

Baseline and Multimodal UAV GCS Interface Design

Progress Report

January, 2012 – March, 2012
Call-up W7711-0-8148-07

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Contract Report
DRDC-RDDC-2014-C136
July 2013

Abstract

To improve operational effectiveness for the Canadian Forces (CF), the Joint Unmanned Aerial Vehicle Surveillance Target Acquisition System (JUSTAS) project is acquiring a medium altitude, long-endurance (MALE) uninhabited aerial vehicle (UAV). In support of the JUSTAS project, Defence Research and Development Canada (DRDC) – Toronto is investigating the human factors issues of UAV ground control stations (GCS) interfaces for UAVs and exploring possible solutions using multimodal displays. This progress report provides an update project from January of 2012 to March of 2012 of this Baseline and Multimodal UAV GCS Interface Design. The report discusses the running of the baseline condition of the experiment for the naïve participants and participants with flying experience. The design and the implementation of the multimodal display are also addressed.

Executive summary

Baseline and Multimodal UAV GCS Interface Design: Progress Report

Background: Uninhabited aerial vehicles (UAVs) are remotely controlled aircraft used for a variety of civilian and military applications including command, control, communications, computers, intelligence, surveillance and reconnaissance (C4ISR). To improve C4ISR capability, the Canadian Forces (CF) is acquiring a medium-altitude, long-endurance (MALE) UAV under the Joint Unmanned Aerial Vehicle Surveillance Target Acquisition System (JUSTAS) project. In support of the JUSTAS project, Defence Research and Development Canada (DRDC) – Toronto is investigating the human factors issues of UAV ground control stations (GCS) interfaces for UAVs and exploring possible solutions using multimodal displays. This project, the Baseline and Multimodal UAV GCS Interface Design, is ongoing as of March of 2012.

Results: As of March of 2012, the participant running of the baseline condition ran smoothly and with few issues. System issues that occasionally occurred were noted and discussed in this report. The design and implementation of the multimodal display was still ongoing. Silent gaps between alarms were added to improve the quality of the auditory warnings. The design of the tactile experiment was finalized and the running of the participants was started.

Significance: Running of the participants of the baseline condition was completed as of March 2012. The known systems issues were examined to reduce the occurrence of such issues in the running of the multimodal condition of the experiment. The significance of the multimodal display design and the implementation of the multimodal display design to the experiment are also addressed.

Future plans: As of March 2012, the goals of the project were to evaluate the running of participants of the baseline condition and decide whether further participants were required and to finalize the design of the tactile display the implementation of the multimodal condition to the experiment.

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1 Introduction

An Uninhabited Aerial Vehicle (UAV) is an aircraft system without an onboard pilot or crew. The UAV is controlled from a Ground Control Station (GCS). Today's UAVs are highly automated and to some extent, autonomous. UAVs can be directed to follow a pre-programmed path; they can fly to designated waypoints, fly specific patterns, correct for course deviations and hold above a particular coordinate or target. Some UAVs can perform automated take-off and landing (ATOL) (e.g., the CU-170 Heron used by the Canadian Forces). UAV developers argue that automation and autonomy provide several benefits: (a) increased flight safety; (b) simplified operations; (c) lower operating costs; and (d) reduced operator workload (Attar, 2005). However, these benefits are not always realized. Along with the benefits of automation, some disadvantages occur such as loss of situation awareness (Endsley and Kiris, 1995; Endsley, 1996), loss of supervisory control (Parasuraman, Molloy, Mouloua, & Hilburn, 1996; Sheridan, 1987), information deprivation that occurs from remote operations (Manning, Rash, LeDuc, Noback, & McKeon, 2004), and high workload levels for operators (Lee, 2008; Woods, 1996). These issues point to the need for improved interfaces to help these operators remain in the loop and maintain situation awareness during the remote monitoring tasks typical of UAV monitoring.

