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Multi-UAS Operational Assessment: Class D Airspace

Simulation Report

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16. Abstract

The Federal Aviation Administration (FAA) is investigating issues pertaining to the integration of Unmanned Aircraft Systems (UAS) into the National Airspace System (NAS). This report documents the results of the Multi-UAS Operational Assessment: Class D Airspace, human-in the-loop (HITL) simulation study conducted on August 23-September 1, 2011, at the FAA William J Hughes Technical Center. This study was one of a series of research activities designed to support the integration of UAS into the NAS. The specific objective of this high fidelity, HITL simulation was to identify and document specific events and their effects on the NAS associated with mixing multiple simultaneous UAS operations with manned aircraft operations within Class D airspace. The simulated airspace chosen to represent the Class D airspace characteristics of interest was the Southern California Logistics Airport, situated in Victorville, CA. The UAS used in the operations of the study were the A-160 Hummingbird, MQ-1B Predator, RQ-11 Raven, and AS800 JPL Blimp. The HITL simulation specifically explored the impact of multiple simultaneous UAS and manned aircraft, in both nominal and off-nominal conditions, to air traffic control communications, workload, situation awareness, efficiency, and safety of the operations. Study results show that the proposed operations were not feasible as simulated, and that several key interoperability requirements must be identified and implemented before simultaneous Class D operations with manned and multiple unmanned aircraft can be considered. This research also highlights the need for additional robust validation studies and comprehensive safety evaluations before the implementation of any operations proposed in this study.

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EXECUTIVE SUMMARY

The Federal Aviation Administration (FAA) is investigating issues pertaining to the integration of Unmanned Aircraft Systems (UAS) into the National Airspace System (NAS). Within the aviation community, interest in using UAS for a broad range of purposes is increasing, making UAS access to the NAS a top priority. There are many challenges to understand and overcome before the basis for certification and operations of UAS are standardized and made routine. These challenges include developing methods to support the integration of UAS into the NAS without causing delays, capacity reduction, and placing the public at risk. Extensive research is required to produce the required safety case evidence. The FAA has multiple activities underway to support the UAS safety case and reach the community-wide objectives of reducing operational restrictions and allowing for more routine UAS access to the NAS.

This report documents the results of the Multi-UAS Operational Assessment: Class D Airspace, human-in the-loop (HITL) simulation study conducted on August 23-September 1, 2011, at the FAA William J Hughes Technical Center. This study was one of a series of research activities designed to support the integration of UAS into the NAS. The specific objective of this high fidelity, HITL simulation was to identify and document specific events and their effects on the NAS associated with mixing multiple simultaneous UAS operations with manned aircraft operations within Class D airspace. This study examined multiple safety and efficiency effects to understand and explore the feasibility of the proposed operations.

The simulated airspace chosen to represent the Class D airspace characteristics of interest for this study was the Southern California Logistics Airport, situated in Victorville, CA (KVCV). The UAS used in the operations of this study were the A-160 Hummingbird, MQ-1B Predator, RQ-11 Raven, and AS800 JPL Blimp.

The HITL simulation scenarios specifically explored the impact of multiple simultaneous UAS and manned aircraft, in both nominal and off-nominal conditions, to air traffic control (ATC) communications, workload, situation awareness, efficiency, and safety of the operations. It also documented the effects to manned aircraft as a result of introducing UAS to the airspace. For data analysis purposes, these scenarios were partitioned into two groups: comparative analysis scenarios and descriptive analysis scenarios. The nine comparative analysis scenarios each consisted of approximately 17 manned aircraft operations, to which UAS operations were incrementally added. The goal of the comparative analyses was to determine any noticeable differences that occurred when incrementally adding UAS. The 17 descriptive scenarios also consisted of approximately 17 manned aircraft operations. These scenarios included unique UAS combinations and/or off-nominal events designed to allow for a case-by-case evaluation of the operations simulated in each of the scenarios.

The findings of this study are based on the data collected during the simulation and the knowledge and experience of ATC subject matter experts (SME) who are proficient in FAA policy and procedures for operating UAS in the NAS. Current FAA policies and standard operating procedures found in a Certificate of Authorization (COA) for operation of UAS were the basis for evaluation. The current limitations of one UAS operating in the Class D airspace at a time was eliminated in order to focus solely on simulating and documenting the effects of

multiple UAS in Class D airspace. Due to the UAS platform's inherent lack of see and avoid capabilities, current FAA policy requires the use of visual observers, either on the ground or airborne, as the sole source for safety mitigation. Although visual observers were not an element of the study design, their presumed duties and roles were evaluated by SME's. Therefore, comments regarding visual observers were based on SME observations, assumptions, and expertise and were not a measured result. The scenarios developed and tested were based on actual flight operations conducted at KVCV. The air traffic controllers who contributed as test participants were also from KVCV and have operational experience working UAS.

A complete summary of the results of this study is included in Section 5 of this document. Several key safety, efficiency, workload, and situation awareness issues were identified during the course of this study. The key issues are: The responsibility for see and avoid was in question when UAS complied with ATC instructions to extend upwind/downwind. This may have placed the UAS in a position that was beyond the visual range of the ground observers. Dissimilar flight characteristics and the inability for UAS pilots in command to visually acquire and follow other aircraft in the traffic pattern were observed as a main causal factor for delays, loss of situation awareness, extended patterns, increased air traffic controller workload, and a general reduction in overall safety. Significant impact to Class D operations was observed when UAS required use of the runways. The presence of UAS in the traffic patterns caused ATC to issue go-arounds and other traffic pattern modifications. ATC altered or denied manned aircraft requests, and/or denied entry into Class D airspace, during UAS fly away and lost link events. The presence of UAS contributed to increased ATC workload especially with more than one UAS present. Lost link events, and in particular fly away events, notably increased workload, affected the manageability of the traffic in Class D airspace, and appeared to reduce ATC situation awareness. Several scenarios highlighted the need for establishing standards for the roles and responsibilities of the visual observer. For example, it was unclear how a visual observer would provide collision avoidance for a UA from a second UA operating in the same area. It was also unclear how two or more visual observers communicated with each other and what instructions are necessary to prevent a collision with multiple UAS present. It was unclear how a visual observer provides instructions to a pilot of a UA to avoid a collision with another UA that cannot be easily seen due to its small size. When multiple visual observers are used, transfer of responsibility for see and avoid from the airborne observer (located in the chase aircraft) to the ground observer was unknown. Standard operating and communication procedures for visual observers are unknown.

This limited scope operational assessment of multiple simultaneous UAS operations in Class D airspace suggests the proposed operations were, in general, not feasible as simulated. This operational assessment brought focus to the fact that UAS are heavily reliant on systems such as voice/data links, onboard sensors, and other entities, such as visual observers and air traffic controllers, in order to safely conduct operations in Class D airspace. The ATC SMEs involved in the study noted that several key interoperability requirements must be identified and implemented before simultaneous Class D operations with manned and multiple unmanned aircraft can be considered. Some key requirements include, but not limited to the follow: standards for visual observers (ground and airborne); ATC roles and responsibilities for handling UAS; standards for wake turbulence; standards for lost link procedures; pilot compliance with

FAR 91.113[1], Right-of-way rules; pilot compliance with Visual Flight Rules (VFR); and, most importantly, pilot compliance with visual ATC instructions in the NAS.

It is anticipated that the exploratory role of this study will help to identify further areas of research in Class D airspace operations as the UAS community progresses toward the goal of UAS integration into the NAS.

Prior to implementing any operation observed in this study, it is recommended that robust validation studies and comprehensive safety evaluations first be conducted.

[1] FAR 91.113: (b) *General.* When weather conditions permit, regardless of whether an operation is conducted under instrument flight rules or visual flight rules, vigilance shall be maintained by each person operating an aircraft so as to see and avoid other aircraft. When a rule of this section gives another aircraft the right-of-way, the pilot shall give way to that aircraft and may not pass over, under, or ahead of it unless well clear.

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1. Introduction

1.1 Background

The Federal Aviation Administration (FAA) is investigating issues pertaining to the integration of Unmanned Aircraft System (UAS)[2] into the National Airspace System (NAS).

Within the aviation community, interest in using UAS for a broad range of purposes is increasing, making UAS access to the NAS a top priority. Current requests for access to the NAS are subject to technical and operational assessments of the specific UAS operation in question based on interim approval guidance. UAS operations are subject to operational limitations when there is any perceived risk to the public. It has been a growing imperative within the UAS community, including public and civil users, to reduce these restrictions and support more routine access in order to improve and advance integration of UAS into the NAS. Therefore, validated operational standards and policies need to be established.

To standardize the certification processes and ultimately reduce restrictions associated with UAS certification, the FAA needs to determine the parameters, operations, and procedures that define acceptable UAS behavior while maintaining the highest level of safety and not reducing NAS efficiency. There are many challenges we must overcome before the basis for certification and operations of UAS are standardized and made routine. This includes developing methods to support the integration of UAS into the NAS without causing delays, capacity reduction, or placing the public at risk. Extensive research is required to produce the required safety case evidence. This study, the Multi-UAS Operational Assessment: Class D Airspace, was one of a series of research activities that support the integration of UAS into the NAS.

In addition to the simulation exercise set forth in this report, the FAA has multiple complementary activities underway which are funded via the Research, Engineering and Development; Facilities and Equipment; and Operations portfolios to support the UAS safety case and reach the community-wide objectives. The exercise described herein leveraged work from these efforts as well as those being addressed by other community parties, allowing for the mitigation of risks associated with the accomplishment of future UAS research and demonstration activities.

1.2 Objective

The objective of this high-fidelity, real-time, human-in-the-loop (HITL) simulation was to understand, identify, and document specific events and their effects on the NAS associated with mixing multiple, simultaneous, UAS operations with manned aircraft operations within Class D airspace. This study examined multiple safety and efficiency effects to explore the feasibility of the proposed operations. The Southern California Logistics Airport, situated in Victorville, CA (KVCV), was the airspace chosen to represent the Class D airspace characteristics of interest.

[2] A UAS is the unmanned aircraft (UA) and all of the associated support equipment, control station, data links, telemetry, communications and navigation equipment, etc., necessary to operate the UA. The UA is the flying portion of the system, flown by a pilot via a ground control system, or autonomously through the use of an on-board computer, communication links, and any additional equipment that is necessary for the UA to operate safely. A UA is operated without the possibility of direct human intervention from within or on the aircraft.

1.3 Research Partner Roles and Responsibilities

1.3.1 Federal Aviation Administration

The roles and responsibilities of the FAA organizations involved in this study are described below.

Unmanned Aircraft Systems Group

The FAA's Unmanned Aircraft Systems Group (AJV-13) served as the FAA liaison to the industry partner and to the UAS community members involved. AJV-13 was also the sponsoring organization responsible for the planning and funding of this project, providing the overall leadership and direction. Members of AJV-13 also served as Subject Matter Experts (SME) on the research team.

Engineering Development Services Branch

The FAA's Engineering Development Services Branch (ANG-C3) designed and conducted a real-time HITL simulation and analyzed the resulting data. ANG-C3 provided a Principal Investigator (PI), research team members, and all technical staff to support the study. ANG-C3 was in turn supported by other FAA organizations

William J. Hughes Technical Center

The William J. Hughes Technical Center (WJHTC) houses the laboratories and supplied laboratory support services utilized during our simulation activities.

1.3.2 Industry Partner

Serco Inc. was the industry partner working with the FAA on this study. Serco Inc. provides contract tower services at KVCV for the FAA. For this simulation, they provided information on current operations and participated in the planning and development of the study. Serco Inc. also provided SME to take part as study participants.

1.3.3 UAS Community

In support of the study, UAS community members provided highly detailed aircraft performance data for the UAS platforms involved in the simulation. Specifically, General Atomics Aeronautical Systems, Inc. and the California Air National Guard provided performance parameters related to the MQ-1B (Predator). The Boeing Company provided data for the A-160 (Hummingbird Helicopter). AeroVironment provided information related to the RQ-11 (Raven), while the National Aeronautics Space Administration (NASA) – Jet Propulsion Laboratory (JPL) provided data related to the AS800 (JPL Blimp).

2. Method

2.1 Participants

Two representatives from the target population, Class D air traffic controllers, participated in this limited scope exploratory study. Participants alternated working ground and local control throughout the first half of the study, as appropriate. They interacted with each other as well as with simulation support staff (see Section 2.3). Participation in this study was voluntary and participants had the freedom to withdraw at any time without penalty (see Appendix A).

2.2 Research Team

Researchers from the FAA, together with contract support personnel, designed and implemented the research effort. A PI, supported by research and laboratory support services staff, was responsible for the overall administration of the exercise, including briefings, experimental procedures, and data collection. Supporting research staff prepared experimental materials and assisted in the collection and analysis of data. Members of the research team served as laboratory coordinators to facilitate the conduct of the study.

2.3 Simulation Support Staff

Trained simulation pilots and air traffic control (ATC) SME developed the simulated environment in which the exercise participants operated.

2.3.1 TGF Simulation Pilots

A total of 13 simulation pilots supported this exercise. The simulation pilots supporting this study were licensed manned pilots. Two of the simulation pilots also held rotorcraft certificates. To maintain consistency throughout the study, the same simulation pilots were available throughout the entire process, including training, scenario shakedown, and simulation runs without substitutions (however, minimal exceptions were permissible).

All simulation pilots gained familiarity with the airspace scenarios, activities, and procedures during scenario development and shakedown. A robust and thorough pilot training program was conducted prior to the start of the exercise to familiarize the simulation pilots with the airport, airspace, and air traffic operating environment. Each simulation pilot controlled a limited number of individual aircraft, both manned and unmanned, by issuing commands on their own workstation. The simulation pilots communicated on the appropriate simulated frequencies and issued aircraft commands in response to verbal instructions from the air traffic controllers.

2.3.2 Ghost Coordinator Position

During the simulation, one ATC SME served in the Ghost Coordinator Position. The Ghost Coordinator simulated all peripheral and inter-facility coordination, including the controlling authority for the surrounding and overhead airspace. The Ghost Coordinator also emulated airport operations such as KVCV crash/fire/rescue and weather services. Finally, the Ghost Coordinator conducted the UAS pilot in command (PIC) operations (both control and voice) for the JPL Blimp and Raven. To be fully prepared for the simulation runs, the Ghost Coordinator

gained familiarity with the airspace, scenarios, and ATC and UAS procedures during scenario development and scenario shakedown. The Ghost Coordinator had the ability to communicate appropriately (via frequencies or land lines) for his designated roles.

2.3.3 Expert Observers

Two ATC SMEs served as Expert Observers, one for each air traffic controller participant. The SME monitored the frequency of the position they observed and manually collected supplemental simulation data via the Observer Rating Form (Appendix E).

2.4 Assumptions and Limitations

Since UAS operations are currently restricted as to where and how they operate, rules and procedures for operating outside Special Use Airspace (SUA) were required. Specific assumptions and limitations were identified and acknowledged as they relate to the conduct and analysis of this exercise. They are detailed below:

- Weather conditions were at or above basic Visual Flight Rules (VFR), as required for Class D airspace (3 statute mile visibility, 1,000' ceiling)
- Certificates of Waiver or Authorization (COA) for the UAS were in effect with the exception that multiple UAS activities within the Class D airspace were allowed
- All UAS aircraft operated under VFR. However, participating non-UAS aircraft were able to operate under VFR or Instrument Flight Rules (IFR), depending on the particular flight operation
- Compliance with current ATC separation standards in accordance with FAA JO7110.65
- SUA within R-2508 complex was active
- The Cab Simulation Suite (CSS) provided a 2-dimensional presentation of a 3-dimensional operational environment
- In the CSS, visual acuity was simulated to approximately 85% (when compared to the live environment)
- There was a limited sample size of participants
- REHOST radar display was utilized as a Situation Awareness (SA) aide
- Helicopter performance limitations
- No passing on the taxiways or runways (a/c and vehicles)
- No 180 degree turns on taxiways or runways
- No head-on traffic on the airport surface

2.5 Equipment

2.5.1 Unmanned Aircraft Simulation Models

The Target Generation Facility (TGF) custom-developed four physical aircraft models for use in this simulation: the A-160 Hummingbird, the JPL Blimp, the MQ-1B Predator A, and the Raven. The aircrafts' physical models were developed and tested by TGF engineers and based on proprietary data provided by the aircraft manufacturers specifically for this simulation. They are highly realistic models that accurately represent the performance characteristics and physical attributes of each aircraft type.

Specifically, the Hummingbird and JPL Blimp used the TGF's newest 6 Degrees of Freedom (DoF)[3] vehicle kinetic simulation programs developed for rotary-wing and airship kinetics. The Predator A and Raven used the TGF's legacy 4 DoF fixed-wing kinetic simulator. All models were validated and verified by input from current air traffic controllers and airline pilot SME. In addition, all four UAS have very accurate, high-quality 3D visual models developed by Digimation, Inc. specifically for use in this simulation.

2.5.2 Manned Aircraft Simulation Models

All of the manned aircraft physical models that were used in this simulation were either fully developed by TGF or derived from EUROCONTROL's Base of Aircraft Data and enhanced by TGF. They are highly realistic models that accurately represent the performance characteristics and physical attributes of each aircraft type. All models were validated and verified with input received from current air traffic controllers and airline pilot SME. The kinetics of the physical models were simulated from the rotary-wing kinetic simulator or the fixed-wing kinetic simulator, as appropriate.

The following 17 manned aircraft models were used in the simulation. Although every attempt to exactly replicate the aircraft type, paint scheme/livery, and registration number of the manned aircraft was made, substitutions were made for certain aircraft where the performance differences were deemed insignificant. The substitutions were made in order to leverage modeling resources readily available at the FAA WJHTC. Those substitutions are noted, where applicable:

- CH-46
- H/C-17 (Slam 88)
- F-18
- C-12
- PA-34, deemed an appropriate substitute for the PA-44
- C-172
- C-182
- BE-58, deemed an appropriate substitute for the BE-70
- DC-10
- C-402, deemed an appropriate substitute for the C-414
- B-206
- H-500
- B-767
- B-707
- B-737 (Justice 703)
- B-737 (SWA3471)
- MO-20 Mooney (used in the exclusive role of chase plane in a limited set of scenarios)

[3] Six degrees of freedom (6 DoF) refers to motion of a rigid body in three-dimensional space, namely the ability to move forward/backward, up/down, left/right (translation in three perpendicular axes) combined with rotation about three perpendicular axes (roll, yaw, pitch). As the movement along each of the three axes is independent of each other and independent of the rotation about any of these axes, the motion indeed has six degrees of freedom.

The visual models for the manned aircraft came from two different sources: Digimation, Inc. and the FAA's Tower Visualization System. To expressly represent aircraft in the simulation, Digimation, Inc. provided several accurate high-quality 3D models (namely the B206, H500, YMQ-18A, and a Ryan Air paint job for the B763). In addition, Digimation Inc. models created for previous simulations were used wherever possible (example: B738).

2.5.3 Cab Simulation Suite

The CSS is located at the Airport Facilities Tower Integration Laboratory (AFTIL) in Building 170 of the WJHTC. The CSS contains a 360 degree out-of-the-window tower visualization display, a control tower wrap-around console, and tower support equipment. The CSS laboratory provides a realistic operational environment for evaluating enhanced ATC procedures. Figure 1 shows the display area layout of the CSS. For this study, the tower emulated aircraft flying in the KVCV Class D airspace. The CSS was driven by the TGF and Distributed Environment for Simulation, Rapid Engineering, and Experimentation (DESIREE) systems.

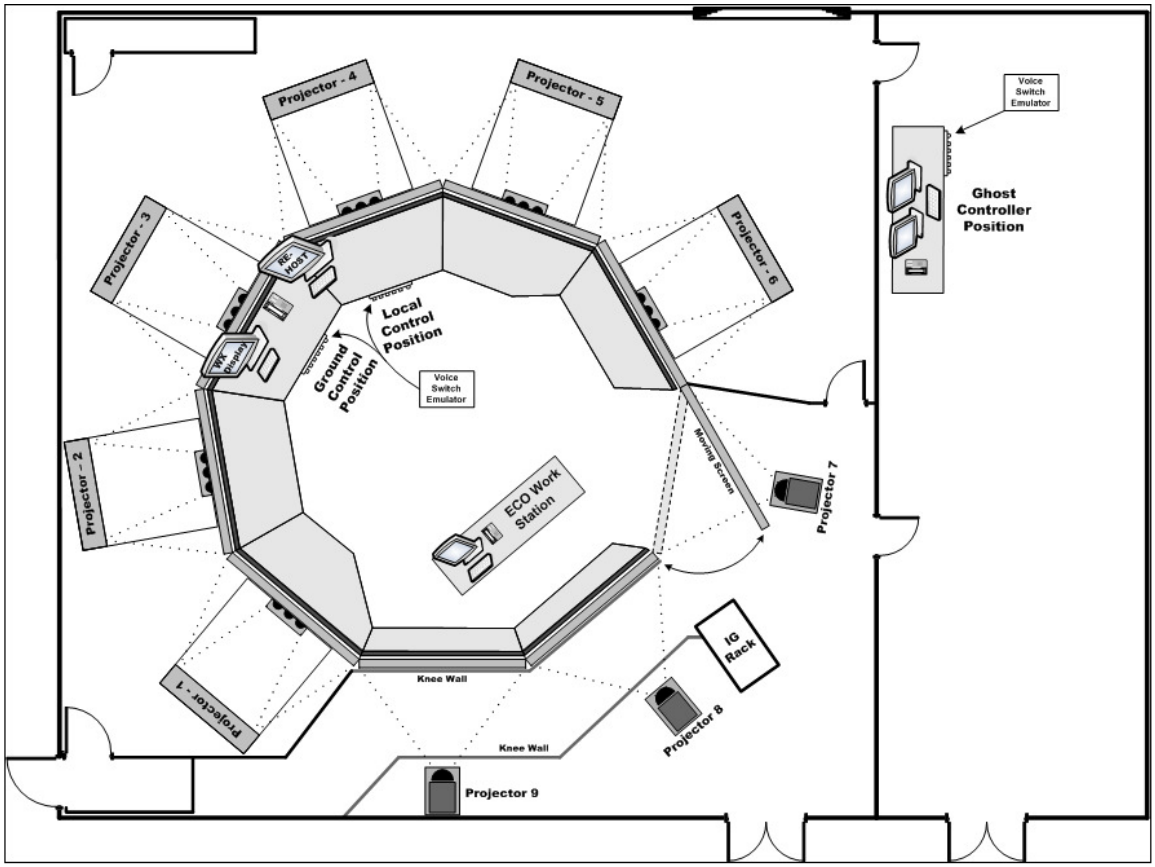

Figure 1: Cab Simulation Suite Layout within the WJHTC's AFTIL

2.5.4 TGF and DESIREE

The TGF is a multi-function, crosscutting infrastructure that is capable of simulating air and ground traffic and driving terminal, en route, and developmental laboratories. The TGF enables researchers to investigate new systems and procedures without having to fly actual aircraft operations.

