before a vehicle can be placed in sensor slave mode. The operator also indicated that in all likelihood, a formal checklist detailing each of the steps required to place the control station, vehicle and sensor in operational mode for that mission would have been performed. During simulation, experimenters relied on participants remembering the procedural steps required to engage each of the modes. While such checklist might be considered a work around, and should not replace sound interface design concepts, they are part of the operational culture and should not be ignored when evaluating systems for military use.

One other problem noted when interacting with the sensor slaved mode was the name itself. The term “slaved” has been used for other modes such as loiter slaved and lat/lon slaved. In loiter slaved mode, rather than the vehicle being slaved to the sensor starepoint (sensor slaved) the sensor is slaved to the vehicles loiter point. The confusion was most evident when operators were trying to engage either of these modes using voice commands. On several occasions operators either inadvertently engaged the wrong mode or the utterance used to engage the voice command was in appropriately spoken (e.g., improper grammar or syntax). Given the frequency with which such errors occurred, it appeared evident to the MUSCIT team that an alternative label for the sensor slaved mode would be appropriate, minimizing the potential for mode engagement errors. A couple participants commented that the term "slaved" typically refers to the sensor given that sensors are slaved to particular points or locations. Conversely, vehicles are steered or guided, not slaved; further suggesting that a change in the mode label is warranted.

Automatic Target Tracking. Probably the second most desirable feature incorporated into the control station was the automatic target tracking capability. However, the desirability of this feature is fundamentally dependent upon its reliability. When functioning as intended, the system can be a tremendous aid in supporting operators during multi-UAV operations. Using the "red box" as an indicator of the track quality, operators could quickly cross-check tracking performance and realign the tracker as necessary if it appeared that track quality might be degrading. This afforded the opportunity for operators to attend to other activities within the mission, reasonably confident that the autotracker would maintain contact. The interval of time between cross check might provide a viable indicator of the level of confidence the operator placed on the tracker during the course of the trial. The longer the interval between crosschecks, the more confident the operator might be in the ability of the tracker to maintain target contact. Shorter crosscheck intervals might indicate less confidence in tracker performance.

Across trials there was a great deal of variability in terms of how well and how reliably the auto tracker could maintain a positive track on a moving target. Given that the auto tracker available via the RTVS system was a third party application integrated into the control station, the development team had little insight into the internal algorithms that enable the feature. Therefore, it is difficult to identify with any certainty the specific conditions that might have contributed to the frequent loss of tracking. However, having observed several trials, one can begin to identify certain patterns that emerge as operators have difficulty getting the system to maintain contact.

One of the conditions that appeared to have a significant impact on the ability of the auto tracker to maintain sufficient track quality was the FOV setting selected by the operator. Image FOV influences two factors that weigh heavily in track quality; resolution and rate of target movement across the image. At wider fields of view a target moving at a constant rate will tend to move across the image at a slower rate than the same target viewed within a smaller FOV. As the rate at which the target moves across the image increases there will come a point where the tracker will no longer be able to effectively track the pixels that define the target. In short, the slower the target moves, which coincides with a wider image FOV, the better the track will be able to maintain track quality. The tradeoff then is target size, that is, the number of pixels that constitute the target within the image (i.e., resolution). At wider fields of view, the ground sample distance (the distance on the ground subtended by a single pixel) becomes larger. At the widest FOV settings the current target (i.e., HVT on motorcycle) may subtend only a couple of pixels making tracking of transitions in the leading and trailing edge of target pixels extremely difficult. Therefore, target tracking via pixel analysis, like target detection and identification, is made easier as the ground sample distance decreases, or as image resolution increases.

Operators tended to converge on a FOV setting that established a balance between these two factors. The tracker seemed to work at its best during the HVT tracking when the FOV was set at a mid-range setting (~28^o). Many of the operators also would switch to the IR sensor mode to provide better target contrast against the background. The limitation associated with the IR mode was that, as opposed to a continuous FOV setting available in the EO mode, IR imagery was available at only two FOV settings.