The work described in this report is in support of the Canadian Forces (CF) Joint Unmanned Aerial Vehicle Surveillance Target Acquisition System (JUSTAS) project. The JUSTAS project entails the acquisition of a long-endurance UAV. This work is directed towards understanding the human monitoring challenges with UAVs similar to the UAVs that could be acquired through the JUSTAS project. Further, this project will explore the use of multimodal interfaces for UAV control leading to new design criteria for UAV ground control stations, or improved requirements for future acquisitions.

This work builds on the work of Giang et al., 2010 which reviewed the current research on multimodal displays and ecological displays for UAV control. This report is a mid-project progress report detailing the work that has occurred in order to prepare for a large scale study of two GCS designs. One of the GCS designs will be a visual interface (called the “baseline condition”), essentially simulating as closely as possible the current interface for a MALE UAV. The other design will be a multimodal interface where tactile and auditory information will be added to the interface to see if this new information can improve operator performance and situation awareness.

A number of goals have been accomplished between January and March of 2012, since the beginning of this call-up, to support the Baseline Condition running and the design and testing of a multimodal Uninhabited Aerial Vehicle (UAV) Ground Control Station (GCS) simulator. This report will outline the progress in two activities: the participant running of the baseline condition of the experiment and the design of the multimodal GCS interface.

2 The Baseline Condition

2.1 Introduction

Running of the baseline condition of the experiment was started in January 2012. The purpose of the baseline condition is to provide a referent by which to gauge the influence of the multimodal GCS displays. In the baseline condition, novice and expert participants fly the UAV in a range of scenarios using visual displays that are representative of UAV displays currently in use.

2.2 Method

2.2.1 Ethics Approval

The experimental protocol described in this document received clearance from the Human Research Ethics Committee at Defence Research and Development Canada (DRDC), as well as the Office of Research Ethics, at the University of Waterloo.

2.2.2 Experiment Room Setting

The experiment has two work stations, one for the participant flying the UAV and one station for the experimenter to monitor the progress of the experiment. A partition was placed between the experimenter and the participant to minimize the disruption to the participant. In order to monitor the participant's computer in case of software problems, a video camera was placed in the participant zone as shown in Figure 1. The camera is oriented to monitor the displays and not to observe the face of the participant. This camera provides a live feed but the video is not recorded from the camera.

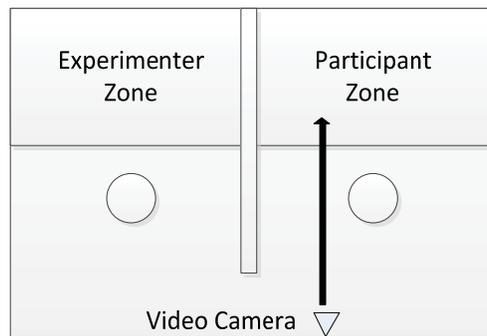


Figure 1. The layout of the GCS experiment room

2.2.3 Participant Recruitment

There are two participant groups in this experiment: naïve participants with no pilot experience; and expert participants with at least 10 hours of self-declared pilot experience. Expert participants were recruited from students in the University of Waterloo Aviation program as well as from a local flying club “Wings Over Waterloo”. Expert and naïve participants received identical experimental treatments.

All participants were required to complete 3 two hour sessions within a one week time period. The typical time-slots were: 9am-11am, 12:30pm- 2:30pm, 3pm- 5pm, 5:30pm- 7:30pm. However, the time-slots were adjusted sometimes to meet the special requests of the participants. No participants ran past 7:30pm at night. A sample schedule from the week of March 5 2012 is shown below in Figure 2.



Figure 2. The participant schedule of the week March 5 – March 11 of 2012.

2.2.4 Participant Attrition

From January 1 to March 31 of 2012, 30 naïve participants and 9 expert participants successfully completed the GCS baseline condition (Table 1). It should be noted that due to the requirements for participants to be eye-tracked, there was some attrition due to participants not reliably meeting the eye tracking calibration requirements. While these requirements could cause a participant to leave the experiment at any session, in most cases these participants were removed at the first session.