The TGF uses preset flight plans to generate radar tracks using dynamic flight models and presents aircraft targets on the simulation pilot displays. The TGF simulation pilot displays can be used as an interface to enter flight plan changes. The TGF algorithms can control aircraft maneuvers so that they appear, to the air traffic controllers, to represent realistic aircraft climb, descent, and turn rates. In addition, the TGF allows researchers to capture information about aircraft trajectories, aircraft proximity, and other relevant data for use in analysis.

For this study, the TGF drove the CSS by providing all air and ground traffic, radar tracks, simulation pilot stations, and the Ghost Coordinator positions. The TGF operated in conjunction with DESIREE to generate the simulation environment.

DESIREE consists of a series of interchangeable Human Machine Interfaces. It has the capability to emulate multiple ATC platforms and displays. Its purpose is to enable researchers to modify or add information and functionality to a variety of current ATC environments to allow for the evaluation of new concepts and procedures. DESIREE receives input from TGF that allows it to present information on a radar display (e.g., STARS, DSR, and ERAM), including radar tracks, data blocks, and sector maps. It also allows air traffic controllers to perform the typical functions that they would perform in the appropriate ATC operational environment (e.g., performing handoffs, entering data into the host computer). DESIREE can also emulate "Ghost Sector" operations by providing automation to control these unstaffed sectors. When needed, this automation can communicate with the TGF to act as a simulation pilot for the aircraft. Like TGF, DESIREE has data collection capabilities and can collect information on all air traffic controller entries made during a simulation run.

For this study, the DESIREE system supplied the REHOST radar display and information, the static weather display in the CSS, the Workload Assessment Keypad (WAK), and the Event Marker.

2.5.4.1 TGF Simulation Pilot Workstations

The TGF Simulation Pilot laboratory is located in the WJHTC's Building 300. A total of 13 TGF simulation pilot workstations were used for this experiment. These workstations each consisted of a computer, keyboard, monitor, and communication equipment. Each simulation pilot controlled the TGF-generated aircraft by issuing commands on their respective workstations. The commands were pre-defined strings of alphanumeric characters entered using a standard workstation keyboard.

Each simulation pilot also had a plan view (i.e., 2D) display of traffic and a list of assigned aircraft. The JPL Blimp and Raven were controlled automatically and did not require simulation pilots. All aircraft were equally distributed among the manned simulation pilots, with the exception of the Predator, the Hummingbird, Slam 88, and N5604H, and, when necessary, aircraft in closed traffic. The exceptions were high level, control-intensive aircraft which required maximum attention on the part of the pilots and were therefore controlled by one pilot each. For each assigned aircraft, the simulation pilots had information regarding the aircraft's current state and corresponding flight plan data.

2.5.4.2 Ghost Coordinator Workstation

One Ghost Coordinator workstation was required. The workstation included audio communications, a monitoring capability of the simulated frequencies, and direct communication ability to/from the study participants to simulate coordination, as needed, during the study. The workstation also included the Simulation Action Viewer/Java Plan View Display (SAV/JPVD) capability to monitor and/or interact within a simulation run, as well as the appropriate monitors and keyboards needed to perform these functions.

2.5.4.3 REHOST Radar Display

In the field, the REHOST system displays radar target and aircraft track data for air traffic and mission control within the Restricted Area R-2508[4] Complex, High Desert Terminal Radar Approach Control (TRACON), and at several airfields in the immediate area including KVCV. High Desert TRACON is an IFR-certified ATC facility staffed and controlled by the FAA that provides terminal and en route radar ATC services in the NAS. The REHOST system was initially designed as an interim replacement for the existing Mosaic-tracking Direct Access Radar Channel (MDARC) system and is continually being upgraded to serve the R-2508 community's unique and changing requirements. To economically satisfy these requirements, the REHOST system utilizes off-the-shelf technology and offers a high degree of reliability.

For this study, the REHOST radar display was located in the CSS. Actual map and adaptation data from the fielded REHOST system was used to create a simulated, functional version of the system that is in use at KVCV. The simulated REHOST system functions as an integrated component of the DESIREE environment.

2.5.4.4 Workload Assessment Keypad

Subjective workload measures were obtained from the air traffic controller participants using the Air Traffic Workload Input Technique (ATWIT) methodology. The WAK was present at each participant position, allowing the participants to record their perceived workload levels during the simulation runs.

The WAK consists of a touch panel display with seven sequentially numbered buttons (see Figure 2). Through auditory and visual cues, the WAK prompted participants to provide their subjective workload ratings every two minutes. During the prompt, the numbered buttons on each device illuminated and emitted a brief tone. The participants indicated their current level of workload by pressing one of the numbered buttons, with "1" indicating low workload, "4" indicating typical workload, and "7" indicating high workload.

The buttons remained illuminated for the duration of the response period (20 seconds) or until a participant made a response, whichever came first. If no response was made within the 20-second period, a score of "99" was entered, indicating that a miss was recorded or the participant was too busy to respond (a determination made by an SME observer).

The participants received complete WAK instructions at the beginning of the experiment and at the daily in-briefing. Workload was defined as the combined cognitive and physical demands experienced by an operator. The workload experienced by an operator depends on the task, along with the skill, knowledge, abilities, and training of that particular operator. Generally, workload is considered to be an operator's response to task load. Participants also received brief reminders of the WAK instructions before each training and simulation run to refresh their memory and

[4] The R-2508 Complex includes all the airspace and associated land presently used and managed by the three principal military activities in the Upper Mojave Desert region: Air Force Flight Test Center, Edwards Air Force Base; National Training Center, Fort Irwin; and Naval Air Weapons Station China Lake. The R-2508 Complex is composed of internal restricted areas, Military Operations Areas, Air Traffic Control Assigned Airspace areas, and other special airspace. Use of these areas include bombing ranges, supersonic corridors, low altitude high speed maneuvers, radar intercept areas, and refueling areas.

increase the likelihood that they would use the same rating criteria every time. WAK data was collected and time stamped by DESIREE.

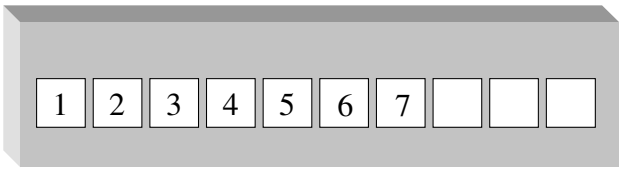

Figure 2: Workload Assessment Keypad (WAK)

2.5.4.5 Event Marker

The time of occurrence of particular events of interest were captured by an SME observer through the use of an Event Marker button. The events of interest were specified beforehand and reflected the individual goals and objectives of the study. These included events such as operational errors, delays, missed approaches, etc. The Event Marker button created a timestamp in the DESIREE data recordings that were used post hoc to help point to specific events of interest that require further analysis.

2.5.5 Communications

A simulated communication environment permitted realistic air-ground and ground-ground voice communications between the KVCV controllers, simulation pilots, and Ghost Coordinator. The communications set up allowed for selection, interconnection, and activation of the Local, Ground, and Ghost frequencies (118.350 MHz, 124.450 MHz, and 124.550 MHz, respectively) in the simulated operational environment. Landline communications were also available to support the simulated KVCV operations, as appropriate.

In addition, the communications environment was used to support coordination between various research team resources located in the AFTIL and TGF laboratories. A special “Team” frequency (411.411 MHz) and landline connections were put in place solely to support the execution of the study and did not interfere with the simulated ATC operational environment. Table 1 and Figure 3 describe the communications set up for this study.

Table 1: Frequency to Position Mapping

	Frequencies			
Station	**Local 118.350 MHz**	**Ground 124.450 MHz**	**Ghost 124.550 MHz**	**"Team" Frequency 411.411 MHz**
Local Controller	Tx/Rx	Tx/Rx	Tx/Rx	
Ground Controller	Tx/Rx	Tx/Rx	Tx/Rx	
Ghost Coordinator (Adjacent ATC)	Tx/Rx	Tx/Rx	Tx/Rx	
TGF Simulation Pilots	Tx/Rx	Tx/Rx	Tx/Rx	
TGF Predator A & A-160 PIC	Tx/Rx	Tx/Rx	Tx/Rx	
Local Observer	Rx Only			
Ground Observer		Rx Only		
	Research Team			
AFTIL Coordination Position	Rx Only	Rx Only	Rx Only	Tx/Rx
TGF/Simulation Pilot Coordinator	Rx Only	Rx Only	Rx Only	Tx/Rx

Rx: Receive
Tx/Rx: Transmit and Receive

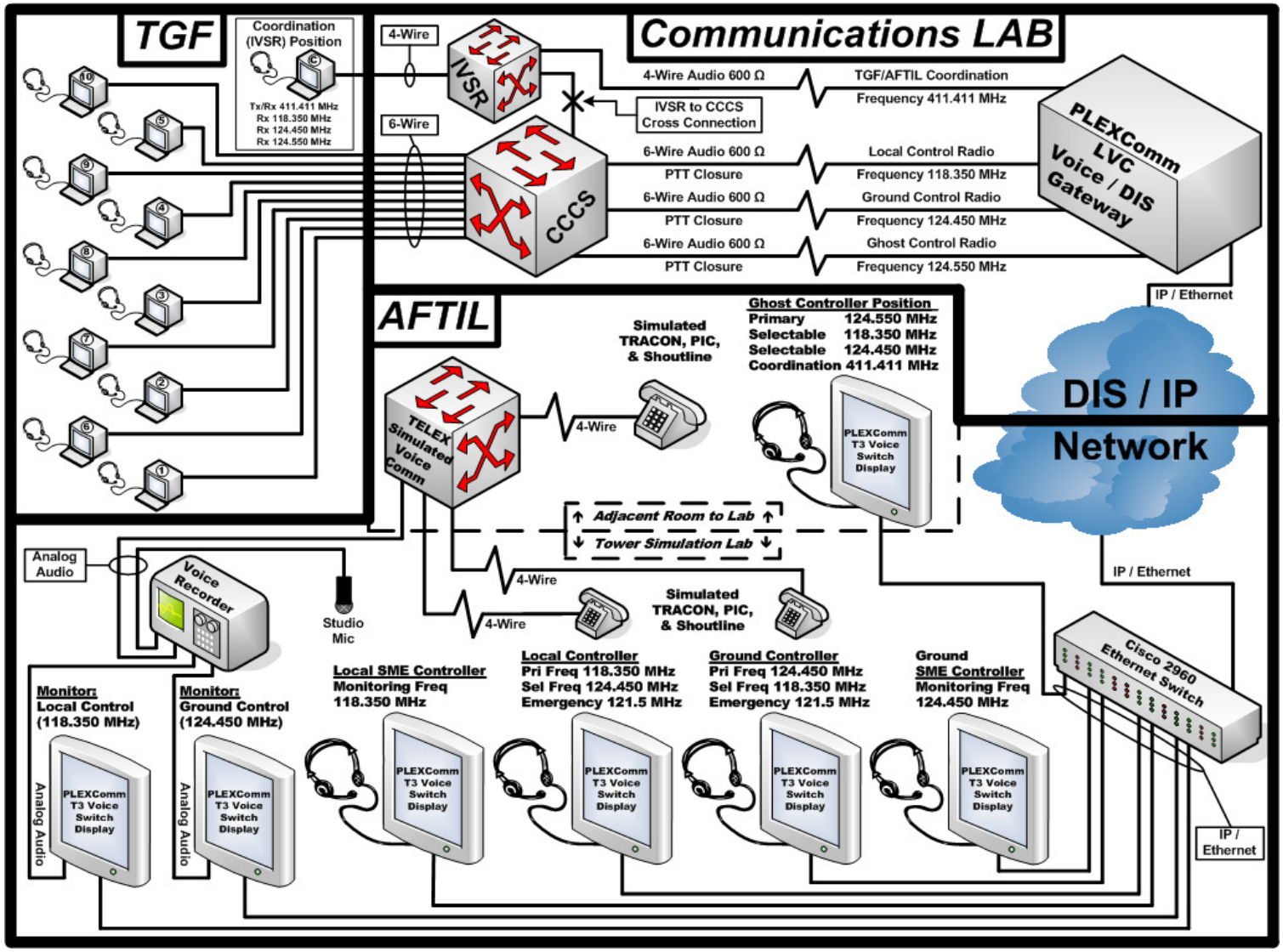

Figure 3: Communications Configuration

2.5.5.1 Air-Ground Communications

At KVCV, several air-ground voice communications methods are used between ATC and the aircraft. Specifically, for communications with manned aircraft, the MQ-1B Predator, and the A-160 Hummingbird, KVCV utilizes standard VHF/UHF communications. ATC communicates with the RQ-11 Raven and the AS800 JPL Blimp via land-line and/or cellular telephone. The following describes how these communications were simulated for the study.

The TGF simulation pilots used standard ATC headsets with push-to-talk (PTT) capability, which are plugged into the voice communications interface of the simulation pilot workstations. Each workstation's voice communication interface was directly connected to the Combined Control and Communications System (CCCS)[5]. The CCCS provided the selection and switching between the simulation pilot workstations and the three designated frequencies to the air traffic controllers — KVCV Local Control (118.350 MHz), KVCV Ground Control (124.450 MHz), and the Ghost Coordinator Position (124.550 MHz) — just as any of the operational NAS voice switches would. Within the CCCS, each frequency was assigned a unique physical port where the CCCS placed the corresponding PTT signaling.

Each of the CCCS ports, for the three simulated frequencies of this study, were linked to a unique physical port in the PLEXComm® Live Virtual Constructive (LVC) via a 6-wire, 600 ohm twisted pair cable. The PLEXComm® LVC is a Distributed Interactive Simulation over Internet Protocol (DIS/IP) Gateway. Distributed Interactive Simulation is an open standard for interconnecting voice switches, radar systems/simulators, and host computers for the purpose of conducting real-time, platform-level simulation. DIS is defined under the Institute of Electrical and Electronics Engineers (IEEE) Standard 1278. For the air-ground communications of this study, the PLEXComm® LVC took in the voice communications from the CCCS, including the PTT signaling, and converted it into DIS data packets for real-time IP transport over the DIS/IP Network. This network is configured between the two WJHTC laboratories: one in Building 300, the other in Building 170. Network security was not a risk or concern as this DIS/IP network is a closed private network supplied by a dedicated fiber optic backbone between the two buildings.

Once across the DIS/IP network, the packetized voice data traveled through a Cisco 2960 Ethernet Switch for dissemination to the appropriately IP-addressed PLEXComm® T3 Voice Switch Display[6]. For this study, the Local controller, Ground controller, and Ghost Coordinator each had a dedicated PLEXComm® T3 Voice Switch Display. There were also two additional PLEXComm® T3 Voice Switch Displays for the Expert Observer to monitor the Local and Ground frequencies. These two additional PLEXComm® T3 Voice Switch Displays were connected to a voice recorder for the purpose of recording the Local and Ground frequencies. There was also a studio microphone connected to the voice recorder for capturing ambient audio.

[5] The CCCS is an automated switching and communications system that connects and interconnects various FAA voice switching systems at the WJHTC such as the TGF simulation pilots, external cockpit simulation pilots, live radios, and voice recorders.

[6] The PLEXComm® T3 Voice Switch Display is a stand-alone communications system which allows the selection and de-selection of frequencies or channels that are configured into it. Either a standard ATC headset with PTT or Universal Serial Bus (USB) based headset with PTT can be used with the PLEXComm® T3 Voice Switch Display.

2.5.5.2 Ground-Ground Communication

Normal landline communications at KVCV included inter-facility coordination between KVCV and the High Desert TRACON (E10/JOSHUA Approach), between KVCV and two of the UAS platforms (i.e., the JPL Blimp and Raven), and other routine airport operations such as crash, fire, rescue, and weather services. These communications were simulated within the AFTIL using the TELEX® Radio/Intercom system. This system was configured to allow the Local and Ground controllers to communicate with the Ghost Coordinator via telephone handsets that have a PTT function, thereby simulating regular telephone service.

2.5.5.3 Research Team Communication

To allow for direct coordination between the Ghost Coordinator Position in the AFTIL and the Laboratory Coordinators (in areas of the different laboratories), spare capacity on the voice portion of the DIS/IP network was utilized to enable a "Team" frequency on 411.411 MHz. This worked in the same manner as the voice communications between the simulation pilots and the air traffic controllers except instead of utilizing the CCCS, a different system called the Interim Voice Switch Replacement (IVSR) was used. This configuration prevented the simulation pilots from accessing the team coordination frequency. To ensure start synchronization and aid in overall monitoring of the simulation, a cross connection between the CCCS and IVSR was added so that the Laboratory Coordinators could also listen non-intrusively to the communication exchanges between the air traffic controllers and simulation pilots as they interacted.

2.5.6 Video Recordings

Two black and white cameras provided input to video capture cards installed in a Windows-based PC utilizing two Digital Rapids video capture cards. The cameras were mounted in front (and slightly to the side) of each air traffic controller position to capture their actions during the study. . A time code converter synched the video files with the simulation time generated by TGF. Each video signal was captured by the card and processed by a Windows Media encoder. A Windows Media File was generated for each video capture. After each day of runs, all files were networked to a data repository in Building 28 of the WJHTC. In a post-simulation process, two corresponding audio signals were added to each video view file. These audio signals were derived from the appropriate air-ground frequency for the controller position.

2.5.7 Virtual Binocular System

In order to simulate the use of handheld binoculars that are in use today by ATC personnel, CSS was equipped with a handheld Virtual Binocular System SV (VBSV) from nVis Inc. The VBSV featured a 800x600 display and 40 degree field-of-view, with focus-adjustable eyepieces. Stereopsis was supported via two independent video outputs. The VBSV was equipped with an internal, ISC-900 Mini-Trax motion tracker from InterSense®. The tracking system also included associated tracking hardware and software that required installation within the CSS.

Figure 4: Handheld Virtual Binocular System

2.6 Materials

2.6.1 Airspace

The Southern California Logistics Airport, KVCV, Class D Airspace was the representative airspace environment simulated for this study. It encompasses a 6 nautical mile (nm) radius of the published airport reference point and extends from the surface up to and including 5,400 feet above mean sea level (MSL).

E10 "Antelope Sector" at High Desert TRACON is the controlling authority for the airspace above, and surrounding, the KVCV Class D airspace.

SUA in the vicinity of the KVCV airport consists of Restricted Area R-2515, Barstow Military Operations Area (MOA), and the Buckhorn MOA (which are all part of the R-2508 Complex). The SUA begins approximately 15 nm north of the KVCV airport and extends from the surface to FL200. Figure 5 depicts the Los Angeles Sectional Aeronautical Chart showing KVCV Class D airspace and the SUA nearby.

Although some of the simulated flights either initiated, or terminated, up to 15 nm from the Southern California Logistics Airport and within the High Desert TRACON's delegated airspace, the focus of this study concerned operations within the KVCV Class D airspace.

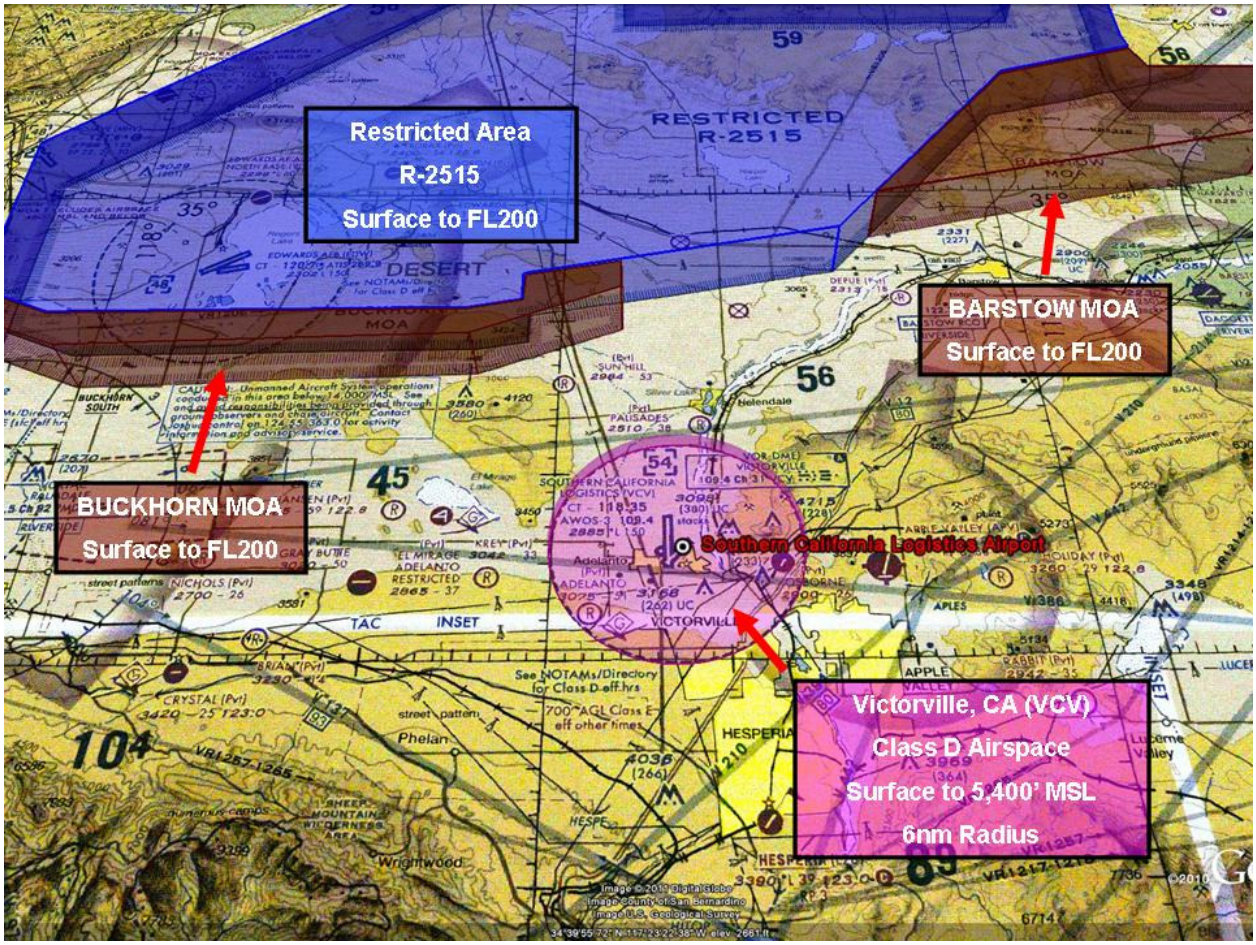

Figure 5: KVCV Class D Airspace and Surrounding Area

2.6.2 Air Traffic Control Operations

KVCV ATC is responsible for air traffic services within the Class D airspace (an approximately 6 nm radius, up to and including 5,400 feet MSL). These services are in accordance with FAA Air Traffic Control Order (JO) 7110.65 and all other Federal Rules and Regulations. For this study, one Local and one Ground controller provided services for the simulated KVCV operations.

