Chapter 14 – US-1: MULTI-UAV SUPERVISORY CONTROL INTERFACE TECHNOLOGY (MUSCIT) DEMONSTRATION

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14.1 DATE

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14.2 LOCATION

Camp Atterbury, Indiana, USA.

14.3 SCENARIO/TASKS

The objective of the MUSCIT program is to develop, integrate and demonstrate technology for effective single-operator control of multiple Unmanned Aerial Vehicles (UAVs) conducting dynamic tactical intelligence, surveillance, and reconnaissance and close air support missions. The program has set up a series of spirals, made up of simulation and flight tests (see Figure 14-1), to examine human and system performance for an assortment of UAV Reconnaissance, Surveillance, and Target Acquisition (RSTA) tasks and operations.

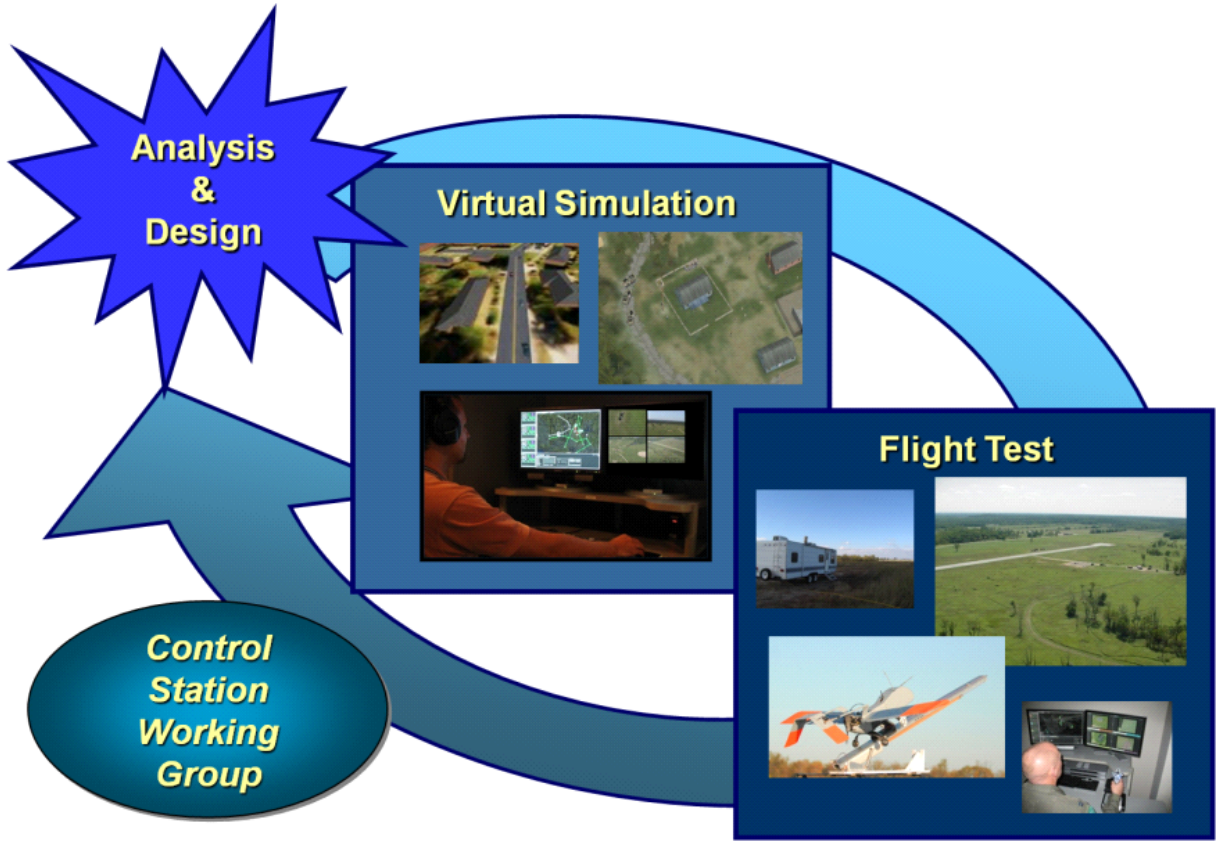

Figure 14-1: MUSCIT Program's Spiral Approach.