Table 1. Participants recruited and completed in the baseline condition.

	Number of Naive Participants	Number of Expert Participants
Expected	30	10
Successfully Completed	30	9
Recruited	34	10
Failed	4	1
- Failed in the first session	3	1
- Failed in the second session	1	n/a
- Failed in the third session	n/a	n/a
Failure Rate	12%	10%

2.2.5 Participant Remuneration

All participation in the study was on a voluntary basis. Remuneration was in accordance with DRDC stress allowances. Participants were remunerated \$10.00 if they failed to meet the training criteria and the initial calibration, \$20.00 if they withdrew after completing the first session, \$40.00 if they withdrew after completing the second session and \$61.20 at the end of the third session.

2.2.6 Procedure

At the start of each session, participants gave their wristwatches, pagers or cellphones to the experimenter in order to reduce distractions. At the first session, participants read the information package and, if willing to proceed, signed the informed consent form. Subsequently, the participant watched a short training video on the procedures for operating the UAV and responding in the experiment. The participant was calibrated on each of the two eye trackers for the first time and completed two test scenarios to ensure that they had a clear understanding of how to operate the UAV and how to register their responses during the experiment. For the remainder of session one, the participant completed two experimental scenarios. In each of session two and three, the participant completed 5 more experimental scenarios for a total of 12 scenarios. All participants completed the same training scenarios, but the experimental scenarios were randomized for each participant.

Within each scenario, there were two random pauses where participants were asked questions to assess their situation awareness. The participant also rated their confidence in their monitoring performance on a scale of 0 to 100%. At the completion of the scenario, the participant again rated their monitoring performance for the entire scenario on the same scale. During the scenario, participants were expected to detect critical events and report this by pressing an Operator Concern button. During the landing phase, if the participant did not feel the UAV could land safely, they were instructed to abort the landing of the UAV.

While monitoring the UAV, participants also performed a secondary task. The secondary task was a wind shear monitoring task. In this task, a number appeared on the screen of a separate computer (the secondary task computer) every 2 seconds. If the number was less than 130 or greater than 170, the participant was instructed to press the space bar on the computer.

At the completion of the last scenario of each session, the participant was asked to complete a computerized version of the NASA-TLX assessment of perceived mental workload.

2.3 Results

The baseline condition ran smoothly and with few problems. There were a few system issues that occasionally occurred. These are recorded in Appendix 1. Results are not available at this time as the experiment is still in progress and the data analysis approach is under discussion.

3 Design and Implementation of the Multimodal Displays

In the last contract report (Giang et al, 2011), a number of ideas were proposed for the auditory and tactile interfaces for the multimodal GCS interface. This section of the report will describe the finalized auditory and tactile displays and their implementation in the multimodal condition of the experiment.

3.1 Design of the Auditory Displays

Two multimodal displays were integrated into the code of the GCS simulation. Stub code for interfacing with the Tucker Davis Technologies (TDT) System 3 and the Engineering Acoustics Inc. (EAI) Tactor Unit the multimodal displays was added to the GCS simulation code.

TDT provided sound generator that was integrated into the GCS simulation. The TDT also provided a visualized auditory circuit development environment called System 3. An auditory circuit was built (shown in Figure 3) under the System 3 development environment to create the sonification as well as overlay alarms. We obtained written approval from Dr. Judy Edworthy to use high urgency sounds she had developed in previous research (Edworthy et al., 1991) and used these sounds as alarms in our sonification. We have established six links in the circuit. The links (shown in Table 2) are used to turn auditory alarms on and off and to adjust the TDT System 3 volumes in the GCS code. The volumes include control over the signal to noise ratio of the auditory alarms and the engine RPM sonification volume.