Services outside of the Class D airspace were provided by E10, which completely surrounds KVCV Class D airspace (both adjacent to and above). The ATC operations of E10 were simulated by the Ghost Coordinator Position.

2.6.3 Flight Operations

Current flight operations at KVCV are a mix of civil and Department of Defense (DoD) aircraft. Many different DoD units use KVCV Class D airspace and runways for mission training.

There is currently no scheduled civilian air carrier or air taxi service at KVCV. However, KVCV does have Million Air, a civil Fixed Base Operator located on site. Other users making KVCV their home base include Mercy Air (a subsidiary of Air Methods Corporation), a medical services helicopter service that provides rescue flights and air tankers used for fighting wildfires in rural areas.

Several air taxi operators operate at KVCV providing troop transportation under DoD contracts. The Department of Justice also commonly has flights arriving and departing. There are 205 aircraft based on the field, including two single-engine aircraft, two multi-engine aircraft, 191 jet aircraft, one helicopter, and nine military aircraft.

KVCV aircraft operations average 119 per day (based on a 12-month period ending December 31, 2011). A total of 31% is transient general aviation, 46% is military, 16% is local general aviation, 4% is air taxi, and 3% is commercial.[7]

Also present at KVCV are UAS operations that include the four types of UAS previously identified: the Hummingbird, Raven, Predator A, and JPL Blimp. Present day UAS operations at KVCV are authorized under the provisions of a COA issued for each operator and UAS platform. A description of how each UAS currently operates at KVCV follows. Currently (i.e., at the time of the study), these COAs prohibit the simultaneous operation of multiple UAS within the KVCV Class D airspace. For the purposes of the study, the simulated UAS operated within the same bounds of the existing COAs except for the significant change that multiple, simultaneous UAS operations were permitted.

A160 Hummingbird - The Hummingbird is a single engine rotorcraft, 36' rotor diameter and 35' length aircraft. The maximum takeoff weight (MTOW) for the Hummingbird is approximately 6,500 lb. The Hummingbird launches and recovers at the Warrior Ramp, adjacent to the northeastern edge of Runway 21. The Hummingbird is transported via a flatbed truck from its hangar to the Warrior Ramp just prior to launch. Upon launch, it turns to the northeast and moves into its ATC-approved UAS operations area, which is north of Runway 03/21 and extends west to the eastern edge of Runway 17/35. Although not specifically described in the current COA (i.e., at the time of the study), there are two overlapping Hummingbird operations areas, both rectangular flight patterns: one for east/west operations and one for north/south operations. The Hummingbird typically flies at approximately 1000 feet AGL until within the ATC-approved operations area. The Hummingbird recovers at the Warrior Ramp and is trucked back to its hangar. Although in practice the operating altitude of the A-160 varies depending upon the requirements of the UAS operator(s), for the purposes of this study the A-160 requested 5,000' MSL as an operational altitude while in each of the previously described areas. The ATC participants were informed of this altitude exception during the formal in-brief.

RQ-11 Raven - The Raven is a handheld, single engine, fixed-wing, hand-launched aircraft with a 4.5' wingspan and an approximate weight of 4.2 lb. All Raven operations take place within a half nm radius over the area south of the airport known as "Combat Town." Although the current COA (i.e., at the time of the study) allows operations up to 1,000' AGL, typically flights are below 400'AGL and in tight quarters over or within the buildings and compounds.

[7] These numbers are estimates and/or may be rounded off. No data is available for 2011.

MQ-1B Predator A - The Predator A is a single engine, fixed-wing aircraft with a 55' wingspan and an MTOW of 2,300 lb. The Predators are housed in Quonsets south of taxiway Bravo near the approach end of Runway 21. When ready to go, the Predator is taxied to the requested runway and given takeoff clearance. The majority of the work within the KVCV Class D airspace is pattern work, which involves repetitious maneuvers in the traffic pattern culminating with either a landing with a full stop or a touchdown and immediate takeoff, also known as a touch and go. While doing pattern work, only ground observers are required for the UAS flight. If the UAS will be departing the Class D airspace, en route to the Edwards Complex, then a chase aircraft (an airborne visual observer) is required to act as the pilot's eyes (for see and avoid/sense and avoid). Typically, the Predator will do pattern work while the chase aircraft loiters at the High Key Point. When the Predator is ready to proceed out of the Class D airspace, the chase aircraft joins the Predator on its departure roll down the runway and continues out of the Class D airspace.

AS800 JPL Blimp - The JPL Blimp is a lighter-than-air vehicle with a length of 36' and maximum 8' diameter. The JPL Blimp is currently launched early in the day and only on days when the weather conditions do not exceed the operating limitations of the aircraft. The daily weather at KVCV usually provides for calm winds in the morning that begin to gust in the afternoon. Once winds reach 9 knots or greater, the blimp is deflated and returned to storage. The JPL Blimp currently launches and operates at the southwestern end of Runway 17/35 within a very limited area west of the runway. Although the current COA (i.e., at the time of the study) authorizes operations as high as 800' AGL, the JPL Blimp typically operates at a much lower altitude, which is generally at or below 200' AGL.

2.6.4 Traffic Scenarios

Two training scenarios and 26 data collection scenarios were developed for this simulation. They were derived from actual data and field observation of operations at KVCV and verified for realism by the facility Air Traffic Manager. The training scenarios were approximately 60 minutes in duration, while the data collection scenarios were approximately 45 minutes in duration.

For analysis purposes, the 26 data collection scenarios were divided into two separate groups: comparative analysis scenarios and descriptive analysis scenarios.

The comparative analysis portion of the study had nine unique scenarios. The first one was considered a baseline and did not consist of any UAS operations. The remaining eight scenarios consisted of approximately 17 manned aircraft operations, to which UAS operations were incrementally added. The type and mix of the manned aircraft represented typical operations at KVCV today and included air carrier/charter, general aviation, military, local law enforcement, contract air tanker/firefighting, and medical rescue aircraft. Vehicular traffic was present intermittently during all scenarios. See Table 2 for a summary description of the comparative scenarios.

The descriptive analysis portion of the study had 17 unique scenarios. The mix, type, and operations of manned aircraft and vehicles were similar to those used for the comparative analysis scenarios. However, the order in which the aircraft appeared in the scenarios was

slightly altered to mitigate learning effects. In addition, these scenarios had a different variety of UAS operations and in some cases the situation was further complicated by off-nominal events (e.g., UAS experienced lost link, aircraft experienced engine failures, REHOST failure). See Table 3 for a summary description of the descriptive scenarios.

A total of 21 aircraft types (four UAS and 17 manned aircraft) were included in this study. Scenarios included an assortment of approximately 17 to 20 aircraft per scenario. Each scenario included four additional VFR (1200 beacon code) targets to simulate over-flight traffic above and/or adjacent to the Class D airspace. In this simulation, these targets were also referred to as "non-cooperative" aircraft. These aircraft simulated VFR traffic not in contact with ATC, and with no intention of future KVCV Air Traffic Control Tower (ATCT) contact. The aircraft were introduced into the scenarios at a predetermined sequence.

The flight paths of the traffic either overflew the Class D airspace or circumnavigated within a mile or two, as one would expect in the field. The flight tracks and altitudes are depicted in Figure 6. The VFR aircraft were pre-allocated to the Ghost Coordinator's workstation and flew autonomously. Traffic appeared at exactly the same time for Scenarios 1-9, then randomly distributed for Scenarios 10-26.

All traffic scenarios were stored as files on a secure database in the UAS suite at the WJHTC.

Table 2: Scenario Descriptions - Comparative

Scenario Type	Scenario Number	UAS Details	Scenario Details
Training	T1		
	T2		
Comparative Analysis	S1	Manned Baseline. **No UAS**	16 Aircraft. No chase
	S2	**AS800 and RQ-11**	AS800 airborne. RQ-11 calls TWR 5 min into scenario and will T/O 5 min later
	S3	**AS800 and A-160**	AS800 airborne. A-160 calls TWR 17 min into scenario for T/O from Warrior Ramp
	S4	**AS800 and MQ-1B** (MQ-1B and chase on RWY 21)	AS800 airborne. MQ-1B calls for Taxi 5 min into scenario, 3 T&G, joins chase at high key departs to north to EDW.
	S5	**AS800 and MQ-1B** (MQ-1B on RWY 21. No chase)	AS800 airborne, MQ-1B departs 15 min into problem, BU time to call for taxi, 3 T&G RWY 21 FS
	S6	**AS800, RQ-11, and A-160**	AS800 airborne, RQ-11 requests launch at sim+7, T/O 5 mins later., A-160 same as #3
	S7	**AS800, A-160, MQ-1B** (MQ-1B on RWY 21. No chase)	AS800 airborne, A-160 same as #3, MQ-1B same as #5, 3 T&G RWY 21 FS
	S8	**AS800, RQ-11, and MQ-1B** (MQ-1B and chase on RWY 17)	AS800 airborne, RQ-11 same as #2, MQ-1B req taxi 1 min into problem, T/O RWY 17, 3 T& G's depart EDW with chase
	S9	**AS800, RQ-11, A-160, and MQ-1B** (MQ-1B and chase on RWY 21)	AS800 airborne, RQ-11 same as #2, A-160 same as #3, MQ-1B same as #4, 3 T&G's depart EDW w/chase

Notes: Comparative Analysis is measuring the effects to manned aircraft, effects to controller workload, effects to airspace/patterns, and how the controllers do his/her job when UAS are introduced. Each scenario numbered 2-9 will be compared to baseline scenario #1. Additional matched comparisons may be made between scenarios where appropriate.

Table 3: Scenario Descriptions – Descriptive

Scenario Type	Scenario Number	UAS Details	Scenario Details
Descriptive Analysis	S10	**AS800 and RQ-11** (RQ-11 fly away)	**Similar to S2**, 25 min into problem PIC calls ATC, lost link attempt to recover at GCS. 2 min, PIC calls ATC, did not recover link, last seen heading towards approach end of RWY 21
	S11	**AS800 and A16** (A-160 lost link)	**Similar to S3**, Except: 1 min A-160 request T/O, 15 min Lost Link, RTB direct Warrior Ramp
	S12	**AS800, MQ-1B/**Chase (MQ-1B, taxi, takeoff, RWY 21 1 T&G, change to RWY 17 w/chase)	**Similar to S4**, Once airborne, on abbreviated LT clsd traffic 21, at midfield, after T&G, request RT clsd RWY 17, 2 T&G joins chase departs to EDW
	S13	**AS800 and MQ-1B** (Add an extra MQ-1B A (no chase))	**Similar to S5**, Except: 1 min MQ-1B 1 calls taxi, immediate departure. 5 MIT MQ-1B 2 departs RWY 21 8 T&G
	S14	**AS800, RQ-11, and A160** (Blimp exits pattern and crosses RWY 17)	**Similar to S6**, PIC errs, causes Blimp to exit pattern, east crosses RWY 17 to Old Taxi E extension, corrects back to west, then contacts TWR.
	S15	**MQ-1B and A160** (MQ-1B lost link; No AS800)	**Similar to S7**, After 2nd T&G, LL occurs upwind, fly FRH to 2nm, then climbing LT to 5000' direct to Lost Link Orbit, hold until end of problem, (A-160 in N/S pattern)
	S16	**A160 and MQ-1B** (A-160 LL; No AS800)	**Similar to S7**, Except: MQ-1B 8 T&G, A-160 E/W pattern @5000', LL at westerly point, direct and descending to Warrior Ramp
	S17	**AS800, RQ-11, and MQ-1B/**Chase (MQ-1B changes to RWY 21 after airborne)	**Similar to S8**, After 1 T&G RWY 17, midfield downwind RWY 17, PIC request right traffic RWY 21, 2 T&G's depart with chase
	S18	**AS800, RQ-11, A160, and MQ-1B/**Chase (A-160 goes 2nm west of RWY 17 centerline)	**Similar to S9**, Except A-160 requests T/O 5 min into problem, A-160 exits normal east west orbit pattern
	S19	**AS800 and MQ-1B/**Chase (MQ-1B returns from complex)	**Similar to S4**, MQ-1B RTB from complex (EDW) 15 min into problem, 8500 descending via reverse of outbound route, RT base RWY 21, FS (with chase)
	S20	**AS800, RQ-11, A160, MQ-1B/**Chase (MQ-1B returns from EDW complex)	**Similar to S9**, MQ-1B RTB from complex (EDW) 15 min into problem, 8500 descending via reverse of outbound route, RT base RWY 21, FS (with chase)
	S21	**AS800, A160, and MQ-1B** (N744PA has emergency)	**Similar to S7**, N744PA calls TWR 6 NE 6500 descending direct SuzzQ X SuzzQ @4300, ILS RWY 17, T&G, after 1 T&G RWY 17, 200' losses #2 engine, flys RH to 3300', wide RT downwind RWY 17 FS, exits Taxiway Delta.
	S22	**A160 and MQ-1B** (A-160 T&G RWY 21); No AS800,	**Similar to S7**, Except A-160 requests T/O 5 min into problem for 4 T&G RWY 21 with MQ-1B 8 T&G RWY 21
	S23	**AS800 and A160** (Add 2nd A-160)	**Similar to S3**, A-160 1 airborne in ops area, 5 min into problem, A-160 #2 req T/O wariior RT Clsed traffic Warrior Ramp multiple T&G, 15 min into, A-160 #1 RTB Warrior Ramp
	S24	**AS800, RQ-11, A160, MQ1B/Chase REHOST Failure 0:20:00 - 0:45:00**	**Similar to S20**, MQ-1B RTB from complex (EDW) 15 min into problem, 8500 descending via reverse of outbound route, RT base RWY 21, FS (with chase)
	S25	**AS800, RQ-11, A160, MQ1B/Chase Temp REHOST Failure 0:20:00 - 0:28:00**	**Similar to S20**, MQ-1B RTB from complex (EDW) 15 min into problem, 8500 descending via reverse of outbound route, RT base RWY 21, FS (with chase)
	S26	**AS800, RQ-11, A160, MQ1B/Chase REHOST Inop entire scenario**	**Similar to S9**, Except A-160 requests T/O 5 min into problem, A-160 exits normal east west orbit pattern

Notes: Descriptive Analysis evaluates each scenario individually. For these scenarios, the order in which the aircraft appear were shuffled. All statistics reported from these scenarios will be descriptive in nature.

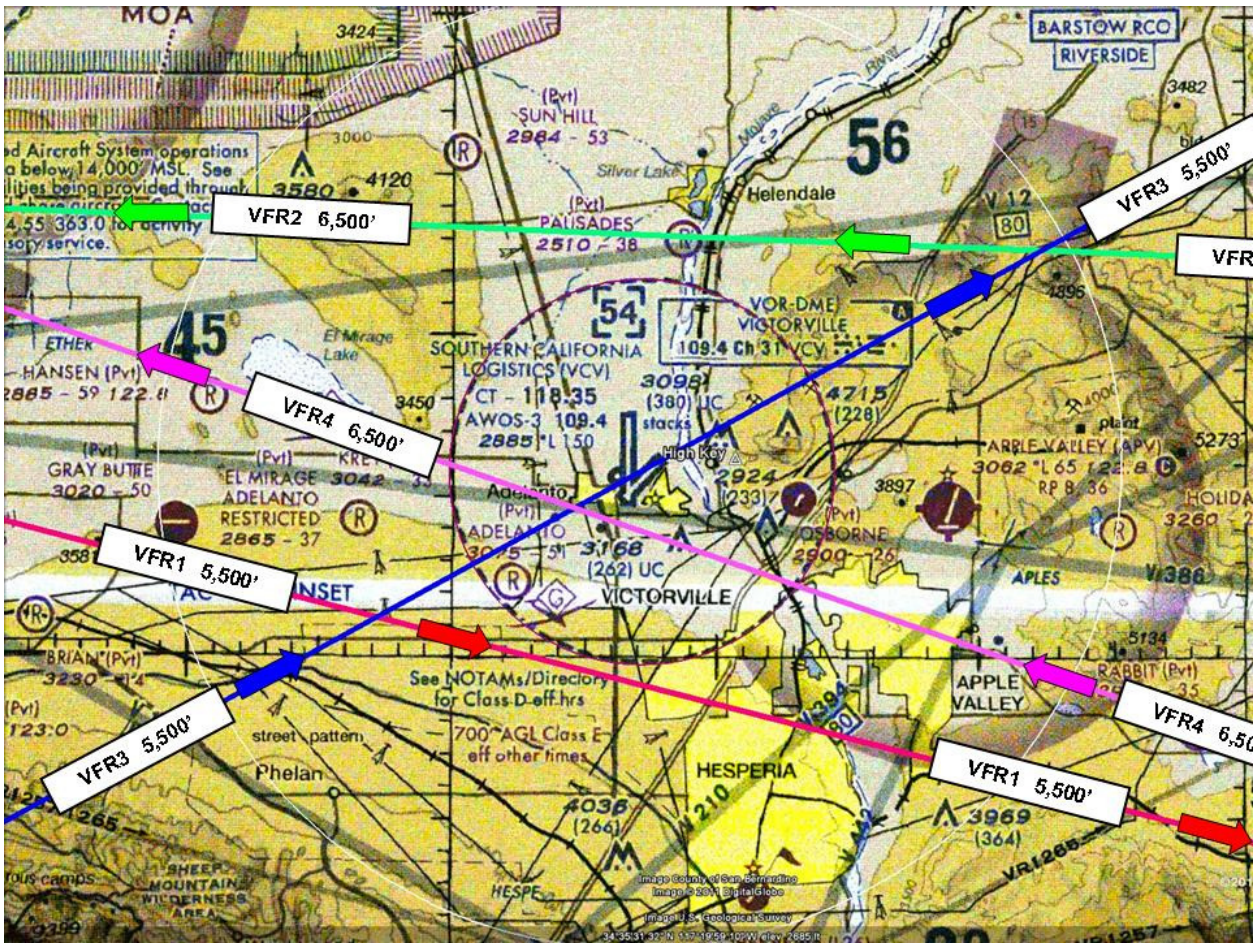

Figure 6: KVCV VFR Flight Tracks and Altitudes

2.6.5 Simulation Support Materials

Standard ATCT paper flight progress strips were available to the controllers for use during the simulation.

Multiple job aids were provided to support the roles of the KVCV controllers, simulation pilots, and Ghost Coordinator. The job aids included materials such as UAS lost link procedures, an airport facility directory, approach plates, sectional charts, pilot reference guides, simulation pilot scripts, master scenario scripts, and additional reference materials to support the conduct of the study.

For this study, a specialized simulation pilot training program, with tailored materials, was developed to support the unique requirements of the proposed operational environment.

The collection of support materials is stored as project files within a secure database at the WJHTC.

2.6.6 Informed Consent

Each participant read and signed an Informed Consent Form before the experiment commenced (see Appendix A). Informed consent forms ensure voluntary participation in the study, assure participant anonymity, and outline any risks the participant may be subjecting themselves to by participating.

2.6.7 Biographical Questionnaire

Each participant completed a Biographical Questionnaire before the experiment commenced. Participants provided general information about themselves including gender, age, and level of operational experience (see Appendix B).

2.6.8 Post-Run Questionnaires

After completing each experimental run, the participants answered questions about the operations they just experienced and provided subjective ratings about their own assessment of operations, workload, and situation awareness by making ratings on a 7-point Likert rating scale for items on a Post-Run Questionnaire (PRQ). The participants also had the opportunity to respond to open-ended questions, so as to be able to provide feedback concerning any facet of the scenarios they considered relevant (see Appendix C).

2.6.9 Post-Experiment Questionnaire

The participants answered a Post-Experiment Questionnaire (PEQ) after the experiment's conclusion (see Appendix D). On the PEQ, the participants had the opportunity to provide their opinions and observations of the proposed operational concepts. Using a 7-point Likert rating scale, they also answered questions regarding general characteristics of the experiment (e.g., realism). The PEQ posed mostly open-ended questions.

2.6.10 Observer Rating Form

After each simulation run, an Expert Observer used an Observer Rating Form (ORF) to make ratings concerning operations and the participant's performance of their duties with respect to the overall operation. For each position simulated, separate ratings were made by the Expert Observer. The Expert Observer also provided additional comments for each simulation run (see Appendix E).

2.6.11 Debriefing

A debriefing session was held at the end of each day of simulation. All participants participated. The purpose of the debriefing was to offer an opportunity for those involved to provide information that may not have been captured in the questionnaires or other data collection means. Similarly, a longer and more comprehensive debriefing session was held at the end of the eighth and final day of simulation. Again, this debriefing allowed participants to express information not captured by questionnaires, as well as to gain further insight regarding the purpose and scope of the study. All debriefing sessions were audio recorded.

2.7 Design

2.7.1 Experimental Design

This study was purposely designed to be a limited-scope HITL exercise focused on understanding, identifying, and documenting operational events, including the human factors perspective, for multiple UAS operations in Class D airspace; it was not a validation study. The data sample was small and the number of participants was limited. The study was designed for two distinct analyses: 1) a comparative examination of the first nine scenarios and 2) a case-by-case analysis of the remaining 17 scenarios.

2.7.2 Dependent Variables

Multiple safety, efficiency, communications, workload, situation awareness, and performance metrics were collected to support the objectives of this study (see Table 4).