Another consequence of using the RTVS tracking system was the limitation associated with fully integrating the interface into the control station. One example of this limitation was the inability to integrate symbology into the imagery while the RTVS system (and by definition the auto tracker feature) was active. Based on participant feedback, the most significant impact of this limitation was the loss of the orienting North pointer presented as part of the symbology overlay. Modeled after the north pointer incorporated into the sensor imagery overlay on the Sensor Operator station, the north pointer is a floating “N” symbol that indicates the north direction within the sensor image. Operators often rely on this symbol to provide necessary orienting cues. In the absence of such a cue operators report that one can easily become disoriented, particularly in the absence of any significant cultural or natural features within the terrain being surveyed. Participants compensated for this limitation by creating a repeater image window such that one image window could have the RTVS system active and the other window could have the symbology overlay. Given the current configuration of the control station, such an approach worked during the 2 UAV conditions or during the 2 operator 4 UAV condition; although in this case operators would be unable to monitor the imagery feeds from the vehicles that were not under their control. While the limitation does not represent a significant technical challenge, its presence in the current study did serve to highlight the importance of the symbology overlay feature and the extent to which operators come to rely on the information it makes available.

Crew Coordination. One of the objectives of the Spiral 3 evaluation, both in simulation and in flight test, was to assess how operators coordinated their activity under conditions of 2-operators, and how the approach toward allocation of available assets and operator attention changed when performing the scenario under the 1 operator condition. One of the first issues that was typically resolved prior to trial initiation was who would be the primary “voice” for MUSCIT to EAGLE15. In nearly all cases, one of the MUSCIT operators was designated as the primary point of contact to external entities from all MUSCIT vehicles. In several cases however strict adherence to this division of roles applied only to those communications that were initiated by EAGLE15 (i.e., those instances where EAGLE15 was providing information and directing MUSCIT to perform some task). Those instances where communications were initiated by MUSCIT; such as contact reports, vehicle status, situation reports, the crew often found it more convenient to have the operator assigned they vehicle/sensor from which the information was generated make the report directly to EAGLE15. In some cases crews initially limited communications to EAGLE to a single operator however given the frequency and details of reports they eventually agreed that each operator would report separately, identifying themselves as using the vehicle callsign (e.g., MUSCIT22) rather than MUSCIT Lead (or MUSCIT).

During the 2-operator conditions the crew also needed to determine the appropriate distribution of tasking and assets to support this tasking. Prior to initiation of each trial, crews would typically decide which operator would have responsibility for each of the HVT compounds, Cowboys and Steelers. When four vehicles were available the allocation of the remaining two vehicles was at the discretion of the crew as to how to distribute these assets. In every instance each operator took control of one of the remaining vehicles, how they were tasked varied significantly across tasks. I several cases one of the vehicles was positioned over the Giants objective to provide ongoing situation reports. The final vehicle was either left in its original orbit, positioned over FOB Freedom, or in a couple of instances the final vehicle was placed in an orbit at a center of the area of operations, providing a general overlook of the area. One crew member mentioned that the positioning at the center of the area of operations would allow him to move quickly to any position where the vehicle may be tasked or an additional sensor asset may be needed.

While the majority of tasking could be accomplished with minimal coordination, crews often reported to one another their current status and any significant events occurring within their area of responsibility. Those instances when new tasking was assigned to MUSCIT from EAGLE 15 (e.g., forced distracter, IED event, approaching mob) without exception crews would coordinate on the course of action and the appropriate assignment of vehicles to the required tasking. In most cases, the vehicle that was in closest proximity to the assigned tasking was repositioned to provide the desired sensor coverage.

Because of the dynamic nature of the assault and the required tracking of multiple squirters from Objective Giants, this task tended to require a higher degree of crew coordination, particularly in preparation for the assault itself. As the assault force moved into their respective blocking positions, crew would typically discuss how they would distribute the available assets, often dividing the compound to sections (north-south or east-west). The east-west distribution seemed to be the most common as the northern escape routes were well covered by the assault forces blocking positions. Therefore, the most vulnerable escape routes were to the south, east and west. Once the assault was initiated and squirters began exiting the compound, operators would report the location and direction of squirters and their approach toward established blocking positions. Those moving away from blocking positions were tracked until they stopped moving, at which time the operators were to provide position coordinates and help direct ground forces to intercept and take personnel into custody. The extent to which operators coordinated the search and tracking of squirters during this phase of the mission was to alert potential movement of individuals from one area of responsibility to another (e.g., squirter moving from the east to the west).