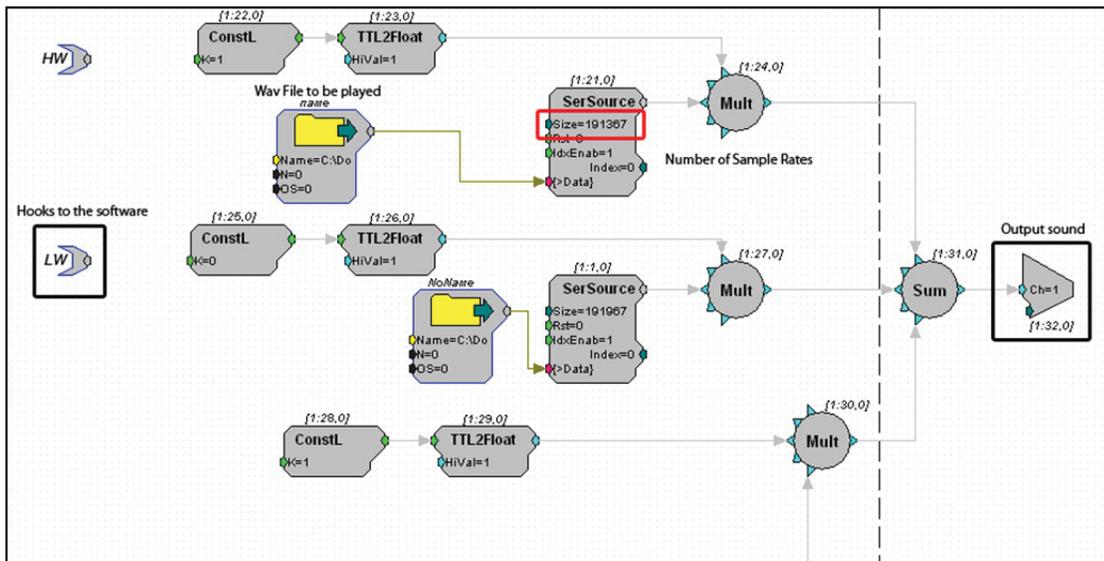


Figure 3. Tucker-Davies Technologies auditory circuit.

Table 2. Auditory links.

Links	Level
LW	Turn the Low Engine RPM alarm on or off
HW	Turn the High Engine RPM alarm on or off
LWVol	Increase or decrease Low Warning volume
HWVol	Increase or decrease High Warning volume
Freq	Set the fundamental frequency of the engine RPM sonification
FreqVol	Increase or decrease engine RPM sonification

3.1.1 Silent Gaps between Alarms

The original alarm sounds were bursts of sound separated by brief silent intervals. To ensure the alarms were distinguishable, the silent gaps (Figure 4) between each of the alarms were adjusted (Table 3). This ensured that individual bursts could be distinguished.

Table 3. Gaps between two bursts of alarms.

	Original (milliseconds)	Current (milliseconds)
Low Warning	100	500
High Warning	200	1000

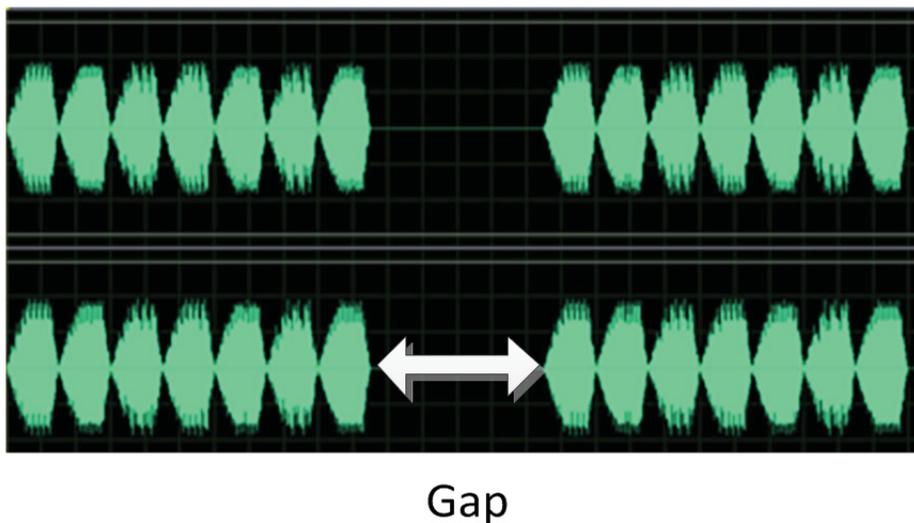


Figure 4. The gap between alarm bursts.