Table 4: ATC Operation Metrics

Safety		
Data Type	**Data Capture**	**Comment**
# operational errors	TGF, ORF	root cause analysis
# operational deviations	TGF, ORF, PRQ	root cause analysis
# mid-air collisions	TGF, ORF, PRQ	root cause analysis
# near mid-air collisions	TGF, ORF, PRQ	root cause analysis, subjective by operator
# runway incursions/accidents	TGF, ORF, PRQ	root cause analysis
# losses of separation (LOS)	TGF, ORF	root cause analysis
closest point of approach per LOS	TGF, ORF	distance
Perceived safety	PRQ, ORF	subjectively assessed
Efficiency		
Data Type	**Data Capture**	**Comment**
# departure delays to manned a/c	TGF, ORF, PRQ	
# arrival delays to manned a/c	TGF, ORF, PRQ	
# departure delays to UAS	TGF, ORF, PRQ	
# arrival delays to UAS	TGF, ORF, PRQ	
# Class D airspace clearance denials	TGF, ORF, PRQ event marker	
# and type of modified traffic patterns	ORF	downwind, upwind, re-sequencing due to UAS, etc.
# missed approaches (unplanned)	TGF, ORF, PRQ, event marker	root cause analysis and who initiated [metric is also safety related]
# go-arounds (unplanned)	TGF, ORF, PRQ, event marker	root cause analysis [metric is also safety related]
# re-sequenced a/c arrivals	TGF, ORF, PRQ, event marker	[metric is also workload related]
# re-sequenced a/c departures	TGF, ORF, PRQ, event marker	[metric is also workload related]
# altered/canceled manned a/c requests	PRQ	
# altered/canceled UAS requests	PRQ	
Communications		
Data Type	**Data Capture**	**Comment**
# transposed call signs, headings, airspeeds, altitudes	ORF, A/V recordings	[also safety metric]
# and type of additional/excessive controller responses	ORF, A/V recordings	e.g., say again, unable, stand by [also workload metric]
# misidentified a/c (by call sign)	ORF, A/V recordings	[also safety metric]
Workload and Situation Awareness		
Data Type	**Data Capture**	**Comment**
# arrivals, departures, over flights, touch and go maneuvers	TGF	basic data to establish level of complexity

controller loss of situation awareness	ORF, PRQ	Subjective (e.g., does not maintain position awareness of a/c, "lost the flick")
# and type of repeat clearances by controllers	ORF, PRQ, A/V recordings	root cause analysis [also communications metric]
instantaneous workload measures for controllers	PRQ, ORF, WAK/DESIREE	every 2 minutes
perceived workload	PRQ, ORF	
perceived complexity	PRQ, ORF	
Observed ATCS Performance Metrics		
Data Type	**Data Capture**	**Comment**
used prescribed phraseology	ORF, A/V recordings	
priority of duties maintained	ORF	subjective by SME
correct speech cadence, volume, and delivery	ORF, A/V recordings	subjective by SME
traffic and safety alerts provided	ORF, A/V recordings	subjective by SME
coordination is effective and timely	ORF	subjective by SME
rapidly recovers from equipment malfunctions, failures, emergencies	ORF, A/V recordings, TGF	subjective by SME
functions effectively as a radar/tower team member	ORF, A/V recordings	subjective by SME
communication is clear and concise	ORF, A/V recordings	subjective by SME
positive control exercised	ORF, A/V recordings	subjective by SME
readback errors handled appropriately	ORF, A/V recordings	subjective by SME
issued accurate and effective control instructions	ORF, A/V recordings	subjective by SME

2.8 Procedure

2.8.1 General Schedule of Events and Run Order

Two KVCV controllers were required to complete the study. Over the span of two consecutive weeks, participants were scheduled for eight days of testing plus two days of travel. The eight days of testing was split as follows: the first day was dedicated to the in-brief, training runs, and one simulation run, while the following seven days included simulation runs and debriefs designed to allow for participant feedback on various topics. Participants traveled to duty the first Monday (8/22) of the first week and departed the Friday (9/2) of the second week. The daily schedule of events is illustrated in Table 5.

Table 5: Schedule

Time	Mon 08/22	Tues 08/23 (Day 1)	Wed 08/24 (Day 2)	Thurs 08/25 (Day 3)	Fri 08/26 (Day 4)	Time	Mon 08/29 (Day 5)	Tues 08/30 (Day 6)	Wed 08/31 (Day 7)	Thurs 09/01 (Day 8)	Fri 09/02
8:30	Travel In	Intro,In-Briefing, & Forms	Team Recap	Test Run 7 S9	Test Run 12C S17	8:30	Refresher	Test Run 18 S21	Test Run 23 S2	Test Run 25 S26	Travel Out
8:45						8:45					
9:00						9:00	Training/ Technical				
9:15			Test Run 2B S5			9:15					
9:30				Break	Break	9:30		Break	Break	Break	
9:45				Test Run 8A S10	Test Run 13 S14	9:45		Test Run 19 S20	Test Run 24 S25	Test Run 26 S24	
10:00		Break	Break			10:00					
10:15						10:15					
10:30			Test Run 3 S19			10:30					
10:45		Training Run 1 T1		Break	Break	10:45		Break	Break	Break	
11:00				Test Run 9 S7	Test Run 14 S4	11:00		Test Run 20 S6	Test Run 8B S10	LUNCH	
11:15						11:15					
11:30			Break			11:30					
11:45		LUNCH	Test Run 4 S22			11:45					
12:00				LUNCH	LUNCH	12:00		LUNCH	LUNCH		
12:15						12:15				Debrief, Forms, & Lessons Learned	
12:30						12:30	LUNCH				
12:45			LUNCH			12:45					
1:00		Training Run 2 T2				1:00					
1:15				Test Run 10 S8	Test Run 15 S16	1:15		Test Run 21 S23	Test Run 17C S18		
1:30			Test Run 5 S1			1:30	Test Run 16 S13				
1:45						1:45					
2:00		Break				2:00					
2:15				Break	Break	2:15		Break	Break		
2:30		Test Run 1B S3	Break	Test Run 11 S11	Discussion	2:30	Break	Test Run 22 S15	Test Run 1C S3		
2:45			Test Run 6 S12			2:45	Test Run 17A S18				
3:00					End of Day	3:00					
3:15		Break			Buffer	3:15					
3:30		Discussion		Break		3:30		Break	Break		
3:45			Break	Discussion		3:45	Break	Discussion	Discussion		
4:00		End of Day	Discussion			4:00	Discussion				
4:15		Buffer				4:15					
4:30			End of Day	End of Day		4:30	End of Day	End of Day	End of Day	End of Day	

The simulation runs were presented in a random order to ensure all conditions and operational configurations appeared in a non-systematic manner. The run order is presented in Table 6.

Table 6: Run Order

Day	Tuesday 08/23 Day 1	Wednesday 08/24 Day 2	Thursday 08/25 Day 3	Friday 08/26 Day 4	Monday 08/29 Day 5	Tuesday 08/30 Day 6	Wednesday 08/31 Day 7	Thursday 09/01 Day 8
Scenario Number	In-Briefing	Run 2B S5	Run 7 S9	Run 12C S17	Training/ Technical	Run 18 S21	Run 23 S2	Run 25 S26
		Run 3 S19	Run 8A S10	Run 13 S14		Run 19 S20	Run 24 S25	Run 26 S24
	Training 1 T1	Run 4 S22	Run 9 S7	Run 14 S4		Run 20 S6	Run 8B S10	Debrief
	Training 2 T2	Run 5 S1	Run 10 S8	Run 15 S16	Run 16 S13	Run 21 S23	Run 17 S18	
	Run 1B S3	Run 6 S12	Run 11 S11		Run 17A S18	Run 22 S15	Run 1C S3	

2.8.2 In-Briefing

Upon arrival, and prior to participating, introductions were made and all participants were briefed on the background and objectives of the study. After the briefing, the participants completed the Informed Consent Form, which assured their anonymity and voluntary participation in the study, followed by the Biographical Questionnaire, which collected information related to the participants' background and experience. An SME then gave a brief overview of the airspace, procedures, and simulated laboratory environment the participants were to experience.

2.8.3 Training Runs

Following the in-brief, the participants were led to the laboratory and given a brief overview of the laboratory equipment. Participants then controlled traffic in two training/practice runs. During these runs, participants had the opportunity to control traffic from both the Local and Ground positions. These practice runs served to familiarize participants with the test environment, interactions with the simulation pilots, and usage of the WAK. Scenarios used for the training runs were similar to the actual simulation scenarios. These runs were supervised by research personnel and lasted until participants were sufficiently prepared to begin data collection runs.

2.8.4 Simulation Runs

Simulation runs for data collection followed the training/practice runs. The research team provided participants with general instructions prior to each run. Participants worked a total of 26 45-minute simulation runs that were recorded for data collection purposes. Certain scenarios were rerun due to system malfunctions. Participants performed their ATC duties as they normally would in the field today and adhered to all applicable FAA procedures for the airspace.

While participants worked each simulation run, they provided workload ratings on a WAK every two minutes. Two Expert Observers oversaw the controllers' interaction with the ATC system and collected the dependent measures requested in the ORF.

During simulation runs, air traffic controller actions were audio and video recorded, all voice communication with pilots was audio recorded, and air traffic controller interactions with the ATC system was recorded.

A total of 15 minutes was allotted after each simulation run for participants to complete the PRQ (Appendix C). Participants then had a 15-minute break before the next scenario began. At the end of each day, the participants and research team met to discuss the runs and conditions presented for that day. This procedure was repeated each day throughout the experiment.

When all of the simulations runs were done, participants completed the PEQ to answer questions about their overall experience participating in the study. At the end of the study, the research team also conducted a final debriefing to discuss the overall simulation, perceptions of the study, as well as the effects of the proposed operations. In addition, the research team answered all questions the participants had with respect to the study in which they had just participated. All discussions and debriefings were audio recorded.

2.8.5 Data Handling Procedures

A coded identifier was assigned to each participant and used to ensure the anonymity of the data. All data collection forms, computer files, electronic recordings, and storage media were tagged with the coded identifier to conceal the identifiable information of the participants.

All study data including system data, questionnaires, simulation support materials, training briefs, in-briefs, scenarios, and visual databases were stored as files on secure databases at the WJHTC.

2.9 Risks

There were little to no risks anticipated for participants in this simulation other than those ordinarily encountered in daily life or during the performance of routine physical or psychological examinations or tests. Risks did not exceed those normally found in the practice of ATC. These include fatigue, eyestrain, and other issues one might find in an office or simulation environment.

The study objective was not to assess individual air traffic controller performance or competency. Rather, the focus was on the collection of necessary operational and subjective data to explore the integration of multiple simultaneous UAS operations within Class D airspace using the existing ATC framework, rules, and federal regulations. The study required approval from the FAA's Institutional Review Board and study participants were required to willingly sign an Informed Consent Form prior to participation. Strict adherence to all federal, union, and ethical guidelines was maintained throughout the study.

Participants were allowed to terminate their voluntary participation at any time and for any reason without penalty. Additionally, researchers were allowed to terminate a participant's role in the study at any time if they felt it was in the best interests of the participant or study (with no penalty to the participant).

3. Data Analysis

This research endeavor was purposely designed to be a limited scope HITL exercise focused on understanding, identifying, and documenting operational events, including the human factors perspective, for multiple-UAS operations in Class D airspace. The data collected in the study was not from a sample size large enough to provide for true rigor for the purposes of statistical analysis. Although the data itself is considered valuable and valid for the purposes of the descriptive statistics reported, it does not allow for advanced inferential statistical methods to be employed. This exercise does, however, provide an opportunity for early visualization and understanding of information concerning the impact of the simulated operations.

The process for descriptive and comparative scenario analysis is outlined in the following sections.

3.1 Comparative Analysis Process

The first nine scenarios did not contain off-nominal conditions. Scenario 1, "the baseline scenario," contained manned aircraft only. The other eight scenarios contained incremental levels of UAS operations. The goal of the comparative analysis was to discern any noticeable differences that occurred when incrementally adding UAS. "Threads" of similar scenarios were grouped together for comparison. By design, most of the statistical analysis is descriptive in nature.

3.2 Descriptive Analysis Process

Scenarios 10-26 contained varying levels of UAS operations with the added complexity of off-nominal conditions. It was intended that most of the data and statistical analysis from this study would be descriptive in nature. Analysis by SME was also descriptive in nature. As such, scenarios 10-26 were designed to be analyzed on a case-by-case basis.

4. Results

4.1 Participant Background Information

Two air traffic controller participants were required for this study. Both participants were male and their average age was 60 years. These participants were both active air traffic controllers from the Southern California Logistics Airport, situated in Victorville, CA. On average, they had approximately 30 years of experience as an air traffic controller. One participant reported having 34 years of experience, all of which was spent in an ATCT. The other participant reported having 27.5 years of experience as an air traffic controller, 7.5 years of which were spent in an ATCT, with the remaining 20 years spent at an another facility. Both controllers reported having controlled traffic during all 12 out of the 12 months prior to the study. Both participants also reported previous experience working with the Predator, Raven, A-160 Hummingbird, and JPL

Blimp at their facility. The participants also both reported an average of 10 months of experience using REHOST and had used it within the week prior to the study.

On a 7-point scale, with "1" corresponding to "Not Skilled" and "7" corresponding to "Very Skilled," one participant rated his skill as an air traffic controller a "4," or average, and the other participant rated himself a "6," or highly skilled. The two participants rated their current stress level as just below average and just above average, giving ratings of "3" and "5," on a 7-point scale, with "1" corresponding to "Not Stressed" and "7" corresponding to "Very Stressed." Both participants also reported that their level of motivation to participate in the study was relatively high, giving ratings of "6" and "7," on a 7-point scale, with "1" corresponding to "Not Motivated" and "7" corresponding to "Very Motivated."

4.2 Comparative Analysis Results

4.2.1 Scenarios 1, 5, and 7

The comparative analysis scenarios each consisted of approximately 17 manned aircraft operations, to which UAS operations were incrementally added. The goal of the comparison was to identify and document the impact of the UAS operations on manned aircraft, standard ATC operations, and routine operations in Class D airspace. The comparative scenarios did not contain any off-nominal events such as lost link or in-flight emergencies. This scenario comparison "thread" contains Scenario 1 (Scen1), Scenario 5 (Scen5) and Scenario 7 (Scen7).

4.2.1.1 Scen1-5-7 Design

All scenarios were developed with the following characteristics:

Airport and Weather Conditions: Simulation start-time was mid-afternoon, and VFR prevailed throughout the scenarios. Winds were 210° at 9kts. The active runways were 21 and 17.

Manned Aircraft: Seventeen manned aircraft were introduced to simulate normal traffic flows at the airport. Operations included both military and civilian departures, arrivals, over-flights, and local traffic pattern work. Four additional VFR (1200 code) targets were introduced to simulate over-flight traffic above and/or adjacent to the Class D airspace; these targets did not communicate with ATC.

Special Military Operations: In addition to other manned military flights, a C17 Globemaster II (Slam 88) was added to simulate specialized military tactical maneuvers practiced by USAF crews at KVCV and similar airports.

Ground Vehicles: Two Ground vehicles were added to the scenarios to replicate vehicular traffic at a typical airport. The vehicles simulated routine airfield maintenance and runway sweeping operations and communicated with ATC on the Ground Control (GC) frequency.

Unmanned Aircraft Systems: Table 7 captures the type of UAS present in each scenario.

Table 7: Comparative Scenarios (Scen1, Scen5, Scen7)

	Number of UAS	UAS
Scen1	0	None
Scen5	2	AS800 JPL Blimp, MQ-1B Predator
Scen7	3	AS800 JPL Blimp, MQ-1B Predator, A-160 Hummingbird

4.2.1.2 Scen1-5-7 Safety

The ATC operations presented in these scenarios were evaluated in regard to the safety and efficiency of the flow of traffic. Several notable observations are described in this section.

As rated on a 7-point scale in the PRQ, with "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High," the Local controller reported having average or above average confidence in the overall safety of operations, giving ratings of 5, 4, and 5 for Scen1, Scen5, and Scen7, respectively. The Ground controllers' confidence in safety was extremely high for all three scenarios (rated 7 for all).

The SME Observers generally agreed in their perceived levels of safety across these scenarios. On a 7-point scale, with "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High," the Local SME Observer rated the overall safety of the pattern sequence above average for all three scenarios (rated as 6, 6, and 5 for Scen1, Scen5, and Scen7, respectively). The Ground SME Observer's ratings were average or above for this metric (rated as 5, 6, and 4 for Scen1, Scen5, and Scen7, respectively).

On the same scale as above, the Local SME Observer rated the overall safety and efficiency of the traffic flow as average or above (rated as 5, 5, and 4 for Scen1, Scen5, and Scen7, respectively). The Ground SME Observer's ratings were similar for these metrics (rated as 5, 5, and 3 for Scen1, Scen5, and Scen7, respectively).

Both SME Observers also noted that in Scen7, which included three UAS, there were instances in which the controllers did not exercise 'positive control,' thus compromising the safety of the operations.

The Local controller in Scen5 indicated that he provided an extra margin of spacing for the UAS; however, the Local controller in Scen7 did not.

In general, SME Observer ratings related to perception of safety appeared to be consistently lower for Scen7 as compared to the other two scenarios.

From an operational perspective, there are several types of incidents that adversely affect the safe, orderly, and expeditious movement of air traffic. These include Mid-Air Collisions (MAC), other Accidents (ACC), Near Mid-Air Collisions (NMAC), Operational Errors (OE), Operational Deviations (OD), Runway Incursions (RI), and Pilot Deviations (PD). Concerning some of these measures, it is important to note that the focus of this study was to examine the potential effects

of UAS operations on Class D airspace. By design, the simulation pilots, both manned and unmanned, were not the direct subject of study in this simulation. Therefore, any occurrences of pilot-induced incidents (e.g., PD, RI, or NMAC caused by pilot error or actions) are considered part of the realistic, complex situations presented to the controller participants and not reported as deficiencies or safety-related findings for the purposes of this evaluation.

Information concerning the study's valid incident safety measures are summarized in Table 8, with reported incident details provided in Table 9. All scenarios were 45 minutes in length.

In Scen1, there were three incidents attributed to ATC. All were caused by ATC not complying with the proper intersecting runway standards as prescribed in FAO JO7110.65, Sections 3-9-8 and 3-10-4, Intersecting Runway Separation, and resulted in OE. None of the OE involved UAS.

In Scen5, there were six incidents attributed to ATC. All were caused by ATC not complying with the proper intersecting runway standards as prescribed in FAO JO7110.65, Sections 3-9-8 and 3-10-4, Intersecting Runway Separation, and resulted in OE. One OE involved a UAS.

In Scen7, there were five incidents attributed to ATC. Three were caused by ATC not complying with the proper intersecting runway standards as prescribed in FAO JO7110.65, Sections 3-9-8 and 3-10-4, Intersecting Runway Separation, and resulted in OE. One OE involved a UAS. The other two incidents were caused by ATC's failure to coordinate use of adjacent airspace as prescribed in FAO JO7110.65, Sections 2-1-14, and resulted in OD. Neither of the OD involved a UAS.

The data shows that the scenarios with UAS present (Scen5 and Scen7) had noticeably more safety incidents than Scen1 (which had no UAS). Scen5 and Scen7 also had UAS-involved incidents.

Table 8: Scen1-5-7 Safety Metrics

	# MAC	# Other Accidents	# NMAC	# OE	# OD	# Runway Incursions	TOTAL # INCIDENTS
Scen1	0	0	0	3	0	0	**3**
Scen5	0	0	0	6	0	0	**6**
Scen7	0	0	0	3	2	0	**5**

Table 9: Scen1-5-7 Incident Table

	Incident Type	Aircraft #1	Aircraft #2	Incident Description
Scen1	OE	N744PA	TNKR911	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
	OE	N744PA	N44EL	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
	OE	OMEGA70	DOJ703	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
Scen5	OE	Slam 88	N90PH	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
	OE	RYN5	N744PA	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
	OE	Slam 88	N44EL	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
	OE	Slam 88	N44EL	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
	OE	Slam 88	N44EL	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
	OE	R50095	Grizzly 21 *(UAS)*	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
Scen7	OE	Slam 88	Grizzly 21 *(UAS)*	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
	OE	Slam 88	N44EL	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
	OE	RYN5	N744PA	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
	OD	Slam 88	n/a	ATC Failed to coordinate use of adjacent airspace * Reference FAA JO 7110.65 Section 2-1-14
	OD	Slam 88	n/a	ATC Failed to coordinate use of adjacent airspace * Reference FAA JO 7110.65 Section 2-1-14

4.2.1.3 Scen1-5-7 Efficiency

Several metrics were captured to evaluate the efficiency of the operations simulated. Table 10 captures the observed occurrences of the efficiency metrics for these scenarios.

In Scen1, one pilot initiated a go-around and three traffic pattern modifications were observed. There was also one re-sequenced arrival and two instances where a manned aircraft request was altered and/or cancelled — for a total of seven efficiency-related events.

In Scen5, four pilots initiated go-arounds, three manned aircraft were delayed, one UA was delayed, and seven traffic pattern modifications were observed. There was also one instance where a manned aircraft request was altered and/or cancelled and one instance where a UA request was altered and/or cancelled — for a total of 17 efficiency-related events.

In Scen7, ATC initiated one go-around, three manned aircraft were delayed, and nine traffic pattern modifications were observed. There was also one manned aircraft request and one UA request that was altered and/or cancelled — for a total of 15 efficiency-related events.

The scenarios with UAS present (Scen5 and Scen7) had noticeably more efficiency-related events than Scen1 (which had no UAS).

Table 10: Scen1-5-7 Efficiency Metrics

	Scen1	Scen5	Scen7
Go-Arounds			
ATC Initiated Go-Arounds	0	0	1
Pilot Initiated Go-Arounds	1	4	0
Total	**1**	**4**	**1**
Delays			
Manned A/C Departure Delays	0	3	2
Manned Aircraft Arrival Delays	0	0	1
Unmanned A/C Departure Delays	0	0	0
Unmanned A/C Arrival Delays	0	1	0
Total	**0**	**4**	**3**
Traffic Pattern Modifications			
Extended Down-Winds	0	4	4
360° Turns	2	1	0
ATC Initiated Runway Changes	0	1	3
ATC Requested Short Approaches	0	0	0
ATC Requested Early Departure Turns	0	0	0
ATC Assigned Straight-Out/Runway Headings	1	1	2
Total	**3**	**7**	**9**
Miscellaneous Efficiency Measures			
Class D Airspace Denials	0	0	0
Re-Sequenced Arrivals	1	0	0
Re-Sequenced Departures	0	0	0
Altered and/or Cancelled Manned A/C Requests	2	1	1
Altered and/or Cancelled Unmanned A/C Requests	0	1	1
Total	**3**	**2**	**2**
TOTAL: All Efficiency-Related Occurrences	**7**	**17**	**15**

Though it appears the manned aircraft delays were not directly attributed to the UAS operations in the scenarios, participant input indicated that some of the other observed efficiency measures captured in Scen5 and Scen7 may be directly attributed to the presence of UAS in the operations. The UAS was sent to High Key numerous times to accommodate other aircraft in the pattern in both Scen5 and Scen7. In Scen5, this caused the UAS itself to be delayed. Also in Scen7, the Local controller indicated the UAS notably affected the traffic pattern (rated 3 on a 7-point scale, with "1" corresponding to "not at all" and "7" corresponding to "a great deal"). He commented that he "had to call base [turn] for Predator." Similar to observances in other scenarios, this is a

result of the fact that UAS PIC are not on board the aircraft, and they currently do not have an alternate approved method to visually acquire and follow other aircraft in the pattern[8].

The Local controller also indicated that the UAS required a notable amount of additional attention (as compared with manned aircraft) in Scen7 (rated as 3), and even more significant attention in Scen5 (rated as 5).

On a 7-point scale, with "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High," the Ground SME Observer rated overall efficiency of the pattern sequence as above average for Scen1 and Scen5 (rated as 5 and 6, respectively) and below average for Scen7 (rated as 3).

The Local SME Observer rated the overall efficiency of taxiway and runway assignments as above average for Scen1 and Scen5 (rated as 5 and 5, respectively) and as average for Scen7 (rated as 4).

Both SME Observer ratings also suggest a decrease in efficiency for Scen7, as compared to Scen1 and Scen5.