The NATO technology demonstration was conducted in conjunction with MUSCIT's Spiral 2 flight test and represented a sub-set of the tasks and conditions tested. The NATO technology demonstration consisted of a live flight demonstration of advanced single-operator, multi-UAV control station technology conducting point surveillance and vehicle re-routing tasks. The control station technology, referred to as the Vigilant Spirit Control Station (VSCS) (see Figure 14-2) [1], was demonstrated in a four-vehicle configuration made up of two flight test UAVs (MLB Bat 3s) and two simulated UAVs. The main task demonstrated was point surveillance where the control station operator positioned the UAVs and manipulated their gimbaled sensors to detect individuals either entering or exiting specified locations and reported whether or not the individuals were armed with a mock weapon (see Figure 14-3).

Figure 14-2: Flight Demonstration of Vigilant Spirit Control Station Performing Multi-UAV Operations.

Figure 14-3: Point Surveillance Actor Carrying Mock Weapon During Flight Test.

Secondary tasks included monitoring radio calls and reporting vehicle heading, power remaining, position reports, any simulated air tracks transiting the area of operations, monitoring and reporting system cautions and warnings, and responding to vehicle relocation requests. The point surveillance portion represented a second test of point surveillance for the MUSCIT program to determine if added technology and design enhancements significantly improved target acquisition and secondary task performance from that found in the Spiral 1 test. The goal was to strive for near-equivalent performance (e.g., percentage of targets detected) and subjective ratings (e.g., situation awareness ratings) across the different number of UAV conditions.

14.4 TECHNOLOGIES EXPLORED

The control station consists of a desktop computer with two side-by-side 24” widescreen liquid crystal displays (see Figure 14-4 and Figure 14-5), a keyboard and a mouse. The user interface is comprised of vehicle and system status information, a Tactical Situation Display (TSD), vehicle and payload controls, and a sensor management area. The vehicle status area provides current and commanded state information to help the operator maintain situation awareness of the UAV(s). The TSD provides a 2-dimensional map or image with vehicle locations and other points of interest depicted on it. The operator can directly control certain UAV actions on the TSD. For example, the operator can select a UAV and change its direction of flight by manipulating graphic controls associated with the UAV symbol. The vehicle and payload controls provide additional control options. For example, the operator can place the sensor in latitude/longitude slaved mode and control the zoom level. The sensor management area allows the operator to control and view the sensor feeds, manipulate the presentation using digital video recorder and mosaic tools, and perform additional payload control.

Figure 14-4: Left Control Station Display with System Status Display, Tactical Situation Display, and Vehicle and Payload Controls.

Figure 14-5: Right Control Station Display with Aircraft Video and Sensor Management Area.

14.5 HUMAN FACTORS ISSUES EXPLORED

The objective of MUSCIT Spiral 2 was to investigate the impact and demands associated with multi-UAV control within the context of a static and dynamic RSTA mission scenario and establish a performance benchmark for the control of multiple UAVs. Elements of the test included:

1) Evaluating the value of the operator control station design enhancements;
2) Investigating the performance effects and behavioral adaptation of operators as the number of UAVs being controlled and video image streams being monitored increased; and
3) Identifying opportunities via automation, visualizations, control mechanization, and employment concepts that would enhance the feasibility of multi-UAV control.

The previous spiral's tests generally showed that as the number of UAVs increased there was an overall decrease in the percentage of targets detected and the associated performance in identifying whether or not the individual was armed. This downward trend was also seen in the secondary task performance. In addition, higher workload and lower situation awareness ratings were noted. Technical challenges for the MUSCIT team to address included improving attention management, sensor selection and control, and information access. With the objective data and the subjective feedback from Spiral 1, the MUSCIT team modified portions of the control station and integrated additional control, display, and decision aiding technologies. Additional technologies utilized for Spiral 2 to enhance situation awareness and improve operator performance included the following:

- Speech recognition and synthetic speech reporting to allow the operator to request information of the system and have the system retrieve and report the requested information. The speech recognition and speech synthesis technology was included in an attempt to reduce the overall visual demand/load and permit the operator to focus more on the sensor videos during the RSTA operations.
- Sensor steering using the mouse/cursor to allow a point and click method to steer the sensor, along with zooming via the mouse scroll wheel. The rationale for integrating the mouse sensor steering was to reduce control time and errors in aircraft video selection/manipulation and alleviate the need to switch between two input devices (sensor stick and mouse).