Simulation vs Flight Test. As in previous spirals, the flight test was conducted primarily to determine whether results from simulation trials would transfer to the flight test environment. The flight test environment also moves us closer to actual operations. This is because operators must deal with many of the same issues one finds under such conditions. Many of these issues we reported during previous flight test efforts. Given the sample size for the flight test it is very difficult to draw any definitive conclusions regarding the performance differences between the simulation and flight test trials. That being said, we do see that comparisons of the situational awareness and workload ratings between simulation and flight test appeared to track relatively well. In addition, participant responses to the post trial surveys regarding the degree to which various control station features supported operators during both simulation and flight test trials also correlate well. However, from a performance perspective there are many reasons why we might expect differences between the simulation and flight test environments. Probably the most notable difference between the simulation and flight test environment is the stability of the imagery that is captured by each of the sensors. While the environmental conditions present during the Spiral 3 flight test were much more benign than those of the Spiral 2 flight test, image stability remained an issue; particularly while operators narrowed the sensor FOV in their attempt to identify specific targets.

Another environmental condition that appeared to have a significant impact on operator performance was the bright sunlight. While our previous flight tests revealed problems associated with image washout and glare associated with bright sunlight, the impact of sunlight in the current flight test was focused more on how shade influenced the ability of operators to maintain contact on moving targets. In mapping out locations for Objectives Steelers, Cowboys and Giants (See Figures 15 and 16) the MUSCIT team was conscious of the visibility of the route to be travelled by the HVT actors as they moved from their initial locations at Steelers and Cowboys to Giants. There was concern that obscuration of the route due to tree canopies would significantly inhibit the ability to effectively track the targets. While we were confident that the Cowboys location presented little problem, the route segment from Steelers to Route Michigan and along the initial portion of Route Michigan did have trees on either side. However, the tree coverage did not directly obscure visibility of the route itself.

During data collection trials, however, participants discovered that given the sun angle and the position of the trees relative to the route, the route fell in shadow most of the time. Participants found it very difficult to discern the HVT actors once they had gone into the shadows. Several reported that in EO mode the shadows obscured the targets just as if they had been covered by trees. The impact of this effect is evident by the difference in 2 operator HVT tracking performance between the HVT originating from Steelers (64%) and Cowboys (93%) (See Table 8). While the difference was not as apparent during the 1 operator trials, participants reported that the amount of attention directed toward maintaining track on the HVT from Steelers had a negative impact on their ability to establish and maintain track on the HVT from Cowboys. The same effect was reported during the assault phase of the mission when operators attempted to track HVTs departing Giants. While the HVT actors were instructed not to hide under trees, once they entered the shade, operators frequently reported that they had lost track due to targets entering the tree line.

Another difference between simulation and flight test that operators commented on was the impact of the Keep In Box. During the simulation trials participants were unrestricted in creating their Keep In Box. In most cases participants made the box big enough that it never restricted movement of the vehicle. During the flight test however, the Keep In Box was restricted due to the airspace limits imposed for safety of flight issues. On several occasions participants were required to steer their sensors outside the constraints of the established Keep In Box, restricting the movement of the loiter point (Figure 19). The effect of this restriction was the increase in the slant range and decrease in the slant angle of the sensor imagery. While participants commented on this condition, they did not report than it had any significant impact on their performance from an imagery perspective. Those that did report a negative consequence associated with this situation indicated that because the loiter point did not coincide with the sensor stare point, there were times during the orbit when the vehicles landing gear would obscure the imagery. This seemed to be more of an annoyance than a significant problem.