4.2.1.4 Scen1-5-7 Communication

Voice communication is a key element of ATC. Many different communication anomalies can be indicative of traffic saturation and ATC loss of situation awareness. These types of occurrences include transposed call signs, missed transmissions, misidentified aircraft, and repeat ATC instructions. (Note: simulation pilot communication errors are not reported herein since these pilots were not the subject of study.)

In Scen1, the SME Observers noted the observation of one transposed control instruction as well as late coordination with the JOSHUA sector at the High Desert TRACON, both on the part of the Ground controller.

In Scen5, the SME Observers noted two missed transmissions by the Ground controller.

In Scen7, the SME Observers noted one transposed control instruction, two misidentified aircraft, and a lack of prescribed phraseology, all on the part of the Local controller. It was also observed that the Local controller did not maintain correct priority of transmissions. The Local SME Observer specifically noted that it appeared as though many of these anomalies were a direct result of the Local controller occasionally experiencing a loss of situation awareness.

There were noticeably more communication anomalies in Scen7 than in the other two scenarios.

4.2.1.5 Scen1-5-7 Workload and Situation Awareness

In addition to the observations noted in the safety, efficiency, and communications section, other measures of workload and situation awareness were captured via the system recordings, PRQ, and WAK. Table 11 summarizes the traffic counts for these scenarios.

[8] Reference FAA Order JO 7110.65 Section 3-8-1

Table 11: Scen1-5-7 Traffic Counts

	# Arrivals	# Departures	# Touch and Gos/Low Approaches	# Overflights
Scen1	15	14	10	3
Scen5	24	24	18	4
Scen7	18	19	12	5

Table 12 and Table 13 depict subjective ratings of overall complexity and overall workload provided by the participants and SME Observers after each scenario. These ratings were made on a Likert scale of 1-7, with "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High."

All individuals provided average or below average ratings of overall complexity for Scen1. Most individuals also provided average or below average ratings of overall complexity for Scen5, with the exception of the Local SME Observer, who rated the overall complexity as above average. The Local controller, Local SME Observer, and Ground SME Observer all gave above average overall complexity ratings for Scen7.

All individuals provided average or below average ratings for overall workload in Scen1. Most individuals also provided average or below average ratings for overall workload in Scen5, with the exception of the Local SME Observer, who rated the overall workload as above average. The Local controller, Local SME Observer, and Ground SME Observer all gave above average overall workload ratings for Scen7.

Table 12: Scen1-5-7 Ratings of Overall Complexity

Overall Complexity	Local Controller	Local SME Observer	Ground Controller	Ground SME Observer
Scen1	4	4	1	3
Scen5	3	6	3	4
Scen7	6	5	3	5

Table 13: Scen1-5-7 Ratings of Overall Workload

Overall Workload	Local Controller	Local SME Observer	Ground Controller	Ground SME Observer
Scen1	4	3	1	3
Scen5	3	5	3	4
Scen7	6	6	2	5

Factors such as mental demand, effort, and the degree to which UAS required attention are some of the contributing factors to overall workload and complexity.

On a 7-point scale, with "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High," the Local controller reported average and below average ratings for effort and mental demand in Scen1 and Scen5 (rated as 4 and 3, respectively, for Scen1, and rated as 3 and 4, respectively, for Scen5). For Scen7, the Local controller reported high ratings for effort and mental demand (both rated as 6).

In Scen7, the Local SME Observer noted that it appeared as though the Local controller lost situation awareness during the scenario. SME Observer input indicates that these instances of the controller 'losing the flick' may have resulted in some of the communication anomalies described previously.

These results support previous SME observations of increased workload and complexity in Scen7 (which involved three UAS).

Participants were asked to provide instantaneous workload ratings every two minutes during the run via a WAK located at each workstation. Ratings were made on a 7-point scale, with "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High." Figure 7 depicts the average of these workload ratings for each scenario by control position.

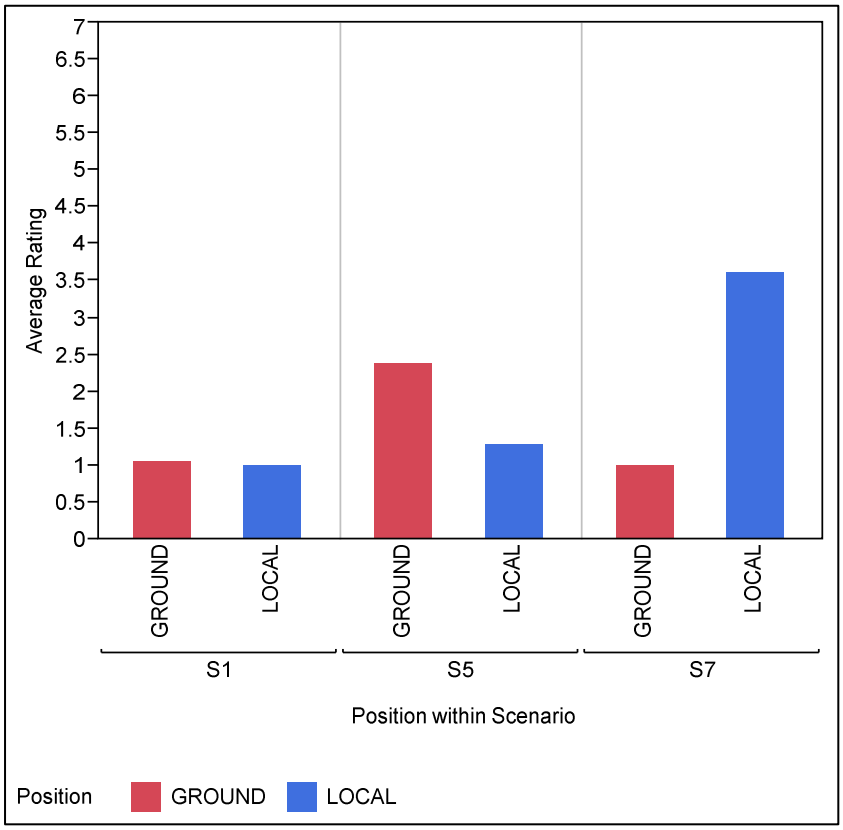

Figure 7: Scen1-5-7 WAK Data

In line with other workload measures reported, the Local controller's mean instantaneous workload rating was higher for Scen7 than those observed in Scen1 and Scen5. Also consistent with other workload measures, the Ground controller's mean instantaneous workload was highest in Scen5.

Though the mean workload ratings for all scenarios were below average, the highest mean workload rating was observed in Scen7 (which included three UAS).

4.2.1.6 Scen1-5-7 Comparison Findings

A summary of observations for this comparison are listed below.

- Scen5 (which included two UAS) and Scen7 (which included three UAS) had noticeably more safety incidents than Scen1 (which had no UAS). Scen5 and Scen7 also had UAS-involved incidents.

- Scen5 and Scen7 had noticeably more efficiency-related events than Scen1.

- Participant input indicates that some of the observed efficiency measures in Scen5 and Scen7 may be directly attributed to UAS present in the operations.

- In general, SME Observer ratings related to perception of safety appeared to be consistently lower for Scen7 as compared to the other two scenarios.

- Both SME Observer ratings also suggest a decrease in efficiency for Scen7, as compared to Scen1 and Scen5.

- There were noticeably more communication anomalies in Scen7 than in the other two scenarios.

- SME observations indicate increased workload and complexity in Scen7.

- SME noted that UAS which required the use of the runways were much more reliant on ATC for sequencing and spacing than manned aircraft. This had the potential to increase controller workload and complexity.

- Though all mean workload ratings for all scenarios were below average, the highest mean workload rating was observed in Scen7.

Upon examination of the complete set of data collected, the presence of UAS accounted for a notable impact on manned aircraft present in these scenarios, standard air traffic control operations, and routine operations in Class D airspace. The trend in findings indicates that the two scenarios with UAS (Scen5 and Scen7) had more safety incidents and efficiency-related events, which contributed to a reduction in overall safety and a decrease in overall efficiency. In addition, Scen7, the scenario with the three UAS, had noticeably more communication anomalies and the highest mean rating for workload. SME Observers also reported observations of higher complexity, increased workload, and generally rated their perceptions of safety as lower for Scen7 as compared to the other scenarios.

4.2.2 Scenarios 1, 4, 8, and 9

The comparative analysis scenarios each consisted of approximately 17 manned aircraft operations, to which UAS operations were incrementally added. The goal of the comparison was to identify and document the impact of the UAS operations on manned aircraft, standard ATC operations, and routine operations in Class D airspace. The comparative scenarios did not contain any off-nominal events such as lost link or in-flight emergencies. This scenario comparison "thread" contains Scenario 1 (Scen1), Scenario 4 (Scen4), Scenario 8 (Scen8), and Scenario 9 (Scen9).

4.2.2.1 Scen1-4-8-9 Design

All scenarios were developed with the following characteristics:

Airport and Weather Conditions: Simulation start-time was mid-afternoon and VFR prevailed throughout the scenario. Winds were 210° at 9kts. The active runways were 21 and 17.

Manned Aircraft: Seventeen manned aircraft were included to simulate normal traffic flow at the airport. Operations included both military and civilian departures, arrivals, over-flights, and local pattern work. Four additional VFR (1200 code) targets were introduced to simulate over-flight

traffic above and/or adjacent to the Class D airspace. These targets did not communicate with ATC.

Special Military Operations: In addition to other manned military flights, an additional C17 Globemaster II (Slam 88) was added to simulate specialized military tactical maneuvers practiced by USAF crews at KVCV and similar airports.

Ground Vehicles: Two ground vehicles were added to the scenario to replicate vehicular traffic at a typical airport. The vehicles simulated routine airfield maintenance and runway sweeping operations and communicated with ATC on the GC frequency.

Unmanned Aircraft Systems: Table 14 captures the type of UAS present in each scenario.

Table 14: Comparative Scenarios (Scen1, Scen4, Scen8, Scen9)

	Number of UAS	UAS
Scen1	0	None
Scen4	2	AS800 JPL Blimp, MQ-1B Predator with chase aircraft (a manned Mooney MO20)
Scen8	3	AS800 JPL Blimp, MQ-1B Predator with chase aircraft (a manned MO20), RQ-11 Raven
Scen9	4	AS800 JPL Blimp, MQ-1B Predator with chase aircraft (a manned MO20), RQ-11 Raven, A-160 Hummingbird

4.2.2.2 Scen1-4-8-9 Safety

The ATC operations presented in these scenarios were evaluated with regard to the safety and efficiency of the flow of traffic. Several notable observations and comparisons are described in this section.

As rated on a 7-point scale in the PRQ, with “1” corresponding to “Extremely Low” and “7” corresponding to “Extremely High,” the Local controller in each scenario appeared to have notable confidence in the overall safety of operations, giving ratings of 5, 5, 5, and 6 for Scen1, Scen4, Scen8, and Scen9, respectively. The Ground controller’s confidence in safety was rather high for all four scenarios (rated 7, 7, 6, and 6, for Scen1, Scen4, Scen8, and Scen9, respectively).

SME Observers generally agreed in their perceived levels of safety across these scenarios. On a 7-point scale, with “1” corresponding to “Extremely Low” and “7” corresponding to “Extremely High,” the Local SME Observer rated the overall safety of the pattern sequence above average to high for all four scenarios (rated 6, 5, 5, and 6 for Scen1, Scen4, Scen8, and Scen9, respectively).

SME Observers noted that in Scen4 and Scen9, there were instances in which the controllers did not exercise ‘positive control,’ compromising the safety of these operations. The Local controller

in Scen8 indicated that he provided an extra margin of spacing for UAS; however, the Local controller in Scen4 and Scen9 did not.

In general, SME Observer ratings related to perception of safety were rather consistent across all four scenarios. However, the observers noted that it appeared as though more safety precautions were taken with regard to UAS operations in Scen8 as compared to Scen4 and Scen9.

From an operational perspective, there are several types of incidents that adversely affect the safe, orderly, and expeditious movement of air traffic. These include MAC, other ACC, NMAC, OE, OD, RI, and PD. Concerning some of these measures, it is important to note that the focus of this study was to examine the potential effects of UAS operations on Class D airspace. By design, the simulation pilots, both manned and unmanned, were not the direct subject of study in this simulation. Therefore, any occurrences of pilot-induced incidents (e.g., PDs, RIs, or NMACs caused by pilot error or actions) are considered part of the realistic, complex situations presented to the controller participants and not reported as deficiencies or safety-related findings for the purposes of this evaluation.

Information concerning the study's valid incident safety measures are summarized in Table 15, with reported incident details provided in Table 16. All scenarios were 45 minutes in length.

In Scen1, there were three incidents attributed to ATC. All were caused by ATC not complying with the proper intersecting runway standards as prescribed in FAO JO7110.65, Sections 3-9-8 and 3-10-4, Intersecting Runway Separation, and resulted in OE. None of the OE involved UAS.

In Scen4, there were two incidents attributed to ATC. One was caused by ATC failing to coordinate use of adjacent airspace as prescribed in the FAA Order JO7110.659, Section 2-1-14, and resulted in an OD. UAS were not involved in the OD. One NMAC also occurred and involved a UAS.

In Scen8, there were three incidents attributed to ATC. All were caused by ATC not complying with the proper intersecting runway standards as prescribed in FAO JO7110.65, Sections 3-9-8 and 3-10-4, Intersecting Runway Separation, and resulted in OE. One OE involved a UAS.

In Scen9, there were five incidents attributed to ATC. Four were caused by ATC not complying with the proper intersecting runway standards as prescribed in FAO JO7110.65, Sections 3-9-8 and 3-10-4, Intersecting Runway Separation, and resulted in OE. One OE involved a UAS. One NMAC also occurred and involved a UAS.

Scen4, Scen8, and Scen9 had UAS-involved incidents. This data shows that Scen9 — involving four UAS — had the highest number of incidents (five in total).

[9] FAA Order JO 7110.65 Section 2-1-14.

Table 15: Scen1-4-8-9 Safety Metrics

	#MAC	# Other Accidents	# NMAC	# OE	# OD	# Runway Incursions	TOTAL # INCIDENTS
Scen1	0	0	0	3	0	0	**3**
Scen4	0	0	1	0	1	0	**2**
Scen8	0	0	0	3	0	0	**3**
Scen9	0	0	1	4	0	0	**5**

Table 16: Scen1-4-8-9 Incident Tables

	Incident Type	Aircraft #1	Aircraft #2	Incident Description
Scen1	OE	N744PA	TNKR911	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8/3-10-4
	OE	N744PA	N44EL	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8/3-10-4
	OE	OMEGA70	DOJ703	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8/3-10-4
Scen4	NMAC	Slam 88	JPL AS800 *(UAS)*	ATC permitted SLAM 88 to operate within the confines of the JPL operations area. (Closest proximity was 414 feet)
	OD	Slam 88	n/a	ATC Failed to coordinate use of adjacent airspace * Reference FAA JO 7110.65 Section 2-1-14
Scen8	OE	SWA3471	Grizzly 21 *(UAS)*	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8/3-10-4
	OE	Slam 88	N744PA	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8/3-10-4
	OE	NASA901	N744PA	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8/3-10-4
Scen9	NMAC	N744PA	RQ11 Raven (UAS)	ATC permitted N744PA to operate within the confines of the Raven operations area. (Closest proximity was 184 feet)
	OE	N744PA	Grizzly 21 *(UAS)*	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8/3-10-4
	OE	N744PA	Slam 88	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8/3-10-4
	OE	RYN5	N744PA	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8/3-10-4
	OE	Slam 88	N44EL	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8/3-10-4

4.2.2.3 Scen1-4-8-9 Efficiency

Several metrics were captured to evaluate the efficiency of the operation simulated. Table 17 captures the observed occurrences of the efficiency metrics for this scenario.

In Scen1, one pilot initiated a go-around and three traffic pattern modifications were observed. There was also one re-sequenced arrival and two instances where a manned aircraft request was altered and/or cancelled for a total of seven efficiency-related occurrences.

In Scen4, ATC initiated one go-around, one pilot initiated a go-around, two manned aircraft were delayed, and 13 traffic pattern modifications were observed. There was also one Class D airspace request denied, one re-sequenced arrival, and one instance where a manned aircraft request was altered and/or cancelled for a total of 20 efficiency-related occurrences.

In Scen8, four manned aircraft were delayed, one UAS was delayed, and eight traffic pattern modifications were observed. There were also two instances where a manned aircraft request was altered and/or cancelled and one instance where an UA request was altered and/or cancelled for a total of 16 efficiency-related occurrences.

In Scen9, three manned aircraft were delayed, one UAS was delayed, and two traffic pattern modifications were observed. There were also three instances where a manned aircraft request was altered and/or cancelled for a total of nine efficiency-related outcomes.

Scen4 and Scen8 had noticeably more efficiency-related events than Scen1 and Scen9. SME noted that the performance characteristics of the MQ-1B Predator were at times incompatible with manned aircraft, thus contributing to inefficiencies. The specific performance characteristics at play were the MQ-1B Predator's slow pattern speed and its inability to comply with ATC instructions by visual means.

Table 17: Scen1-4-8-9 Efficiency Metrics

	Scen1	Scen4	Scen8	Scen9
Go-Arounds				
ATC Initiated Go-Arounds	0	1	0	0
Pilot Initiated Go-Arounds	1	1	0	0
Total	**1**	**2**	**0**	**0**
Delays				
Manned A/C Departure Delays	0	2	2	3
Manned A/C Arrival Delays	0	0	2	0
Unmanned A/C Departure Delays	0	0	0	1
Unmanned A/C Arrival Delays	0	0	1	0
Total	**0**	**2**	**5**	**4**
Traffic Pattern Modifications				
Extended Down-Winds	0	5	2	2
360° Turns	2	0	2	0
ATC Initiated Runway Changes	0	4	2	0
ATC Requested Short Approaches	0	0	1	0
ATC Requested Early Departure Turns	0	0	0	0
ATC Assigned Straight-Out/Runway Headings	1	4	1	0
Total	**3**	**13**	**8**	**2**
Miscellaneous Efficiency Measures				
Class D Airspace Denials	0	1	0	0
Re-Sequenced Arrivals	1	1	0	0
Re-Sequenced Departures	0	0	0	0
Altered and/or Cancelled Manned A/C Requests	2	1	2	3
Altered and/or Cancelled Unmanned A/C Requests	0	0	1	0
Total	**3**	**3**	**3**	**3**
TOTAL: All Efficiency-Related Occurrences	**7**	**20**	**16**	**9**

Participant input indicates that some of the observed efficiency metrics may have been directly attributed to the presence of UAS in the operations.

In Scen4, the Local controller indicated the UAS considerably affected his ability to accommodate manned aircraft (rated 5, on a 7-point scale, with "1" corresponding to "not at all" and "7" corresponding to "a great deal"). This same metric received a lower rating by the Local controller in Scen8 and Scen9 (rated a 2 in both Scen8 and Scen9). The Local SME Observer in Scen8 indicated that the Predator's slow speed while performing touch and gos caused the controller to extend the traffic pattern. In addition, the Local controller in Scen8 noted that a manned aircraft request was altered due to UAS operations.

The Local SME Observer indicated that the go-arounds and manned aircraft delays in Scen4 were not a result of UAS presence in the scenario, but rather a result of other manned aircraft.

The Local controller indicated that he provided a significant amount of priority handling to the UAS in Scen4 but not as much in Scen8 or Scen9 (rated 5, 2, and 1 for Scen4, Scen8, and Scen9, respectively).

Questionnaire responses show that the Local controller in Scen4 noticed some effect of the UAS on traffic flow operations because he now "had to call base [turn] to follow traffic." Similarly, in Scen8, the Local controller reported that he treated UAS differently than manned aircraft. He indicated that this was due to the fact that he was unable to tell the UAS PIC that "[he] is number two to follow [another aircraft in the traffic pattern]." Similar to observations in other scenarios, this is a result of the fact that UAS PICs are not on board the aircraft and they currently do not have an alternate approved method to visually acquire and follow other aircraft[10].

The Ground SME observer rated overall efficiency of taxiway and runway assignments as above average for Scen1, Scen4, and Scen8 (rated as 5, 6, and 5, respectively) and below average for Scen9 (rated as 2).

SME Observer ratings and controller questionnaire responses both indicate that the UAS operations had a larger impact on the efficiency of traffic operations in Scen4 and Scen8, as compared to Scen9.

4.2.2.4 Scen1-4-8-9 Communication

Voice communication is a key element of ATC. Many different communication anomalies can be indicative of traffic saturation and ATC loss of situation awareness. These types of occurrences include transposed call signs, missed transmissions, misidentified aircraft, and repeat ATC instructions. (Note: simulation pilot communication errors are not reported since they were not the subject of study.)

In Scen1, the SME Observers noted the observation of one transposed control instruction and late coordination with the JOSHUA sector at the High Desert TRACON by the Ground controller.

In Scen4, the SME Observers noted the occurrence of two transposed control instructions and two excessive/repeated clearances/control instructions, all on the part of the Local controller. In one specific instance, the SME Observer noted that the Local controller remarked, "I don't know what I said to you" to one aircraft on frequency. The SME Observers also noted that some of the control instructions issued by the Local controller in Scen4 were untimely and seemed to create additional work. It was noted by SME Observers that it did not seem as though the UAS present in the scenario directly contributed to these communication anomalies.

The SME Observers also reported that in some instances, in Scen4, the controllers used nonstandard phraseology in situations involving the UAS. The SME Observers added that, while

[10] Reference JO 7110.65 Section 3-8-1

this type of phraseology is sometimes necessary, it can lead to confusion, adding risk to the safety of operations. This occurred specifically in this scenario when the Local controller was attempting to issue control instructions to the Predator's chase aircraft regarding how and when to join up with the Predator. Observances such as this demonstrate the potential need to examine standards for UAS-specific phraseology.

In Scen8, the SME Observers did not observe any communication anomalies.

In Scen9, SME Observers noted the observation of three missed transmissions, two on the part of the Local controller and one on the part of the Ground controller.

It is clear from this data that Scen4 had more communication anomalies than Scen1, Scen8, and Scen9.

4.2.2.5 Scen1-4-8-9 Workload and Situation Awareness

In addition to the observations noted in the safety, efficiency, and communications section, other measures of workload and situation awareness were captured via the system recordings, PRQ, and WAK.

Table 18 summarizes the traffic counts for these scenarios.

Table 18: Scen1-4-8-9 Traffic Counts

	# Arrivals	# Departures	# Touch and Gos/Low Approaches	# Overflights
Scen1	15	14	10	3
Scen4	21	21	15	5
Scen8	21	22	17	6
Scen9	21	23	17	7

Table 19 and Table 20 depict subjective ratings of overall complexity and overall workload provided by the participants and SME Observers after each scenario. These ratings were made on a Likert scale of 1-7, with "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High."