- Synthetic overlays in the form of targeting flags were developed to permit the operator to mark locations of interest and have graphics overlaid on the sensor video to depict the mark. The flags were color coded to correspond to the aircraft/video source from which the mark was made. The intent was that the synthetic flags would help enhance the operator's situation awareness in recognizing locations and points of interest. The technology could also serve as a method to share information with others about the battlespace and areas of interest.
- Glyph symbology integrated as a sensor overlay in an attempt to reduce the visual scan requirements. The graphic contained vehicle heading, vehicle altitude, sensor heading, communication data link, and fuel state information.
- Caution and warning annunciations to convey important state change information were modified from the Spiral 1 design. Visual alerts were annunciated on the sensor video, as overlays, and aural alerts using synthetic speech to help reduce the visual scan requirements for information retrieval and assessment, and help in overall attention management.

14.6 UNMANNED SYSTEMS USED

The MUSCIT demonstration used the MLB Bat 3 UAV (see Figure 14-6) equipped with Cloud Cap Technology's Piccolo II autopilot and TASE stabilized gimbaled video camera (see Figure 14-7). The Bat 3 version used in the MUSCIT flight demonstration was approximately 5 feet long with an 8.5 foot wingspan. As outfitted, the Bat 3s provided the ability to perform mission, flight and sensor management tasks, which in turn helped the MUSCIT team exercise the control station controls, displays and decision aids and assess operator performance and usability via flight tests and demonstrations. For example, the vehicle could be vectored to fly a commanded heading, follow a waypoint defined route, or loiter about a given latitude and longitude. The sensor steering and management tasks could entail assigning a stare point location based on coordinates, and manually steering and zooming the gimbaled video camera with the control station mouse. VSCS was capable of receiving state data and the sensor video from each Bat 3 while simultaneously displaying multiple videos on the control station displays.

Figure 14-6: Bat 3 UAV.

Figure 14-7: Bat 3 with Gimbaled Sensor Deployed.

14.7 SUMMARY OF ANY NATO COMMUNICATIONS/COLLABORATIONS/ INTERACTIONS

As indicated in the table below (see Table 14-1) the MUSCIT technology demonstration provided information pertaining to the supervisory control technology design, development and the approach for how the technology was tested and evaluated. The information was conveyed primarily at NATO HFM-170 meetings and the flight demonstration (see Figure 14-8). The events provided an opportunity to share information on the nature of the supervisory control tasks, operator interface technology and integration concepts that could help enhance supervisory task performance, and evaluation methods and metrics.

Table 14-1: MUSCIT Technology Demonstration – Level of Interaction with NATO HFM-170.

	Planning/Design	***Execution***	***Analysis***
Communication	*x*	*x*	*x*
Coordination			
Collaboration			

Figure 14-8: Launch of Bat 3 at MUSCIT Technology Demonstration.

14.8 SUMMARY OF RESULTS

In manipulating the number of UAVs (1, 2, and 4), the number of operators (1 and 2), and the target event rate or tempo ("low": 60 seconds on average and "high": 30 seconds on average), Spiral 1's human-in-the-loop simulation data led to the following conclusions:

- UAV, Crew Size, and Tempo each had significant impact on performance;
- Reduction in crew size adversely affected performance as number of UAVs being controlled was increased;
- Increase in event rate had a significant impact on performance as the number of UAVs being controlled increased;
- Secondary task performance dropped as a function of number of UAVs; and
- Operator attitudes relative to feasibility, reasonableness and acceptability was significantly influenced by number of UAVs.