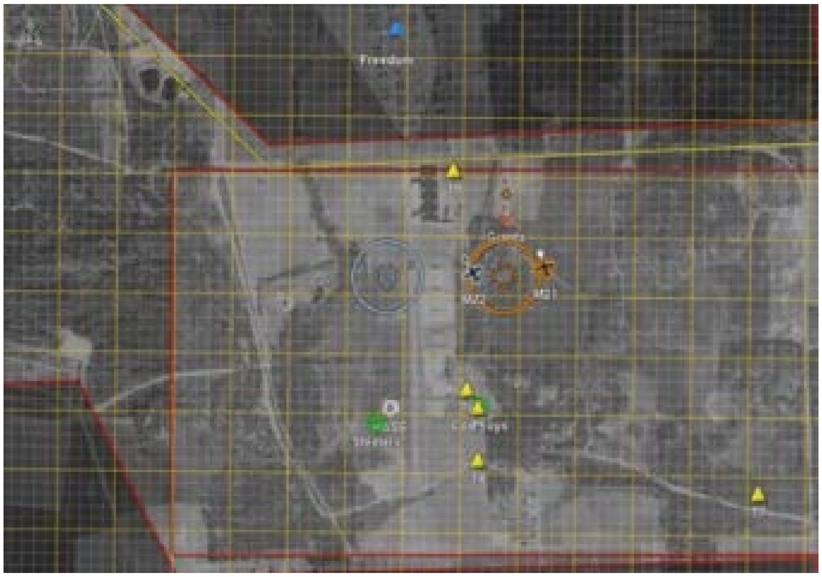


Figure 19. Impact of Keep In Box on vehicle mobility and MacroGrid incorporated into the TSD

The only modification to the control station interface between simulation and flight test was the incorporation of the MacroGrid into the TSD (Figure 19). As previously mentioned, during simulation, operators were required to reference a hardcopy of the MarcoGrid to locate the position of the suspicious activity. Several participants reported that the incorporation of the MarcoGrid on the TSD could reduce the time required to locate the proper grid coordinate as well as the opportunity for error. One of the concerns regarding the incorporation of the MacroGrid on the TSD was the added clutter it would create. To mitigate this concern the MacroGrid could be turned on and off as required using either voice command or an on-screen selection. Flight test participants unanimously favored the incorporation of the MarcoGrid.

6.0 Conclusions

During Spiral 1 MUSCIT investigated multi-UAV control in the context of a static task (i.e., point surveillance). Based on observations during data trials and participant comments it was evident that demands on ***attention management*** increased beyond the ability of operators to cope. The additional demands associated with increases in the number of vehicles (and by definition surveillance tasks) challenged their ability to sustain their level of performance. We also discovered that vulnerabilities in the means by which operators could transition across vehicles/sensors not only increased the difficulty of the task but significantly increased the opportunity for errors. Our focus, therefore, during Spiral 2 was to address these issues and provide better support for attention management, as well as the means to ***seamlessly transition control*** in correspondence with shifts in attention.

In Spiral 2 we approached the attention management issue by looking at how the application of specialized automated features (simulated auto-detection) could help direct operator focus to relevant aspects of the scenario. During Spiral 2 we also expanded the set of tasks to include not only point surveillance, but also route surveillance and area search. By expanding the task set we were interested in incorporating elements of vehicle/mission management functions as well as the sensor management activities that were the focus of Spiral 1. As anticipated, we found that ***reliable automation*** can significantly enhance operator performance and serve to direct attention and help maintain sensor focus on relevant aspects of the mission area. Unsurprisingly, the key to the viability of the approach is reliable automation, a capability that accurately responds to the dynamics of the task under the operational conditions to be anticipated.

During Spiral 2 we also exposed participants to a full-mission context that integrated each of the tasks into a composite mission scenario. The intent was to set the stage for operators and allow them to develop their own strategies in responding to the dynamics of evolving situations. Unlike the part-task trials where tasks were accomplished in isolation, operators were required to simultaneously perform all tasks in coordination to support a broader mission objective. Relaxing the constraints revealed many interesting notions in terms of how operators approached each phase of the scenario. What became immediately apparent was that those participants that had direct operational experience in these types of missions had a very unique mindset relative to the priorities and emphasis placed on individual task performance. Further, as the mission scenario increased in complexity, the ability of operators to actively respond was often inhibited by their lack of familiarity with the mechanics of the control station. Operators were clear in their intent, their strategy was sound; they were just unable to execute due to an incomplete understanding of the control station features.