All individuals provided average or below average ratings of overall complexity for Scen1, Scen8, and Scen9. The Local controller and Local SME Observer rated overall complexity as above average for Scen4.The Ground controller and Ground SME Observer rated overall complexity as below average for Scen4.

All individuals provided average or below average ratings for overall workload in Scen1 and Scen8. The Local controller rated his overall workload in Scen4 as above average, while the rest of the individuals rated overall workload for this scenario as average or below. The Local SME Observer rated overall workload in Scen9 as above average, while the rest of the individuals rated overall workload for this scenario as average or below.

Table 19: Scen1-4-8-9 Ratings of Overall Complexity

Overall Complexity	Local Controller	Local Control SME Observer	Ground Controller	Ground Control SME Observer
Scen1	4	4	1	3
Scen4	6	5	3	3
Scen8	4	4	3	4
Scen9	4	4	4	2

Table 20: Scen1-4-8-9 Ratings of Overall Workload

Overall Workload	Local Controller	Local Control SME Observer	Ground Controller	Ground Control SME Observer
Scen1	4	3	1	3
Scen4	6	4	4	3
Scen8	4	4	3	4
Scen9	4	5	3	2

Factors such as mental demand, effort, and the degree to which UAS required attention are some of the contributing factors to overall workload and complexity.

On a 7-point scale, with "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High," the Local controller reported average and below average ratings for effort and mental demand in Scen1 and Scen8 (rated as 4 and 3, respectively, for Scen1, and both rated as 4 for Scen8). For Scen4 and Scen9, the Local controller reported above average ratings for effort and mental demand (both rated as 6 for Scen4, and 5 for Scen9). The Local controller reported below average temporal demand for Scen1, Scen8, and Scen9 (rated as 3, 2, and 3, respectively), but above average for Scen4 (rated as 5).

The Local controller rated the degree to which UAS required additional attention as above average in Scen4 (rated as 5) and below average in Scen8 and Scen9 (both rated as 2).

These results support previous SME observations of increased workload and complexity in Scen4 and Scen9. The SME Observers identified three contributing factors. They were the requirement of the MQ-1B Predator to safely join with its chase plane (Mooney) before departing the Class D airspace. The second was that the Local controller had to provide progressive pattern instructions to the MQ-1B Predator pilot while in the pattern. This is due to the inability of any UAS to comply with ATC instructions by visual means. The third was the lack of standard phraseology when providing ATC services to UAS.

Participants were asked to provide instantaneous workload ratings every two minutes during the run, via a WAK located at each workstation. Ratings were made on a 7-point scale, with "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High." Figure 8 depicts the average of these workload ratings for each scenario by control position.

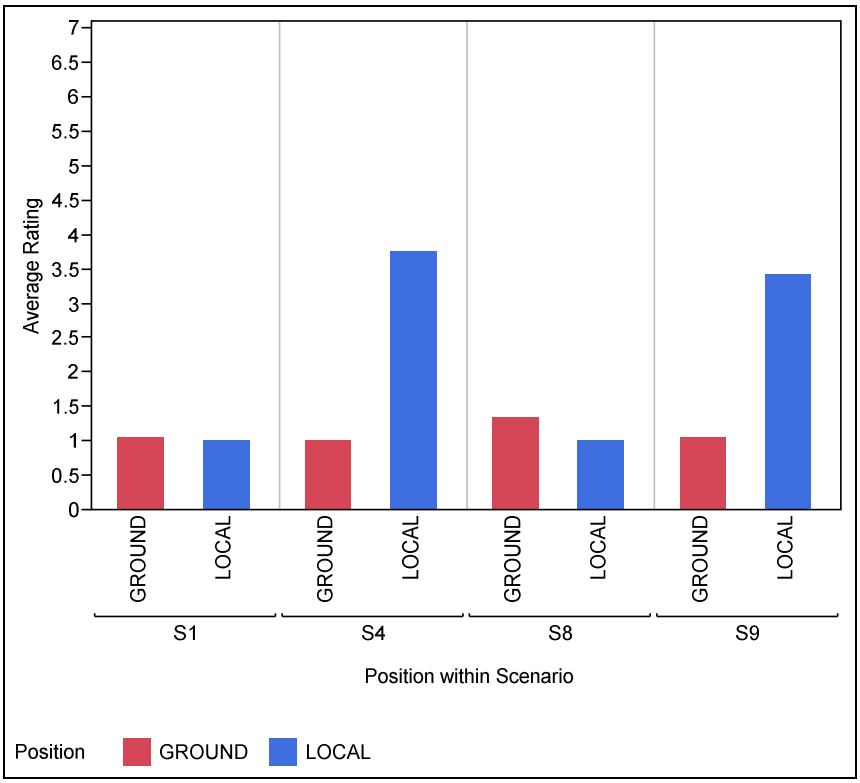

Figure 8: Scen1-4-8-9 WAK Data

In line with other workload measures reported, the Local controller's mean instantaneous workload ratings were higher in Scen4 and Scen9 than those observed in Scen1 and Scen8. Also consistent with other workload measures, the Ground controller's mean instantaneous workload rating was below average for all four scenarios.

Though mean workload ratings for all scenarios were average or below, the highest mean workload ratings were reported by the Local controller in Scen4 and Scen9.

4.2.2.6 Scen1-4-8-9 Comparison Findings

A summary of observations for this comparison are listed.

- SME Observer ratings related to perception of safety appear to be consistent across all four scenarios.

- More safety precautions were taken with regard to UAS operations in Scen8 (included three UAS) as compared to Scen4 (included two UAS) and Scen9 (included four UAS).

- Scen9 had the highest number of incidents. Scen4, Scen8, and Scen9 all had UAS-involved incidents.

- SME Observers noted that there was an increase in the occurrence of OE and OD with the presence of UAS.

- Scen4 and Scen8 had noticeably more efficiency-related events than Scen1 (no UAS) and Scen9. SME Observer ratings and controller questionnaire responses both indicate that the UAS operations had a larger impact on the efficiency of traffic operations in Scen4 and Scen8 as compared to Scen9.

- SME noted a decrease in efficiency with the presence of UAS.

- SME noted that there is often a lack of consistency regarding the application of ATC services to UAS among different controllers. This can be attributed to a lack of written policy and guidance on ATC services to UAS.

- Scen4 had more communication anomalies than Scen1, Scen8, and Scen9.

- SME noted that there is often a lack of consistency of controller-to-pilot phraseology among different controllers when communicating to UAS PIC. This can be attributed to a lack of written policy and guidance pertaining to ATC phraseology when communicating with UAS PIC.

- SME observations indicate increased workload and complexity in Scen4 and Scen9.

- SME noted that there was an increase in ATC workload and complexity with the presence of UAS.

- SME noted that UAS which required the use of the runways were much more reliant on ATC for sequencing and spacing than manned aircraft pilots. This had the potential to increase controller workload and complexity.

- SME noted that the presence of aircraft delays, numerous traffic pattern modifications, re-sequencing of arrivals, denials of entry into Class D airspace, and denials to enter traffic patterns for practice approaches are all symptoms of an operational situation that is too complex or ATC workload that is too high. The actions taken by the controller are tools to manage traffic volume and complexity and to ensure safety. This was observed throughout Scen4, Scen8, and Scen9.

- Though mean instantaneous workload ratings for all scenarios were average or below, the highest mean instantaneous workload ratings were observed by the Local controller in Scen4 and Scen9.

Upon examination of the complete set of data collected, the trend in findings indicates that the three scenarios with UAS (Scen4, Scen8, and Scen9) had noticeably more safety and efficiency incidents than the scenario with no UAS (Scen1). The scenario with all four UAS (Scen9) had

more safety incidents and higher levels of workload and complexity. The scenario with two UAS (Scen4) had noticeably more efficiency-related occurrences, more communication anomalies, and increased levels of workload and complexity. It also appeared in Scen4 that the UAS appeared to have a larger impact on the efficiency of traffic operations. The scenario with three UAS (Scen8) had more efficiency-related occurrences and the UAS appeared to have more of an impact on the efficiency of traffic operations, but more safety precautions seemed to be taken with regard to the UAS operations in this scenario.

4.2.3 Scenarios 4 and 5

The comparative analysis scenarios each consisted of approximately 17 manned aircraft operations, to which UAS operations were incrementally added. The goal of the comparison was to identify and document the impact of the UAS operations on manned aircraft, standard ATC operations, and routine operations in Class D airspace. The comparative scenarios did not contain any off-nominal events such as lost link or in-flight emergencies. This scenario comparison "thread" contains Scenario 4 (Scen4) and Scenario 5 (Scen5). The main difference between the two scenarios is that in Scen4 the MQ-1B Predator departed KVCV, joined with a manned chase aircraft, and exited Class D airspace. In Scen5, the MQ-1B Predator departed KVCV and remained in the Class D airport traffic pattern without a chase aircraft.

4.2.3.1 Scen4-5 Design

All scenarios were developed with the following characteristics:

Airport and Weather Conditions: Simulation start-time was mid-afternoon, and VFR prevailed throughout the scenario. Winds were 210° at 9kts. The active runways were 21 and17.

Manned Aircraft: Seventeen manned aircraft were included to simulate normal traffic flows at the airport. Operations included both military and civilian departures, arrivals, over-flights, and local traffic pattern work. Four additional VFR (1200 code) targets were introduced to simulate over-flight traffic above and/or adjacent to the Class D airspace. These targets did not communicate with ATC.

Special Military Operations: In addition to other manned military flights, a C17 Globemaster II (Slam 88) was added to simulate specialized military tactical maneuvers practiced by USAF crews at KVCV and similar airports.

Ground Vehicles: Two Ground vehicles were added to the scenario to replicate vehicular traffic at a typical airport. The vehicles simulated routine airfield maintenance and runway sweeping operations and communicated with ATC on the GC frequency.

Unmanned Aircraft Systems: Table 21 captures the type of UAS present in each scenario.

Table 21: Comparative Scenarios (Scen4, Scen5)

	Number of UAS	UAS
Scen4	2	AS800 JPL Blimp, MQ-1B Predator with chase aircraft (a manned Mooney MO20)
Scen5	2	AS800 JPL Blimp, MQ-1B Predator

4.2.3.2 Scen4-5 Safety

The ATC operations in these scenarios were evaluated with regard to the safety and efficiency of the flow of traffic. Several notable observations are described in this section.

As rated on a 7-point scale in the PRQ, with "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High," the Local controller reported having average or higher confidence in the overall safety of operations, giving ratings of 5 and 4 for Scen4 and Scen5, respectively. The Ground controller's confidence in safety was extremely high for both of these scenarios (rated a 7 for both). The Local controller in Scen5 also indicated that he provided an extra margin of spacing for the UAS; however, the Local controller in Scen4 did not.

On the same scale, the Ground SME Observer rated the overall safety and efficiency of the traffic flow below average for Scen4 and above average for Scen5 (rated as 3 for Scen4, and 5 for Scen5). The Local SME Observer rated both scenarios as a 5, corresponding to above average.

In general, ratings related to the perception of safety for both scenarios ranged from just below average to extremely high without a clear trend in responses.

From an operational perspective, there are several types of incidents that adversely affect the safe, orderly, and expeditious movement of air traffic. These include MAC, along with other ACC, NMAC, OE, OD, RI, and PD. Concerning some of these measures, it is important to note that the focus of this study was to examine the potential effects of UAS operations on Class D airspace. By design, the simulation pilots, both manned and unmanned, were not the direct subject of study in this simulation. Therefore, any occurrences of pilot-induced incidents (e.g., PD, RI, or NMAC caused by pilot error or actions) are considered part of the realistic, complex situations presented to the controller participants and not reported as deficiencies or safety-related findings for the purposes of this evaluation.

Information concerning the study's valid incident safety measures are summarized in Table 22, with reported incident details provided in Table 23. Both scenarios were 45 minutes in length.

In Scen4, there were two incidents attributed to ATC. One was caused by ATC failing to coordinate use of adjacent airspace as prescribed in FAA Order JO7110.65, Section 2-1-14, and resulted in an OD. UAS were not involved in the OD. One NMAC also occurred and involved a UAS.

In Scen5, there were six incidents attributed to ATC. All were caused by ATC not complying with the proper intersecting runway standards as prescribed in FAO JO7110.65, Sections 3-9-8 and 3-10-4, Intersecting Runway Separation, and resulted in OE. One OE involved a UAS.

The data shows that Scen5 (the MQ-1B Predator remained in the traffic pattern) had noticeably more safety incidents than Scen4 (the MQ-1B Predator and visual observer chase aircraft joined as a flight, then departed Class D airspace). Both Scen4 and Scen5 had UAS-involved incidents.

Table 22: Scen4-5 Safety Metrics

	# MAC	# Other Accidents	# NMAC	# OE	# OD	# Runway Incursions	TOTAL # INCIDENTS
Scen4	0	0	1	0	1	0	**2**
Scen5	0	0	0	6	0	0	**6**

Table 23: Scen4-5 Incident Table

	Incident Type	Aircraft #1	Aircraft #2	Incident Description
Scen4	NMAC	Slam 88	JPL AS800 (UAS)	ATC permitted SLAM 88 to operate within the confines of the JPL operations area. (Closest proximity was 414 feet)
	OD	Slam 88	n/a	ATC Failed to coordinate use of adjacent airspace * Reference FAA Order JO 7110.65 Section 2-1-14
Scen5	OE	Slam 88	N90PH	Required intersecting runway separation was not provided * Reference FAA Order JO 7110.65 Section(s) 3-9-8 / 3-10-4
	OE	RYN5	N744PA	Required intersecting runway separation was not provided * Reference FAA Order JO 7110.65 Section(s) 3-9-8 / 3-10-4
	OE	Slam 88	N44EL	Required intersecting runway separation was not provided * Reference FAA Order JO 7110.65 Section(s) 3-9-8 / 3-10-4
	OE	Slam 88	N44EL	Required intersecting runway separation was not provided * Reference FAA Order JO 7110.65 Section(s) 3-9-8 / 3-10-4
	OE	Slam 88	N44EL	Required intersecting runway separation was not provided * Reference FAA Order JO 7110.65 Section(s) 3-9-8 / 3-10-4
	OE	R50095	Grizzly 21 (UAS)	Required intersecting runway separation was not provided * Reference FAA Order JO 7110.65 Section(s) 3-9-8 / 3-10-4

4.2.3.3 Scen4-5 Efficiency

Several metrics were captured to evaluate the efficiency of the operation simulated. Table 24 captures the observed occurrences of the efficiency metrics for these scenarios.

In Scen4, ATC initiated one go-around, one pilot initiated a go-around, two aircraft were delayed, and 13 traffic pattern modifications were observed. There was also one Class D airspace request denied, one re-sequenced arrival, and one instance where a manned aircraft request was altered and/or cancelled, for a total of 20 efficiency-related occurrences.

In Scen5, four pilots initiated go-arounds, three manned aircraft were delayed, one UA was delayed, and seven traffic pattern modifications were observed. There was also one instance where a manned aircraft request was altered and/or cancelled and one instance where a UA request was altered and/or cancelled, for a total of 17 efficiency-related occurrences.

Scen4 and Scen5 both had a notably high number of efficiency-related events.

Table 24: Scen4-5 Efficiency Metrics

	Scen4	Scen5
Go-Arounds		
ATC Initiated Go-Arounds	1	0
Pilot Initiated Go-Arounds	1	4
Total	**2**	**4**
Delays		
Manned A/C Departure Delays	2	3
Manned Aircraft Arrival Delays	0	0
Unmanned A/C Departure Delays	0	0
Unmanned A/C Arrival Delays	0	1
Total	**2**	**4**
Traffic Pattern Modifications		
Extended Down-Winds	5	4
360° Turns	0	1
ATC Initiated Runway Changes	4	1
ATC Requested Short Approaches	0	0
ATC Requested Early Departure Turns	0	0
ATC Assigned Straight-Out/Runway Headings	4	1
Total	**13**	**7**
Miscellaneous Efficiency Measures		
Class D Airspace Denials	1	0
Re-Sequenced Arrivals	1	0
Re-Sequenced Departures	0	0
Altered and/or Cancelled Manned A/C Requests	1	1
Altered and/or Cancelled Unmanned A/C Requests	0	1
Total	**3**	**2**
TOTAL: All Efficiency-Related Occurrences	**20**	**17**

Participant input indicates that some of the observed efficiency metrics may be directly attributed to the presence of UAS in the operations. In Scen4, the Local controller indicated the UAS considerably affected his ability to accommodate manned aircraft (rated 5, on a 7-point scale, with "1" corresponding to "not at all" and "7" corresponding to "a great deal"). This same metric received a notable, but lower, rating by the Local controller in Scen5, indicating a lesser effect (rated a 3).

The Local controller indicated that he provided a significant amount of priority handling to the UAS in Scen4, and a notable, but lesser, amount in Scen5 (rated a 5 and 3 for Scen4 and Scen5, respectively).

The Local SME Observer indicated that the go-arounds and manned aircraft delays in Scen4 were not the result of UAS presence in the scenario, but rather a result of other manned aircraft.

Questionnaire responses show that the Local controller in Scen4 noticed some effect of the UAS on traffic flow operations because he now "had to call base [turn] to follow traffic." Similar to observations in other scenarios, this is a result of the fact that UAS PIC are not on board the aircraft and they currently do not have an alternate approved method to visually acquire and follow other aircraft[11]. In Scen5, the Local SME Observer indicated that the Predator was cleared to High Key to hold outside of the traffic pattern until the pattern was clear. The Local controller in Scen5 also noted in questionnaire responses that he had to extend the patterns of other aircraft to provide proper spacing for the Predator.

Together, participant and SME observer ratings suggest that the UAS had a notable effect on the efficiency of operations in both Scen4 and Scen5.

4.2.3.4 Scen4-5 Communication

Voice communication is a key element in ATC. Many different communication anomalies can be indicative of traffic saturation and ATC loss of situation awareness. These types of occurrences include transposed call signs, missed transmissions, misidentified aircraft, and repeat ATC instructions. (Note: simulation pilot communication errors are not reported since they were not the subject of study.)

In Scen4, the SME Observers noted the occurrence of two transposed control instructions and two excessive/repeated clearances/control instructions, all on the part of the Local controller. In one specific instance, the SME Observer noted that the Local controller remarked, "I don't know what I said to you" to one aircraft on frequency. The SME Observers also noted that some of the control instructions issued by the Local controller in Scen4 were untimely and appeared to create additional work. It was noted by SME Observers that it did not appear as though the UAS present in the scenario were a direct contributing factor to these communication anomalies.

The SME Observers also reported that in some instances, in Scen4, the controllers used nonstandard phraseology in situations involving the UAS. The Observers added that, while this type of phraseology is sometimes necessary, it can lead to confusion, adding risk to the safety of operations. This occurred specifically in this scenario when the Local controller was attempting to issue control instructions to the Predator's chase aircraft regarding how and when to join up with the Predator. Observances such as this demonstrate the potential need to examine standards for UAS-specific phraseology.

In Scen5, the Ground SME Observer noted the occurrence of two missed transmissions. It is clear from this data that Scen4 had more communication anomalies than Scen5.

[11] Reference JO 7110.65 Section 3-8-1

4.2.3.5 Scen4-5 Workload and Situation Awareness

In addition to the observations noted in the safety, efficiency, and communications section, other measures of workload and situation awareness were captured via the system recordings, PRQ, and WAK. Table 25 summarizes the traffic counts for these scenarios.

Table 25: Scen4-5 Traffic Counts

	# Arrivals	# Departures	# Touch and Gos/Low Approaches	# Overflights
Scen4	21	21	15	5
Scen5	24	24	18	4

Table 26 and Table 27 depict subjective ratings of overall complexity and overall workload provided by the participants and SME Observers after each scenario. These ratings were made on a Likert scale of 1-7, with "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High."

The Local controller rated overall complexity as high in Scen4 and below average in Scen5 (rated as 6 and 3, respectively). The Ground controller and the Ground SME Observer in both scenarios rated overall complexity as average or below.

The Local controller rated his overall workload as high in Scen4 and below average in Scen5 (rated as 6 and 3, respectively). The Ground controller and the Ground SME Observer in both scenarios rated overall workload as average or below.

Table 26: Scen4-5 Ratings of Overall Complexity

Overall Complexity	Local Controller	Local Control SME Observer	Ground Controller	Ground Control SME Observer
Scenario 4	6	5	3	3
Scenario 5	3	6	3	4

Table 27: Scen4-5 Ratings of Overall Workload

Overall Workload	Local Controller	Local Control SME Observer	Ground Controller	Ground Control SME Observer
Scenario 4	6	4	4	3
Scenario 5	3	5	3	4

Factors such as mental demand, effort, and the degree to which UAS required attention are some of the contributing factors to overall workload and complexity.

In Scen4, the Local controller reported above average levels of effort and mental demand (both rated a 6, on a 7-point scale, with "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High)." The Local controller in Scen5 rated effort and mental demand as average or below (rated a 3 and 4, respectively). Interestingly, the Ground controller rated effort and mental demand as very low in Scen4 (rated 2 and 1, respectively) and average or above average in Scen5 (rated 5 and 4, respectively). These results are consistent with the participant's questionnaire responses regarding overall workload and complexity.

In Scen4, the Local SME Observer noted that it appeared as though the Local controller lost situation awareness during the scenario. SME Observer input indicates this may have resulted in some of the communication anomalies described previously.

These results support previous SME observations of increased workload and complexity in Scen4.

Participants were asked to provide instantaneous workload ratings every two minutes during the run via a WAK located at each workstation. The ratings were made on a 7-point scale, with "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High." Figure 9 depicts the average WAK ratings, for each controller position, throughout each of the scenarios of interest.

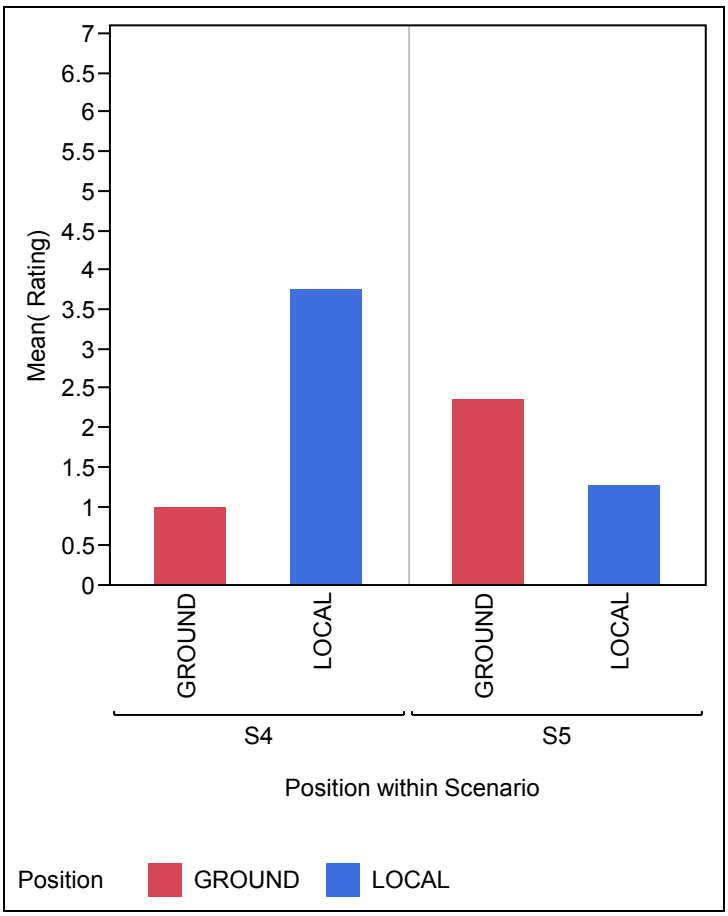

Figure 9: Scen4-5 WAK Data

In line with other workload measures reported, the Local controller's mean instantaneous workload throughout Scen4 was higher than that of Scen5. The Ground controller's mean instantaneous workload throughout was rather low for both scenarios, but lower in Scen4 than in Scen5.