3.2 Design of the Tactile Displays

Different potential tactile display designs are currently being investigated. The four different designs being considered are a full tactile bar (the equalizer display) and a single factor level indicator (the sequential display). These designs are shown in Figure 5. These designs are being tested in one and two column versions to comprise the four designs under consideration. The designs are being evaluated for discriminability and their ability to convey urgency.

3.2.1 Method

Participants completed two tasks, one to examine the discriminability of the displays and one to gauge the perceived urgency of the displays.

The first task, examined a participant's ability to discriminate between different levels of activation after they are presented a tactile pattern. This task tested how a tactile pattern can improve or hinder discrimination, and also tested the effects of habituation and adaptation. Participants were presented with a single level of activation for one of the tactile display designs. Participants were asked to respond to the level of activation and to indicate the level of activation by pressing the appropriate number key (1, 2, 3, or 4) on the keyboard as quickly as possible. Response time and accuracy are recorded for each key press. Each condition was replicated 10 times and the order of presentation randomized. Two types of tactile patterns were used and are shown in Figure 5. In the first pattern, the factors individually actuated to the target level in sequence, with an inter-factor duration set between each level of activation; this type of pattern was named the "up pattern". The second pattern was very similar to the first, but instead of stopping at the target level, the pattern went to the next level before returning to the target level; this type of pattern is named the "up-down" pattern. The participant's task was to indicate the level of activation after the pattern had stabilized and they were asked to do this as quickly and as accurately as possible. Participants indicated the final level of activation using a keyboard by pressing the appropriate number key (0, 1, 2, 3, or 4). The independent variables were the type of pattern, the final level of activation (1, 2, 3, or 4 for the up pattern and 0, 1, 2, or 3 for the up-down pattern), the inter-factor duration, and the display type (4 types). The dependent variables are response time and accuracy. Each condition was replicated 5 times and the order of presentation was randomized.

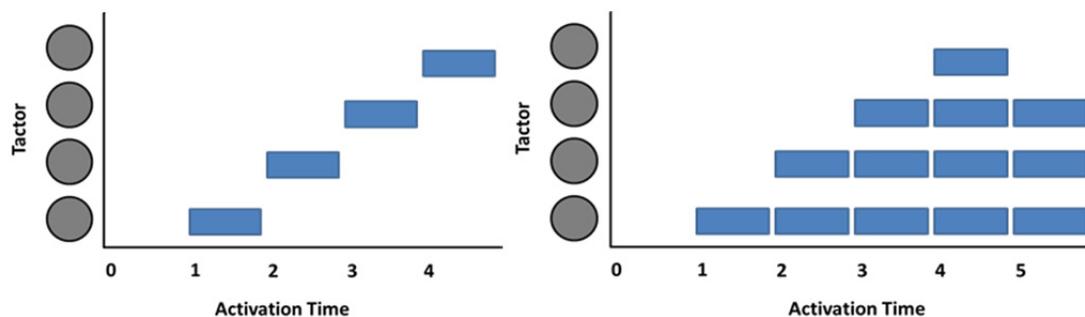


Figure 5. Left - "Up" activation sequence for the "sequential" display. Right - "Up-Down" pattern of activation for the "equalizer" display.