The Spiral 1 flight test, which only tested the number of UAVs and the number of operator's conditions, revealed similar trends in performance and subjective feedback to what was seen in the simulation. The averages across the conditions were generally lower in flight test as compared to the simulation. However, it should be noted that the flight test data was limited as the number of participants was only four (Spiral 1 simulation had 12 participants) and some of the test cells were incomplete due to flight test conditions and constraints.

Both the empirical data collected and experimenter observations from Spiral 1 indicated that the visual load and attention demands were heavily concentrated on the task of sensor video inspection, looking for ground personnel and manipulating the sensors to determine whether or not the detected personnel were armed. This load increased with the number of UAVs resulting in reduced primary and secondary task performance. The empirical findings, both objective and subjective, led the team to the development and integration of additional technology and modifying the operator interface design to help reduce the visual demands (e.g., scanning and dwell time) required across the control station displays. The goal was to make pertinent task information more easily accessible by placing the data on or adjacent to the sensor management area of the control station and provide alternate ways to become aware of state changes and retrieve requested information through multi-modal methods (e.g., visual alerts and state information overlaid on the videos, auditory alerts, speech recognition and synthesis to retrieve and report data).

Preliminary analysis of Spiral 2's simulation results, which had ten participants and only employed the "high" event rate, suggests the methods had a positive impact overall as the multi-UAV point surveillance target detection and secondary task performance data, as well the situation awareness and workload ratings, improved from Spiral 1's simulation results. For example, the 1-operator, 4-ship condition showed an 11% increase in target detection and the secondary task performance increased by 40%. Additionally, across all the UAV levels (i.e., 1-, 2-, and 4-UAVs), Spiral 2's China Lake Situation Awareness ratings were better and the NASA-TLX Workload weighted scores were lower than seen in Spiral 1.

It should be noted that the trial times between Spiral 1 and Spiral 2 point surveillance simulations were different with Spiral 1's lasting approximately 10 minutes whereas Spiral 2 was approximately 8 minutes in length. The interval between target events for the primary task was the same (30 seconds on average) so there was a difference in total number of target events given the total trial times were different, while the number of secondary tasks was the same for both spirals. Another performance measure taken in the point surveillance

task was based on correctly reporting whether or not the personnel detected were armed. The Spiral 2 simulation had a different ground texture and weapon model than used in Spiral 1 which could have had some effect on the ability to identify whether or not the personnel were armed. As a result, the associated performance data (i.e., percentage of targets correctly identified) is not included as part of the comparison.

The MUSCIT Team experienced significant challenges in preparing for and conducting the Spiral 2 flight test. Weather and equipment problems hampered the ability to conduct the tests as planned. Only four of the planned six participants actually completed the tests. Furthermore, due to equipment issues, only two aircraft were available for the data collection which led the team to employ two Bat 3 aircraft and two simulated aircraft for the 4-UAV trials. Additionally, windy conditions for portions of the data collection sessions resulted in less than ideal test conditions. Consequently, the data is somewhat suspect in fulfilling the intended analyses and drawing any firm conclusions, but the data showed similar trends to the simulation but with a sharper drop-off in detection performance for the 4-vehicle condition, along with generally less positive subjective ratings.

14.9 LESSONS LEARNED

As the MUSCIT program proceeded from Spiral 1 to Spiral 2 the need to re-address attention management, information access and control methods became apparent. The multi-vehicle control station prototype design evolved from earlier applied research that concentrated primarily on scenarios with tasks that were typically more sequential in nature. A priori knowledge of the targets (and their locations) and associated operator tasks permitted the mission routes and operator action points to be set up in a scheduled and orderly fashion. The information presentation and control methods supported the tasks and the allotted time could be managed to some degree by the operator through careful mission and route planning. The fact that assorted mission, flight, and sensor management information was spread across a large display area did not surface as a significant issue in previous efforts and demonstrations. The scenarios and RSTA tasks examined in MUSCIT's tests exercised the user interface in some different ways, which in turn, highlighted some areas for improvement.