Though mean workload ratings for both scenarios were below average, the highest workload rating for the Local controller was observed in Scen4 (which includes the Predator's chase aircraft).

4.2.3.6 Scen4-5 Comparison Findings

A summary of observations for this comparison are listed.

- In general, ratings related to the perception of safety for both scenarios ranged from just below average to extremely high without a clear trend in responses.

- The data shows that Scen5 (the MQ-1B Predator remained in the Class D traffic pattern) had noticeably more safety incidents than Scen4 (the MQ-1B Predator with the visual observer chase aircraft joining in the flight then departing the Class D airspace). The data suggests increased safety incidents in Scen5 can be related to the mixing of manned

aircraft and the MQ-1B Predator in the Class D traffic patterns. Both Scen4 and Scen5 had UAS-involved incidents.

- Scen4 and Scen5 both had a notably high number of efficiency-related events. Participant and SME Observer ratings suggest that the UAS operations were a contributing factor. Specifically, the SME Observers noted the requirement for use of the runways and traffic patterns by the MQ-1B Predator in Scen5 contributed to a reduction in efficiency. They also noted that in Scen4, the addition of the chase aircraft and its requirement to join as a flight with the MQ-1B Predator in Class D airspace contributed to a reduction in efficiency.

- Scen4 had more communication anomalies than Scen5. The SME Observers noted the increase in the use of non-standard phraseology contributed to the communication anomalies and added risk to the safety of the operations.

- SME observations indicate increased workload and complexity in Scen4. The SME Observers noted the addition of the chase aircraft and the requirement for it to join with the MQ-1B Predator in Class D airspace increased ATC workload and complexity.

- SME noted the UAS that required the use of the runways were much more reliant on ATC for sequencing and spacing than manned aircraft pilots. This had the potential to increase controller workload and complexity.

- Though mean instantaneous workload ratings for both scenarios were below average, the highest workload rating for the Local controller was observed in Scen4.

Upon examination of the complete set of data collected, the overall presence of UAS accounted for a notable impact on manned aircraft, standard ATC operations, and routine operations in Class D airspace. The trend in findings indicates that Scen5 (when the MQ-1B Predator remained in the Class D traffic pattern) had more safety incidents as the UAS interacted with manned aircraft; however, Scen4 had a near midair collision incident involving a UAS. Both Scen4 and Scen5 showed a notably high number of efficiency-related events. Ratings suggest that the presence of the MQ-1B Predator had a notable effect on the efficiency of operations in both scenarios. Scen4 (the MQ-1B Predator UAS and chase aircraft joined as a flight then departed the Class D airspace) had noticeably more communication anomalies and the highest mean instantaneous rating for workload (though all mean workload ratings were below average).

4.2.4 Scenarios 1, 3, 6, and 9

The comparative analysis scenarios each consisted of approximately 17 manned aircraft operations, to which UAS operations were incrementally added. The goal of the comparison was to identify and document the impact of the UAS operations on manned aircraft, standard ATC operations, and routine operations in Class D airspace. The comparative scenarios did not contain any off-nominal events such as lost link or in-flight emergencies. This scenario comparison "thread" contains Scenario 1 (Scen1), Scenario 3 (Scen3), Scenario 6 (Scen6), and Scenario 9 (Scen9).

4.2.4.1 Scen1-3-6-9 Scenario Design

All scenarios were developed with the following characteristics:

Airport and Weather Conditions: Simulation start-time was mid-afternoon and VFR prevailed throughout the scenario. Winds were 210° at 9kts. The active runways were 21 and 17.

Manned Aircraft: Seventeen manned aircraft were included to simulate normal traffic flows at the airport. Operations included both military and civilian departures, arrivals, over-flights, and local pattern work. Four additional "non-cooperative" targets were introduced to simulate over-flight traffic above and/or adjacent to the Class D airspace. These targets did not communicate with ATC.

Special Military Operations: In addition to other manned military flights, a C17 Globemaster II (Slam 88) was added to simulate specialized military tactical maneuvers practiced by USAF crews at KVCV and similar airports.

Ground Vehicles: Two ground vehicles were added to the scenario to replicate vehicular traffic at a typical airport. The vehicles simulated routine airfield maintenance and runway sweeping operations and communicated with ATC on the GC frequency.

Unmanned Aircraft Systems: Table 28 captures the type of UAS present in each scenario.

Table 28: Comparative Scenarios (Scen1, Scen3, Scen6, Scen9)

	Number of UAS	UAS Description
Scen1	0	None
Scen3	2	AS800 JPL Blimp, A-160 Hummingbird
Scen6	3	AS800 JPL Blimp, A-160 Hummingbird, RQ-11 Raven
Scen9	4	AS800 JPL Blimp, A-160 Hummingbird, RQ-11 Raven, MQ-1B Predator with chase aircraft (a manned Mooney MO20)

4.2.4.2 Scen1-3-6-9 Safety

The ATC operations presented in these scenarios were evaluated with regard to the safety and efficiency of the flow of traffic. Several notable observations and comparisons are described in this section.

As rated on a 7-point scale in the PRQ, with "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High," the Local controller in each scenario reported high confidence in the overall safety of operations, giving ratings of 5, 6, 6, and 6 for Scen1, Scen3, Scen6, and Scen9, respectively. The Ground controller's confidence in safety was very high for all four scenarios (rated 7, 7, 7, and 6 for Scen1, Scen3, Scen8, and Scen9, respectively).

SME Observers generally agreed in their perceived levels of safety across most of these scenarios. On the same 7-point scale, the Local SME Observer rated the overall safety of the pattern sequence high for Scen1, Scen3, and Scen9 (all rated 6). The Local SME Observer did not indicate a response to this question for Scen6. The Ground SME Observer rated this metric as above average to high for all four scenarios (rated 5, 6, 5, and 6 for Scen1, Scen3, Scen6, and Scen9, respectively).

SME Observers noted that in Scen9 there were instances in which the controllers did not exercise 'positive control,' compromising the safety of these simulated operations. The SME Observers noted that operations such as joining the MQ-1B Predator with its chase aircraft MO-20 in the Class D airspace add to complexity and workload. Increased complexity and workload can distract a controller and can be a causal factor when a controller does not exercise positive control.

In general, SME Observer ratings related to perception of safety appear to be consistent across all four scenarios.

From an operational perspective, there are several types of incidents that adversely affect the safe, orderly, and expeditious movement of air traffic. These include MAC as well as other ACC, NMAC, OE, OD, RI, and PD. Concerning some of these measures, it is important to note that the focus of this study was to examine the potential effects of UAS operations on Class D airspace. By design, the simulation pilots, both manned and unmanned, were not the direct subject of study in this simulation. Therefore, any occurrences of pilot-induced incidents (e.g., PD, RI, or NMAC caused by pilot error or actions) are considered part of the realistic, complex situations presented to the controller participants and not reported as deficiencies or safety-related findings for the purposes of this evaluation.

Information concerning the study's valid incident safety measures are summarized in Table 29, with reported incident details provided in Table 30. All scenarios were 45 minutes in length.

In Scen1, there were three incidents attributed to ATC. All were caused by ATC not complying with the proper intersecting runway standards as prescribed in FAO JO7110.65, Sections 3-9-8 and 3-10-4, Intersecting Runway Separation, and resulted in OE. None of the OE involved UAS.

In Scen3, there was one incident attributed to ATC. It was caused by ATC not complying with the proper intersecting runway standards as prescribed in FAO JO7110.65, Sections 3-9-8 and 3-10-4, Intersecting Runway Separation, and resulted in an OE. The OE did not involve UAS.

In Scen6, there were four incidents attributed to ATC. All were caused by ATC not complying with the proper intersecting runway standards as prescribed in FAO JO7110.65, Sections 3-9-8 and 3-10-4, Intersecting Runway Separation, and resulted in OE. None of the OE involved UAS.

In Scen9, there were five incidents attributed to ATC. Four were caused by ATC not complying with the proper intersecting runway standards as prescribed in FAO JO7110.65, Sections 3-9-8 and 3-10-4, Intersecting Runway Separation, and resulted in OE. One OE involved a UAS. One NMAC also occurred and involved a UAS.

This data shows that Scen6 (three UAS present) and Scen9 (four UAS present) had the most safety incidents. Scen9 also had UAS-involved incidents.

Table 29: Scen1-3-6-9 Safety Metrics

	#MAC	# Other Accidents	# NMAC	# OE	# OD	# Runway Incursions	TOTAL # INCIDENTS
Scen1	0	0	0	3	0	0	**3**
Scen3	0	0	0	1	0	0	**1**
Scen6	0	0	0	4	0	0	**4**
Scen9	0	0	1	4	0	0	**5**

Table 30: Scen1-3-6-9 Incident Tables

	Incident Type	Aircraft #1	Aircraft #2	Incident Description
Scen1	OE	N744PA	TNKR911	Required intersecting runway separation was not provided *Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
	OE	N744PA	N44EL	Required intersecting runway separation was not provided *Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
	OE	OMEGA70	DOJ703	Required intersecting runway separation was not provided *Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
Scen3	OE	R50095	N44EL	Required intersecting runway separation was not provided *Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
Scen6	OE	N744PA	N739HZ	Required intersecting runway separation was not provided *Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
	OE	N744PA	TNKR911	Required intersecting runway separation was not provided *Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
	OE	N744PA	N44EL	Required intersecting runway separation was not provided *Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
	OE	OMEGA70	N44EL	Required intersecting runway separation was not provided *Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
Scen9	NMAC	N744PA	RQ11 Raven (UAS)	ATC permitted N744PA to operate within the confines of the Raven operations area. (Closest proximity was 184 feet)
	OE	N744PA	Grizzly 21 (UAS)	Required intersecting runway separation was not provided *Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
	OE	N744PA	Slam 88	Required intersecting runway separation was not provided *Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
	OE	RYN5	N744PA	Required intersecting runway separation was not provided *Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
	OE	Slam 88	N44EL	Required intersecting runway separation was not provided *Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4

4.2.4.3 Scen1-3-6-9 Efficiency

Several metrics were captured to evaluate the efficiency of the operation simulated. Table 31 captures the observed occurrences of the efficiency metrics in these scenarios.

In Scen1, one pilot initiated a go-around and three traffic pattern modifications were observed. There was also one re-sequenced arrival and two instances where a manned aircraft request was altered and/or cancelled for a total of seven efficiency-related occurrences.

In Scenario 3, one manned aircraft was delayed and one traffic pattern modification was observed. There were also two instances where a manned aircraft request was altered and/or cancelled by ATC for a total of four efficiency-related occurrences.

In Scen6, three manned aircraft were delayed and five traffic pattern modifications were observed. There were also three instances where a manned aircraft request was altered and/or cancelled for a total of 11 efficiency-related occurrences.

In Scen9, three manned aircraft were delayed, one UAS was delayed, and two traffic pattern modifications were observed. There were also three instances where a manned aircraft request was altered and/or cancelled for a total of nine efficiency-related outcomes.

This data shows that Scen6 (three UAS present) and Scen9 (four UAS present) had the most efficiency-related events.

Table 31: Scen1-3-6-9 Efficiency Metrics

	S1	S3	S6	S9
Go-Arounds				
ATC Initiated Go-Arounds	0	0	0	0
Pilot Initiated Go-Arounds	1	0	0	0
Total	**1**	**0**	**0**	**0**
Delays				
Manned A/C Departure Delays	0	1	1	3
Manned Aircraft Arrival Delays	0	0	2	0
Unmanned A/C Departure Delays	0	0	0	1
Unmanned A/C Arrival Delays	0	0	0	0
Total	**0**	**1**	**3**	**4**
Traffic Pattern Modifications				
Extended Down-Winds	0	0	2	2
360° Turns	2	0	2	0
ATC Initiated Runway Changes	0	1	0	0
ATC Requested Short Approaches	0	0	0	0
ATC Requested Early Departure Turns	0	0	0	0
ATC Assigned Straight-Out/Runway Headings	1	0	1	0
Total	**3**	**1**	**5**	**2**
Miscellaneous Efficiency Measures				
Class D Airspace Denials	0	0	0	0
Re-Sequenced Arrivals	1	0	0	0
Re-Sequenced Departures	0	0	0	0
Altered and/or Cancelled Manned A/C Requests	2	2	3	3
Altered and/or Cancelled Unmanned A/C Requests	0	0	0	0
Total	**3**	**2**	**3**	**3**
TOTAL: All Efficiency-Related Occurrences	**7**	**4**	**11**	**9**

Participant input indicates that some of the observed efficiency metrics may have been directly attributed to UAS presence in the operations.

The Local controller reported that a notable amount of priority handling was provided to the UAS in Scen3 and Scen6 (both rated as 3 on a 7-point scale, with "1" corresponding to "not at all" and "7" corresponding to "a great deal").

The Ground controller reported that a notable amount of priority handling was provided to the UAS in Scen9 (rated 4).

The Local controller indicated that the UAS required a notable amount of additional attention as compared to manned aircraft in Scen3 and Scen6 (both rated as 4). The Ground controller indicated the UAS required a notable amount of additional attention as compared to manned aircraft in Scen9 (rated 3).

The Local controller reported that the UAS affected his ability to accommodate manned aircraft in Scen6 (rated 3). The Ground controller indicated that UAS had an effect on his ability to accommodate manned aircraft and the efficiency of manned aircraft operations in Scen9 (both rated a 4).

On a 7-point scale, with "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High," the Ground SME Observer rated overall efficiency of taxiway and runway assignments as above average for Scen1, Scen3, and Scen6 (rated as 5, 4, and 5, respectively) and below average for Scen9 (rated 2).

SME Observer ratings and controller questionnaire responses indicate that the UAS operations had a notable impact on the efficiency of traffic operations in all three scenarios involving UAS.

4.2.4.4 Scen1-3-6-9 Communication

Voice communication is a key element of ATC. Many different communication anomalies can be indicative of traffic saturation and ATC loss of situation awareness. These types of occurrences include transposed call signs, missed transmissions, misidentified aircraft, and repeat ATC instructions. (Note: simulation pilot communication errors are not reported since they were not the subject of study.)

In Scen1, the SME Observers noted one transposed control instruction and late coordination with the JOSHUA sector at High Desert TRACON by the Ground controller.

In Scen3, the SME Observers did not observe any communication anomalies.

In Scen6, the SME Observers noted a lack of effective and timely coordination as well as a lack of prescribed phraseology by the Ground controller.

In Scen9, SME Observers noted the observation of three missed transmissions, two by the Local controller and one by the Ground controller.

In general, Scen9 (included four UAS) had the most communication anomalies as compared to the other scenarios.

4.2.4.5 Scen1-3-6-9 Workload and Situation Awareness

In addition to the observations noted in the safety, efficiency, and communications section, other measures of workload and situation awareness were captured via the system recordings, PRQ, and WAK. Table 32 summarizes the traffic counts for these scenarios.

Table 32: Scen1-3-6-9 Traffic Counts

	# Arrivals	# Departures	# Touch and Gos/Low Approaches	# Overflights
Scen1	15	14	10	3
Scen3	19	21	14	5
Scen6	16	17	11	6
Scen9	21	23	17	7

Table 33 and Table 34 depict subjective ratings of overall complexity and overall workload provided by the participants and SME Observers after each scenario. These ratings were made on a Likert scale of 1-7, with "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High." All individuals provided average or below average ratings for overall complexity of all four scenarios.

All participants provided average or below average ratings for overall workload in Scen1, Scen3, and Scen6. The Local SME Observer rated overall workload in Scen9 as above average (rated 5), while the rest of the individuals rated overall workload for this scenario as average or below.

Table 33: Scen1-3-6-9 Ratings of Overall Complexity

Overall Complexity	Local Controller	Local Control SME Observer	Ground Controller	Ground Control SME Observer
Scen1	4	4	1	3
Scen3	4	3	1	2
Scen6	4	3	2	2
Scen9	4	4	4	2

Table 34: Scen1-3-6-9 Ratings of Overall Workload

Overall Workload	Local Controller	Local Control SME Observer	Ground Controller	Ground Control SME Observer
Scen1	4	3	1	3
Scen3	4	3	1	2
Scen6	4	3	1	2
Scen9	4	5	3	2

Factors such as mental demand, effort, and the degree to which UAS required attention are some of the contributing factors to overall workload and complexity.

On a 7-point scale, with "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High," the Local controller reported average and below average ratings for effort and mental demand in Scen1 (rated as 4 and 3, respectively) and Scen3 and Scen6 (both rated as 3). For Scen9, the Local controller reported above average ratings for effort and mental demand (both rated 5).

The Local controller in Scen3 and Scen9 indicated that handling the UAS had a notable effect on his workload (both rated 4 on a 7-point scale, with "1" corresponding to "not at all" and "7" corresponding to "a great deal").

The results support previous SME observations of increased workload in Scen9. The SME Observers identified five contributing factors. The first is the requirement of the MQ-1B Predator UAS to safely join with its chase plane (Mooney) as a flight before departing the Class D airspace. The second was that the Local controller had to provide progressive pattern instructions to the MQ-1B Predator pilot while in the pattern. This is due to the inability of any UAS to comply with ATC instructions by visual means. The third was the lack of standard phraseology when providing ATC services to UAS. The fourth was the slow flight characteristics of the MQ-1B Predator in comparison to manned aircraft in the traffic pattern. The fifth was the presence of four UAS. The SME Observers also noted that the presence of aircraft delays, traffic pattern modifications, and denials to manned aircraft to enter traffic patterns for practice approaches are all symptoms of an operational situation that is too complex or ATC workload that is too high. The actions taken by the controller are tools to manage traffic volume and complexity and to ensure safety.

Participants were asked to provide instantaneous workload ratings every two minutes during the run via a WAK located at each workstation. Ratings were made on a 7-point scale, with "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High." Figure 10 depicts the average of these workload ratings for each scenario by control position.

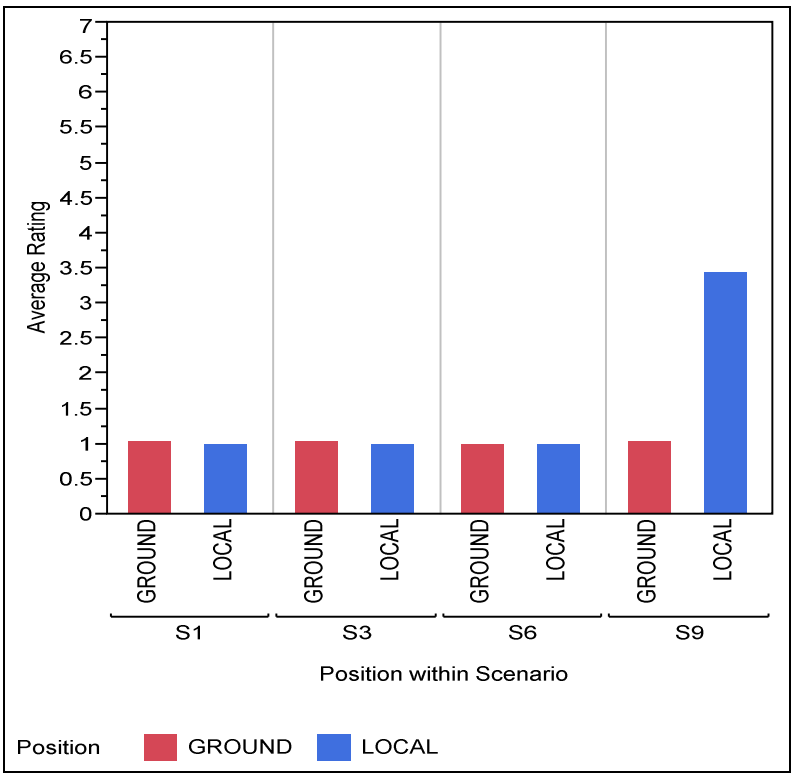

Figure 10: Scen1-3-6-9 WAK Data

In line with other workload measures reported, the Local controller's mean instantaneous workload rating was higher for Scen9 than those observed in Scen1, Scen3, and Scen6. Also consistent with other workload measures, the Ground controller's mean workload rating was well below average for all four scenarios.

4.2.4.6 Scen1-3-6-9 Comparison Findings

A summary of observations for this comparison are listed.

- SME Observer ratings related to perception of safety appear to be consistent across all four scenarios
- Scen6 (three UAS present) and Scen9 (four UAS present) had the most safety incidents. Scen9 also had UAS-involved incidents.
- Scen6 and Scen9 had the most efficiency-related events.
- SME Observer ratings and controller questionnaire responses indicate that the UAS operations had a notable impact on the efficiency of traffic operations in all three scenarios involving UAS.
- Scen9 had more communication anomalies than Scen1 (no UAS), Scen3 (two UAS), and Scen6.

- SME observations indicate increased workload in Scen9 (four UAS present). The SME Observers identified five contributing factors. The first is the requirement of the MQ-1B Predator UAS to safely join with its chase plane (Mooney) as a flight before departing the Class D airspace. The second was that the Local controller had to provide progressive pattern instructions to the MQ-1B Predator pilot while in the pattern. This is due to the inability of any UAS to comply with ATC instructions by visual means. The third was the lack of standard phraseology when providing ATC services to UAS. The fourth was the slow flight characteristics of the MQ-1B Predator in comparison to manned aircraft in the traffic pattern. The fifth was the presence of four UAS.

- SME noted that UAS which required the use of the runways were much more reliant on ATC for sequencing and spacing than manned aircraft pilots. This had the potential to increase controller workload and complexity.

- The SME Observers also noted that the presence of aircraft delays, traffic pattern modifications, and denials to manned aircraft to enter traffic patterns for practice approaches are all symptoms of an operational situation that is too complex or ATC workload that is too high. The actions taken by the controller are tools to manage traffic volume and complexity and to ensure safety

- Though mean workload instantaneous ratings reported by the controllers for all scenarios were well below average in general, the highest mean workload ratings were reported by the Local controller in Scen9.