The second task was the urgency task. The goal of this task was to assess the perceived urgency of the four display types, at different activation levels, and at different inter-tactor durations. (Figure 6)

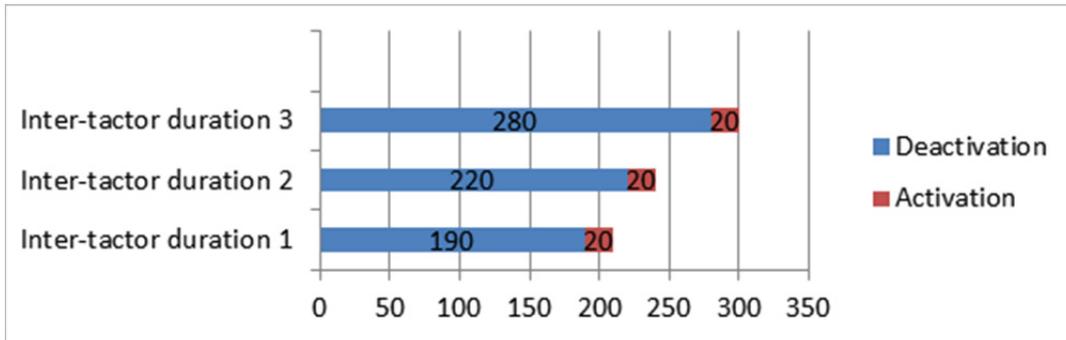


Figure 6. Inter-tactor durations.

Two presentation methods were investigated in the urgency task. The first method used single tactor activations, and the second method used tactile patterns. In the first method of presentation, participants were presented with a single level of activation for one of the displays for 5 seconds. Participants were then asked to report the perceived urgency of the stimuli on a scale between 1 and 100 using an approach adapted from Arrabito et al. (2004). Each presentation method was replicated 5 times and the order of presentation randomized. After completion of all trials, a questionnaire about the annoyance level of each of the designs was presented to the participants.

A 3x3 grid for tactors deployment on the vest was proposed and implemented. Figure 7 shows the layout of the tactor grid. Only tactors in the left and right hand columns activated in the experiment.

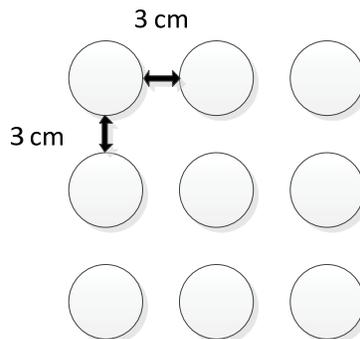


Figure 7. Tactor grid.

3.2.2 Preliminary Results

Three participants completed the experiment by the end of March of 2012. At the time of writing, data analysis was not appropriate. However, the preliminary results confirm that the experiment was running well and further participants are anticipated.

4 Summary

In conclusion, we have made considerable progress between January and March of 2012. The Baseline Condition is almost completed. The project also made progress on the design of the GCS multimodal interface. The tactile design testing was started. In the year of 2012, the goal for the next few months is: 1) to examine the data from the baseline condition and evaluate whether any changes or further participants are required 2) to finalize the GCS multimodal interface design and 3) to complete the multimodal condition.

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List of symbols/abbreviations/acronyms/initialisms

CF	Canadian Forces
DRDC	Defence Research & Development Canada
EAI	Engineering Acoustics Inc.
GCS	Ground Control Station
JUSTAS	Joint Unmanned Aerial Vehicle Surveillance Target Acquisition System
MALE	Medium-altitude, Long-endurance
NASA-TLX	NASA Task Load Index
SA	Situation Awareness
TDT	Tucker Davis Technologies
UAV	Uninhabited Aerial Vehicle

Annex A. System Failures and Defects

The GCS system consists of five networked computers (Table 2) and several interacting software components. While the overall system was quite stable throughout the experiment, the complexity of the system has meant that occasional faults do occur. Several of these faults are known and the experiment team has developed operating protocols to handle the fault and reduce the loss of data. Only the experimenter computer is in the experimenter zone in Figure 1.

Table 4. GCS computers

Computer Name	Duty	Stores Data
Experimenter Computer	Launch the simulation	Yes
XPlane Computer	Operated by the participant; convey the UAV monitoring task	Yes
Eye Tracking Computer - 1	Automatically control the left eye tracker	No
Eye Tracking Computer - 2	Automatically control the right eye tracker	No
Secondary Task Computer	Operated by the participant; convey the secondary task	Yes

The known faults and their treatment are discussed in the following subsections.