Initially MUSCIT's point surveillance scenario was thought to be fairly low in terms of complexity in that the vehicle(s) loitered about the known locations and the operator would concentrate mainly on manipulating the sensor(s) and reporting on the ground activity. However, given the asynchronous nature of the target events, there was a degree of uncertainty on what to expect and when to expect it. This, along with the rate of target events, compelled the operator to visually attend to the sensor management area in an attempt to detect and identify the targets. Cross-checking for system status and tactical information in the mission and flight management areas could come at the cost of not detecting one or more targets. Therefore, the uncertainty and pace of these mission tasks highlighted the need for design enhancements to the control station prototype. As previously noted, the subsequent spiral concentrated on enhancing the design by introducing additional technology and modifying the control station, and improvements in performance were realized. The modified control station provided means to relieve some of the visual demands and ease control, however, challenges remain to enhance operator performance beyond levels achieved.

The spiral approach taken to conduct a human-in-the-loop simulation followed by a closely aligned flight test has afforded important insights into the supervisory control technology and human performance. The simulations were tightly controlled experiments used to manipulate the number of operators and UAVs and permitted a rigorous method to quantify human performance and capture subjective data. The flight tests were more constrained given the flight test environment and resources, and it was subject to more nuisance variables and variability across the conditions and between the participants, but it provided the team a greater

understanding and appreciation for how actual UAV systems perform and can be affected by assorted environmental conditions. The flight tests exposed the test conditions to elements that may have been overlooked, ignored, or over simplified in the simulations. For example, the wind and visual conditions were not varied in the simulation but in flight test the conditions could vary across the course of the data collection for a given participant, as well as between the participants, and could invoke different levels of sensor management workload. Thus, the flight test brought a better understanding of the real-world complexities associated with multi-UAV supervisory control and can be used, with the simulation findings, to derive technology requirements and lead to further advancements in the controls, displays and decision aids, and the overall supervisory control capability.

Finally, given what has been learned in the MUSCIT program to this point, perhaps "the problem" should be examined from another perspective as well. Rather than focus entirely on the operator-to-vehicle ratio and striving for equitable performance as the vehicles are increased, the program might consider including a detailed assessment of the number and type of tasks and sub-tasks that must be completed within an allotted amount of time, with a goal to effectively manage more tasks, of greater complexity, and within the mission time "budget". In essence, try to characterize capability (e.g., mission effectiveness and crew performance) as a function of task complexity, number of simultaneous tasks, task sequence, time available, number of assets, number of operators, etc. This more bottom-up approach to developing MUSCIT's control station technology could potentially complement the top down approach by addressing the fundamental work components which, in turn, might help guide technology development and ultimately provide answers to how many UAVs and operators are needed to effectively and consistently accomplish specified mission tasks. In addition, rather than use equitable operator performance and feedback across all the data collected as a goal when increasing the number of UAVs, perhaps the team needs to more closely examine task and sub-task priorities, dictated by the mission and the operator, and come up with a way to recognize and weight these priorities with regard to assessing the adequacy and effectiveness of the entire system. Finally, it might be useful to explore how multiple vehicles could be concentrated on a single objective or a set of serial objectives, looking at how 1-*n* vehicles can be used to more effectively accomplish RSTA tasks and missions. In other words, determine when it is more effective to use a team of UAVs on a given objective versus one UAV. Certain multi-UAV operations may be more acceptable in terms of situation awareness, workload, and performance levels when the UAVs are concentrated and coupled on one common task or objective, rather than disparate ones.

14.10 STUDY CONSTRAINTS/LIMITATIONS

14.10.1 Flight Testing "Live" and "Virtual" UAVs

For the flight tests, the goal was to conduct the one, two and four UAV case using the Bat 3 UAVs in all the conditions. However, all the Bat 3s planned for were not available due to assorted reasons for both Spiral 1 and 2 flight tests resulting in tests that involved a mixture of "live" and "virtual" UAVs, thus the sensor imagery depicted was actual video and simulated video in the four UAV cases. Observations suggested that the participants attended to the systems differently at times. The participants appeared to spend less time watching and manipulating the simulated systems than they did the "live" systems. Part of this may have been due to the instability (e.g., jitter and bounce), variable image quality, more frequent drift of the live sensor about the target location, and somewhat slower zoom rates seen with the actual sensor. These differences may have attributed to the operator having to manually control the Bat 3 sensor position more frequently than with the virtual system. The bottom-line is that there appeared to be some difference in operator attention to and interaction with the live and virtual systems, which raises concerns with the flight test data collected in the 4-UAV condition.