As we turned toward Spiral 3, the MUSCIT team concluded that the validity of our findings would be dependent upon two critical components. First, Spiral 3 participants should have ***direct operational experience*** in the type of mission to be executed. Second, participants must become fully ***competent in the mechanics and features of VSCS*** to fully exercise the capabilities of the control station. In response to this need a fully-functional VSCS control station simulation was delivered to our sponsor, affording the opportunity to both recruit and train competent operators that would participate in Spiral 3 data collection trials. This single action significantly improved the quality of simulation trials and provided MUSCIT analysts the opportunity to observe and capture the actions of experienced operators as they actively engaged in a representative scenario. The insights gained were invaluable in understanding the operational demands, as well as the opportunities afforded, while employing multiple UAVs within an operational setting.

While developing enhancements to the control station in preparation for the Spiral 3 simulation, discussions with operators challenged our myopic view that sensor and vehicle control were two separate functions. They made us realize that the ultimate reason for vehicle movement was to place the sensor in the position to acquire desired imagery. In other words, where one wants to look directly impacts where we want to place the vehicle. This led us to consider ***coupling sensor control directly to vehicle control***. This feature, which we called Sensor Slaved, was rated by our participants as the most highly desirable feature. The coupling of sensor and vehicle control suddenly relieved operators of the demands of vehicle management. It should be noted that consideration must be given to issues related to vehicle control such as airspace deconfliction and vehicle separation. We accomplished this through altitude separation of MUSCIT vehicles and constrained movement of vehicles to a limited restricted operating zone.

As part of the Spiral 3 control station we also incorporated an auto-tracking capability that was capable of maintaining positive contact on dynamic ground targets. Unlike Spiral 2 where automation was simulated, the auto-tracker used during Spiral 3 was a viable capability. Operators could designate a target and using pixel processing, the tracker would steer the sensor to maintain the target within the sensor FOV. The variable reliability of the auto-tracker provided some unique insights into how operators used the feature and the tolerance to failure they exhibit before they would revert to manual tracking. That said, the incorporation of the auto-tracker coupled with the Sensor Slaved mode proved to be an extremely powerful tool and was considered highly desirable by participants.

In the final analysis, the question remains, "Is multi-UAV operations a viable concept?" Based on observations and findings resulting from the three MUSCIT spirals we believe the answer is yes. MUSCIT's initial spirals focused on the issue of capacity; how many can a single operator manage. Like all such questions, it depends. However, we were certainly able to identify specific capabilities and features that could certainly reduce demands on operators and improve the quality of experience during multi-UAV operations. During our final spiral we found that increasing the number of UAVs can actually improve performance and the ability of operators to adaptively respond to dynamic situations. Given the additional resources available through access to more vehicles, operators were able to position their sensor in anticipation of events, allowing them to respond in a more timely manner to time critical events. The challenge for developers of UAV systems is to ensure that the overhead associated with providing additional vehicles does not outweigh the value gained from additional sensor resources.

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8.0 List of Acronyms and Abbriviations

ACA	Airspace Control Authority
AFRL	Air Force Research Lab
AOI	Area of Interest
ATC	Air Traffic Control
CAS	Close Air Support
CIB	Controlled Image Database
CMF	Common Message Format
DMP	Dynamic Mission Planning
DoD	Department of Defense
DV	Dependent Variable
DVR	Digital Video Recorder
EO	Electro-Optical
ETA	Estimated Time of Arrival
ETE	Estimated Time Enroute
FOV	Field of View
FLAMES	FLexible Analysis Modeling and Exercise System
GNC	Global Navigation and Planning Charts
HCI	Human Computer Interaction
IR	Infrared
JNC	Jet Navigation Charts
JOG	Joint Operation Graphics

LCD	Liquid Crystal Display
MAC	Multi-Aircraft Control
MUSCIT	Multi-UAV Supervisory Control Interface Technology
NASA	National Aeronautics and Space Administration
ONC	Operation Navigation Charts
POI	Point of Interest
RSTA	Reconnaissance, Surveillance, and Target Acquisition
SO	Sensor Operator
SOF C2	Special Operations Forces Command and Control
SUV	Sport Utility Vehicle
TLX	Task Load Index
TPC	Tactical Pilotage charts
TSD	Tactical Situation Display
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle
VoIP	Voice-over Internet Protocol
VRSG	Virtual Reality Scene Generator
VSCS	Vigilant Spirit Control Station