4.1.1 XPlane Computer Slow Reboot

The XPlane computer took 20 minutes to reboot.

Reason: The NVidia video card driver on the XPlane computer was searching the Internet for product updates on startup. However, the computer was not connected to the internet for security reasons.

Solution: The rebooting issue was solved February 23, 2012 by eliminating the update process. This did not affect the functioning of the video card or the simulation..

4.1.2 Secondary Task does not Appear on Secondary Task Computer

After the UAV reaches 400 feet in the GCS Simulation, the secondary task begins. In some cases, the secondary task does not begin. The data from the secondary task would be lost, but the rest of the data was available.

Reason: Currently unknown.

Solution: Confirm all programs on the secondary task computer were properly shut down and nothing else is running on the secondary task computer. If the secondary task monitor is black at the start of the scenario the task will start up correctly. Stop and restart the scenario immediately if the screen is not black. Ensure that the mouse and keyboard are switched to the correct computers before beginning the scenario.

4.1.3 Situation Awareness Questionnaire did not appear on Secondary Task Computer

In each scenario the GCS simulation stops twice for situation awareness questions. In some cases, the Situation Awareness questionnaire did not appear.

Reason: Currently unknown.

Solution: The data from the questionnaire would be lost, but the rest of the data was available.

4.1.4 Crashes on XPlane Computer

There were various kinds of crashes on the XPlane computer. One crash happened with a pop-up message on XPlane computer: "X-Plane Software has encountered a problem and needs to close". All log files up to that point were kept and there was no data loss up to this point.

Reason: Currently unknown.

Solution: Confirm data had been saved correctly. If no events had occurred yet the scenario would be restarted, otherwise the scenario was ended at that point. Data was available until the point of the crash.

4.1.5 Scenario Manager freezes

The Scenario Manager is an application on experimenter computer. This is the center control module of the GCS simulation system for starting, stopping and switching scenarios. In this situation, all log files are lost and the simulator continues running. This can occur at any time during the simulation, but was often occurs around 300 seconds into the scenario.

Reason: Currently unknown.

Solution: Close down the simulator from the XPlane computer using the batch file or from the experimenter computer (as preferred). If no events have occurred yet the scenario could be restarted.

4.1.6 Black Box on Raw Video Recording

A screen saver records the screen of the XPlane computer within GCS simulation. The recording is called "Raw Video". A black box was discovered in January, 2012 that appears on the recording from the Xplane computer screen. There is no data loss and the participant does not see the box while the experiment is running.

Reason: Currently unknown.

Solution: After starting the simulation, click anywhere on the far left hand monitor (X-plane camera view) then launch the UAV and the black box will not appear in the recording.

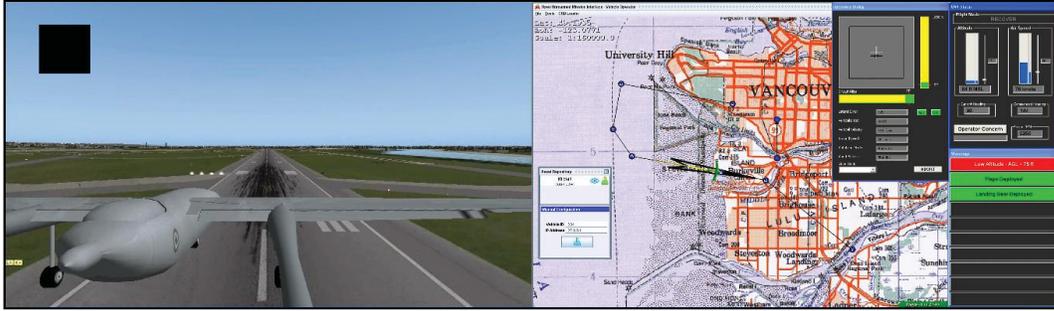


Figure 8. The “Black Box”