14.10.2 Success Criteria

Opinions have varied widely in establishing credible and challenging exit or "success" criteria for the MUSCIT program. How many UAVs should the single operator control station technology effectively support? Under what conditions? What are the appropriate measures of performance and mission effectiveness, and to what levels should the program strive for? One approach is to try to achieve equivalency of performance, effectiveness, and subject-matter expert acceptance. However, as the effort and associated control station technology take on more UAVs and under more complex conditions, the goal of reaching this equivalency may be setting expectations too high. Another opinion expressed is that drop-off of operator performance associated with any one UAV in the multi-UAV operations should be expected to some degree and that the capability or mission "success" is in the aggregate. More is potentially accomplished as more vehicles are introduced. However, this view of the system emphasizes the benefits without addressing the potential costs (e.g., missed targets, mishaps). How much drop-off in performance and effectiveness for any single UAV is acceptable? Given the somewhat exploratory nature of this domain, the MUSCIT team chose to press for equivalency as it sets a measureable level to reach for, realizing it may be very challenging to obtain with the current state of the enabling technologies and resources available.

14.10.3 Testing the System

In setting up the point surveillance task and associated environment the team was uncertain on what rate of target activity was appropriate to represent a meaningful and relevant mission situation. Given there was not a prescribed level to simulate a "typical" mission, the team opted to implement a task rate that would reduce the likelihood of encountering a ceiling effect. Thus, the technology would likely support the one-UAV condition fairly well with regard to performance, but perhaps not perfectly in all cases and, similarly, the 2- and 4-UAV cases would result in less than perfect performance. In essence, the MUSCIT team chose to create a test that was likely too difficult to "ace". Some of the participant feedback suggested that the event rate was higher than they typically encounter so perhaps the bar was set too high, and the performance disparity seen between the 1-, 2-, and 4-UAV conditions amplifies too negatively on the technology and overall capability. A "lesser" test might have resulted in more equivalent performance, effectiveness and opinion across the number of UAVs.

14.11 CONCLUSIONS

The MUSCIT program is attempting to advance UAV control station technology to enable effective multi-UAV RSTA operations by a single operator. It has developed a spiral approach, combining simulation and flight test, to characterize performance, empirically derive and refine technical requirements, and advance the technology and overall capability. Through the approach, the MUSCIT program has advanced control station technology and improved single-operator, multi-UAV performance.

The MUSCIT technology demonstration for NATO HFM-170 consisted of single-operator, multi-UAV point surveillance using the Air Force Research Laboratory's Vigilant Spirit Control Station technology. The demonstration provided the NATO HFM-170 members an opportunity to see the flight test set-up, control station technology, and flight test operations. The demonstration, along with periodic meetings, provided a forum to exchange technical information and discuss possible future collaborations in supervisory control research and development.

14.12 FUTURE RESEARCH NEEDS AND PLANS IN THIS AREA

In the next spiral, the MUSCIT team will increase mission complexity and afford operator(s) more latitude with respect to "managing" the mission. Participants will be afforded an extended training opportunity so they

can become more familiar with the array of technologies and the various ways to employ the controls and displays during the prosecution of a mission. The next spiral will be less structured than the previous in that the participants will be able to employ different strategies in accomplishing the mission tasks, which is expected to provide additional insight into the control station utility and possible enhancements. The evaluation will also include an enhanced 2-operator control station design to allow for transfer of vehicle and sensor control between operators which will permit the MUSCIT team to examine crew task allocation and management methods.

14.13 ACKNOWLEDGEMENTS

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14.14 REFERENCES

[1] Feitshans, G.L., Rowe, A.J., Davis, J.E., Holland, M. and Berger, L. (2008). Vigilant Spirit Control Station (VSCS): The Face of COUNTER. *AIAA Guidance, Navigation and Control Conference and Exhibit* (AIAA-2008-6309).