Upon examination of the complete set of data collected, the trend in findings indicates that the scenarios with three and four UAS (Scen6 and Scen9, respectively) had noticeably more efficiency and safety incidents than the scenarios with zero and two UAS (Scen1 and Scen3, respectively). The scenario with all four UAS in the operation (Scen9) had the highest mean workload rating for the Local controller; it also had the most recorded communication anomalies.

4.2.5 Scenarios 1, 2, 6 and 9

The comparative analysis scenarios each consisted of approximately 17 manned aircraft operations, to which UAS operations were incrementally added. The goal of the comparison was to identify and document the impact of the UAS operations on manned aircraft, standard ATC operations, and routine operations in Class D airspace. The comparative scenarios did not contain any off-nominal events such as lost link or in-flight emergencies. This scenario comparison "thread" contains Scenario 1 (Scen1), Scenario 2 (Scen2), Scenario 6 (Scen6), and Scenario 9 (Scen9).

4.2.5.1 Scen1-2-6-9 Scenario Design

All scenarios were developed with the following characteristics:

Airport and Weather Conditions: Simulation start time was mid-afternoon and VFR prevailed throughout the scenario. Winds were 210° at 9kts. The active runways were 21 and 17.

Manned Aircraft: Seventeen manned aircraft were included to simulate normal traffic flows at the airport. Operations included both military and civilian departures, arrivals, over-flights, and local traffic pattern work. Four additional VFR (1200 beacon code) targets were introduced to simulate over-flight traffic above and/or adjacent to the Class D airspace. These targets did not communicate with ATC.

Special Military Operations: In addition to other manned military flights, a C17 Globemaster II (Slam 88) was added to simulate specialized military tactical maneuvers practiced by USAF crews at KVCV and similar airports.

Ground Vehicles: Two ground vehicles were added to the scenario to replicate vehicular traffic at a typical airport. The vehicles simulated routine airfield maintenance and runway sweeping operations and communicated with ATC on the GC frequency.

Unmanned Aircraft Systems: Table 35 captures the type of UAS present in each scenario.

Table 35: Comparative Scenarios (Scen1, Scen2, Scen6, Scen9)

	Number of UAS	UAS
Scen1	0	None
Scen2	2	AS800 JPL Blimp, RQ-11 Raven
Scen6	3	AS800 JPL Blimp, RQ-11 Raven, A-160 Hummingbird
Scen9	4	AS800 JPL Blimp, RQ-11 Raven, A-160 Hummingbird, MQ-1B Predator with chase aircraft (a manned MO20)

4.2.5.2 Scen1-2-6-9 Safety

The ATC operations presented in these scenarios were evaluated with regard to the safety and efficiency of the flow of traffic. Several notable observations and comparisons are described in this section.

As rated on a 7-point scale in the PRQ, with "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High," the Local controller in each scenario reported high confidence in the overall safety of operations, giving ratings of 5, 6, 6, and 6 for Scen1, Scen2, Scen6, and Scen9, respectively. The Ground controller's confidence in safety was very high for all four scenarios (rated 7, 7, 7, and 6, for Scen1, Scen2, Scen8, and Scen9, respectively).

On the same scale, the Local SME Observer rated the overall safety of the pattern sequence below average for Scen2 (rated 3) but above average for Scen1 and Scen9 (both rated 6). The Local SME Observer did not indicate a response to this question for Scen6. The Ground SME Observer rated this same metric as above average for all four scenarios (rated 5, 6, 5, and 6, for Scen1, Scen2, Scen6, and Scen9, respectively).

SME Observers noted that in Scen2 and Scen9 there were instances in which the controllers did not exercise 'positive control,' compromising the safety of these operations. The Local controller

in Scen2 indicated that he provided an extra margin of spacing for UAS; however, the Local controller in Scen6 and Scen9 did not.

In general, SME Observer ratings and observations related to perception of safety appear to be consistent across all four scenarios, with the one below average rating by the Local SME Observer echoing concerns identified in Scen2.

From an operational perspective, there are several types of incidents that adversely affect the safe, orderly, and expeditious movement of air traffic. These include MAC as well as other ACC, NMAC, OE, OD, RI, and PD. Concerning some of these measures, it is important to note that the focus of this study was to examine the potential effects of UAS operations on Class D airspace. By design, the simulation pilots, both manned and unmanned, were not the direct subject of study in this simulation. Therefore, any occurrences of pilot-induced incidents (e.g., PD, RI, or NMAC caused by pilot error or actions) are considered part of the realistic, complex situations presented to the controller participants and not reported as deficiencies or safety-related findings for the purposes of this evaluation.

Information concerning the study's valid incident safety measures are summarized in Table 36, with reported incident details provided in Table 37. All scenarios were 45 minutes in length.

In Scen1, there were three incidents attributed to ATC. All were caused by ATC not complying with the proper intersecting runway standards as prescribed in FAO JO7110.65, Sections 3-9-8 and 3-10-4, Intersecting Runway Separation, and resulted in OE. None of the OE involved UAS.

In Scen2, there were four incidents attributed to ATC. All were caused by ATC not complying with the proper intersecting runway standards as prescribed in FAO JO7110.65, Sections 3-9-8 and 3-10-4, Intersecting Runway Separation, and resulted in OE. None of the OE involved UAS.

In Scen6, there were four incidents attributed to ATC. All were caused by ATC not complying with the proper intersecting runway standards as prescribed in FAO JO7110.65, Sections 3-9-8 and 3-10-4, Intersecting Runway Separation, and resulted in OE. None of the OE involved UAS.

In Scen9, there were five incidents attributed to ATC. Four were caused by ATC not complying with the proper intersecting runway standards as prescribed in FAO JO7110.65, Sections 3-9-8 and 3-10-4, Intersecting Runway Separation, and resulted in OE. One OE involved a UAS. One NMAC also occurred and involved a UAS.

This data shows that all scenarios had about the same number amount of safety incidents, with Scen9 (included four UAS) having the most. Scen9 also had UAS-involved incidents.

Table 36: Scen1-2-6-9 Safety Metrics

	#MAC	# Other Accidents	# NMAC	# OE	# OD	# Runway Incursions	TOTAL # INCIDENTS
Scen1	0	0	0	3	0	0	**3**
Scen2	0	0	0	4	0	0	**4**
Scen6	0	0	0	4	0	0	**4**
Scen9	0	0	1	4	0	0	**5**

Table 37: Scen1-2-6-9 Incident Tables

	Incident Type	Aircraft #1	Aircraft #2	Incident Description
Scen1	OE	N744PA	TNKR911	Required intersecting runway separation was not provided *Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
	OE	N744PA	N44EL	Required intersecting runway separation was not provided *Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
	OE	OMEGA70	DOJ703	Required intersecting runway separation was not provided *Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
Scen2	OE	N739HZ	N744PA	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
	OE	RYN5	N44EL	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
	OE	Slam 88	N44EL	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
	OE	NASA901	N44EL	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
Scen6	OE	N744PA	N739HZ	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
	OE	N744PA	TNKR911	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
	OE	N744PA	N44EL	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
	OE	OMEGA70	N44EL	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
Scen9	NMAC	N744PA	RQ11 Raven (UAS)	ATC permitted N744PA to operate within the confines of the Raven operations area. (Closest proximity was 184 feet)
	OE	N744PA	Grizzly 21 *(UAS)*	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
	OE	N744PA	Slam 88	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
	OE	RYN5	N744PA	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
	OE	Slam 88	N44EL	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4

4.2.5.3 Scen1-2-6-9 Efficiency

Several metrics were captured to evaluate the efficiency of the operation simulated. Table 38 captures the observed occurrences of the efficiency metrics in these scenarios.

In Scen1, one pilot initiated a go around and three traffic pattern modifications were observed. There was also one re-sequenced arrival and two instances where a manned aircraft request was altered and/or cancelled for a total of seven efficiency-related occurrences.

In Scen2, one aircraft was delayed and four traffic pattern modifications were observed. There was also one re-sequenced arrival and one instance where a manned aircraft request was altered and/or cancelled for a total of seven efficiency-related occurrences.

In Scen6, three manned aircraft were delayed and five traffic pattern modifications were observed. There were also three instances where a manned aircraft request was altered and/or cancelled for a total of 11 efficiency-related occurrences.

In Scen9, three manned aircraft were delayed, one UAS was delayed, and two traffic pattern modifications were observed. There were also three instances where a manned aircraft request was altered and/or cancelled for a total of nine efficiency-related outcomes.

Scen6 (included three UAS) and Scen9 (included 4 UAS) had more efficiency-related events than Scen1 (no UAS) and Scen2 (included two UAS).

Table 38: Scen1-2-6-9 Efficiency Metrics

	Scen1	Scen2	Scen6	Scen9
Go-Arounds				
ATC Initiated Go-Arounds	0	0	0	0
Pilot Initiated Go-Arounds	1	0	0	0
Total	**1**	**0**	**0**	**0**
Delays				
Manned A/C Departure Delays	0	0	1	3
Manned Aircraft Arrival Delays	0	1	2	0
Unmanned A/C Departure Delays	0	0	0	1
Unmanned A/C Arrival Delays	0	0	0	0
Total	**0**	**1**	**3**	**4**
Traffic Pattern Modifications				
Extended Down-Winds	0	1	2	2
360° Turns	2	2	2	0
ATC Initiated Runway Changes	0	0	0	0
ATC Requested Short Approaches	0	0	0	0
ATC Requested Early Departure Turns	0	0	0	0
ATC Assigned Straight-Out/Runway Headings	1	1	1	0
Total	**3**	**4**	**5**	**2**
Miscellaneous Efficiency Measures				
Class D Airspace Denials	0	0	0	0
Re-Sequenced Arrivals	1	1	0	0
Re-Sequenced Departures	0	0	0	0
Altered and/or Cancelled Manned A/C Requests	2	1	3	3
Altered and/or Cancelled Unmanned A/C Requests	0	0	0	0
Total	**3**	**2**	**3**	**3**
TOTAL: All Efficiency-Related Occurrences	**7**	**7**	**11**	**9**

Participant input indicates that some of the observed efficiency metrics may have been directly attributed to the presence of UAS in the operations.

The Local controller reported that a notable amount of priority handling was provided to the UAS in Scen6 (rated a 3 on a 7-point scale, with "1" corresponding to "not at all" and "7" corresponding to "a great deal"). A limited amount of priority handling was also provided to the UAS by the Local controller in Scen2 (rated a 2).

The Local controller indicated that the UAS required a notable amount of additional attention as compared to manned aircraft in Scen2 and Scen6 (rated a 3 and 4 for Scen2 and Scen6, respectively). The Ground controller indicated the UAS required a notable amount of additional attention as compared to manned aircraft in Scen9 (rated a 3).

The Local controller also reported that the UAS affected his ability to accommodate manned aircraft in Scen6 (rated 3). The Ground controller in Scen9 similarly indicated that the UAS had a notable effect on the ability to accommodate manned aircraft and the efficiency of manned aircraft operations (both rated as 4).

On a 7-point scale, with "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High," the Ground SME observer rated overall efficiency of taxiway and runway assignments as above average for Scen1, Scen2, and Scen6 and below average for Scen9 (rated as 5, 5, 5, and 2 respectively).

SME Observer ratings and controller questionnaire responses indicate that the UAS operations had a notable impact on the efficiency of traffic operations in all three scenarios involving UAS.

4.2.5.4 Scen1-2-6-9 Communication

Voice communication is a key element of ATC. Many different communication anomalies can be indicative of traffic saturation and ATC loss of situation awareness. These types of occurrences include transposed call signs, missed transmissions, misidentified aircraft, and repeat ATC instructions. (Note: simulation pilot communication errors are not reported since they were not the subject of study.)

In Scen1, the SME Observers noted one transposed control instruction and late coordination with the JOSHUA Sector at High Desert TRACON by the Ground controller.

In Scen2, the SME Observers did not observe any communication anomalies.

In Scen6, the SME Observers noted a lack of effective and timely coordination as well as a lack of prescribed phraseology by the Ground controller.

In Scen9, SME Observers noted the observation of three missed transmissions, two on the part of the Local controller and one on the part of the Ground controller.

In general, Scen9 (included four UAS) had the most communication anomalies.

4.2.5.5 Scen1-2-6-9 Workload and Situation Awareness

In addition to the observations noted in the safety, efficiency, and communications section, other measures of workload and situation awareness were captured via the system recordings, PRQs, and WAK. Table 39 summarizes the traffic counts for these scenarios.

Table 39: Scen1-2-6-9 Traffic Counts

	# Arrivals	# Departures	# Touch and Go's/Low Approaches	# Overflights
Scen1	15	14	10	3
Scen2	17	17	13	5
Scen6	16	17	11	6
Scen9	21	23	17	7

Table 40 and Table 41 depict subjective ratings of overall complexity and overall workload provided by the participants and SME Observers after each scenario. These ratings were made on a Likert scale of 1-7, with "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High." All individuals provided average or below average ratings for overall complexity of all four scenarios.

All participants provided average or below average ratings for overall workload in Scen1, Scen2, and Scen6. The Local SME Observer rated overall workload in Scen9 as above average (rated 5), while the rest of the individuals rated overall workload for this scenario as average or below average.

Table 40: Scen1-2-6-9 Ratings of Overall Complexity

Overall Complexity	Local Controller	Local Control SME Observer	Ground Controller	Ground Control SME Observer
Scen1	4	4	1	3
Scen2	3	3	1	2
Scen6	4	3	2	2
Scen9	4	4	4	2

Table 41: Scen1-2-6-9 Ratings of Overall Workload

Overall Workload	Local Controller	Local Control SME Observer	Ground Controller	Ground Control SME Observer
Scen1	4	3	1	3
Scen2	4	3	1	3
Scen6	4	3	1	2
Scen9	4	5	3	2

Factors such as mental demand, effort, and the degree to which UAS required attention are some of the contributing factors to overall workload and complexity.

On a 7-point scale, with "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High," the Local controller reported average and below average ratings for effort and mental demand in Scen1, Scen2, and Scen6 (rated as 4 and 3, respectively for Scen1, 2 and 3, respectively for Scen2, and both rated as 3 for Scen6). For Scen9, the Local controller reported above average ratings for effort and mental demand (both rated 5).

The Local controller in Scen9 (four UAS, including the MQ-1B Predator with chase aircraft) indicated that handling the UAS had a notable effect on his workload (rated 4 on a 7-point scale, with "1" corresponding to "not at all" and "7" corresponding to "a great deal").

The results support previous SME observations of increased workload in Scen9. The SME Observers identified five contributing factors. The first is the requirement of the MQ-1B Predator UAS to safely join with its chase plane (Mooney) as a flight before departing the Class D airspace. The second was that the Local controller had to provide progressive pattern instructions to the MQ-1B Predator pilot while in the pattern. This is due to the inability of any UAS to comply with ATC instructions by visual means. The third was the lack of standard phraseology when providing ATC services to UAS. The fourth was the slow flight characteristics of the MQ-1B Predator in comparison to other manned aircraft in the traffic pattern. The fifth was the presence of four UAS. The SME Observers also noted that the presence of aircraft delays, traffic pattern modifications, and denials to manned aircraft to enter traffic patterns for practice approaches are all symptoms of an operational situation that is too complex or ATC workload that is too high. The actions taken by the controller are tools to manage traffic volume and complexity and to ensure safety.

Participants were asked to provide instantaneous workload ratings every two minutes during the run via a WAK located at each workstation. Ratings were made on a 7-point scale, with "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High." Figure 11 depicts the average of these workload ratings for each scenario by control position.

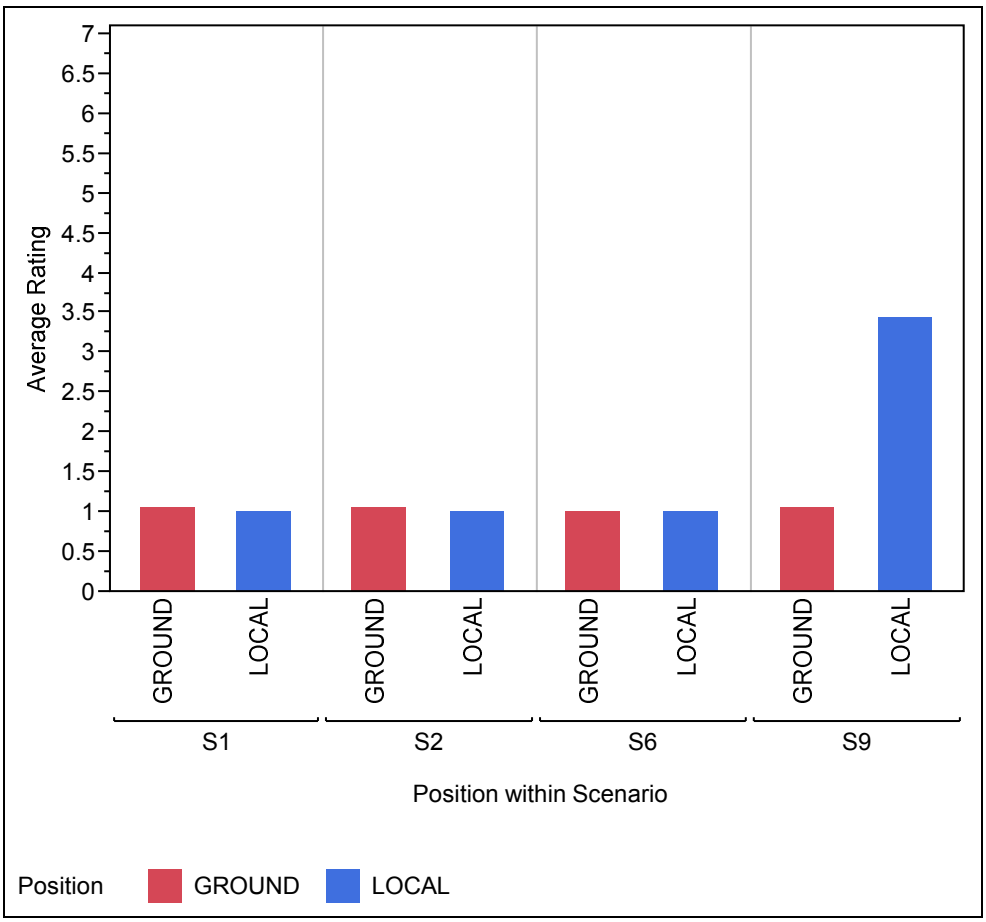

Figure 11: Scen1-2-6-9 WAK Data

In line with other workload measures reported, the Local controller's mean instantaneous workload rating was higher for Scen9 than those observed in Scen1, Scen2, and Scen6. Also consistent with other workload measures, the Ground controller's mean workload rating was well below average for all four scenarios.

4.2.5.6 Scen1-2-6-9 Comparison Findings

A summary of observations for this comparison are listed.

- In general, SME Observer ratings and observations related to perception of safety appear to be consistent across all four scenarios, with the one below average rating by the Local SME Observer echoing concerns identified in Scen2.

- All four scenarios had about the same number amount of safety incidents, with Scen9 (included four UAS) having the most. Scen9 also had UAS-involved incidents.

- SME Observer ratings and controller questionnaire responses indicate that the UAS operations had a notable impact on the efficiency of traffic operations in all three scenarios involving UAS.

- Scen9 (four UAS present) had the most communication anomalies as compared to Scen1, Scen2, and Scen6.

- SME observations indicate increased workload in Scen9 (four UAS present). SME identified five contributing factors. They were the requirement of the MQ-1B Predator UAS to safely join with its chase plane (a Mooney MO20) before departing the Class D airspace. The second was the Local controller had to provide progressive pattern instructions to the MQ-1B Predator PIC while in the pattern. This is due to the inability of any UAS to comply with ATC instructions by visual means. The third was the lack of standard phraseology when providing ATC services to UAS. The fourth was the slow flight characteristics of the MQ-1B Predator in comparison to manned aircraft in the traffic pattern. The fifth was the presence of four UAS.

- SME noted that UAS that required the use of the runways were much more reliant on ATC for sequencing and spacing than manned aircraft pilots. This had the potential to increase controller workload and complexity.

- SME noted that the presence of aircraft delays, traffic pattern modifications, and denials to manned aircraft to enter traffic patterns for practice approaches are all symptoms of an operational situation that is too complex or that ATC workload that is too high. The actions taken by the controller are tools to manage traffic volume and complexity and to ensure safety

- Though mean workload instantaneous ratings reported by the controllers for all scenarios were well below average in general, the highest mean workload ratings were reported by the Local controller in Scen9.

Upon examination of the complete set of data collected, the trend in findings indicates that the scenario with all four UAS in the operation (Scen9) had the highest mean workload rating for the Local controller and also had the most recorded safety incidents and communication anomalies. The scenario with three UAS in the operation (Scen6) had the most recorded efficiency-related occurrences.

4.2.6 Scenarios 1, 2, 8, and 9

The comparative analysis scenarios each consisted of approximately 17 manned aircraft operations, to which UAS operations were incrementally added. The goal of the comparison was to identify and document the impact of the UAS operations on manned aircraft, standard ATC operations, and routine operations in Class D airspace. The comparative scenarios did not contain any off-nominal events such as lost link or in-flight emergencies. This scenario comparison "thread" contains Scenario 1 (Scen1), Scenario 2 (Scen2), Scenario 8 (Scen8), and Scenario 9 (Scen9).

4.2.6.1 Scen1-2-8-9 Design

All scenarios were developed with the following characteristics:

Airport and Weather Conditions: Simulation start-time was mid-afternoon and VFR prevailed throughout the scenario. Winds were 210° at 9kts. The active runways were 21 and 17.

Manned Aircraft: Seventeen manned aircraft were included to simulate normal traffic flows at the airport. Operations included both military and civilian departures, arrivals, over-flights, and local pattern work. Four additional VFR (1200 code) targets were introduced to simulate over-flight traffic above and/or adjacent to the Class D airspace. These targets did not communicate with ATC.

Special Military Operations: In addition to other manned military flights, a C17 Globemaster II (Slam 88) was added to simulate specialized military tactical maneuvers practiced by USAF crews at KVCV and similar airports.

Ground Vehicles: Two ground vehicles were added to the scenario to replicate vehicular traffic at a typical airport. The vehicles simulated routine airfield maintenance and runway sweeping operations and communicated with ATC on the GC frequency.

Unmanned Aircraft Systems: Table 42 captures the type of UAS present in each scenario.

Table 42: Comparative Scenarios (Scen1, Scen2, Scen8, Scen9)

	Number of UAS	**UAS**
Scen1	0	None
Scen2	2	AS800 JPL Blimp, RQ-11 Raven
Scen8	3	AS800 JPL Blimp, RQ-11 Raven, MQ-1B Predator with chase aircraft (a manned Mooney MO20)
Scen9	4	AS800 JPL Blimp, RQ-11 Raven, MQ-1B Predator with chase aircraft (a manned Mooney MO20), A-160 Hummingbird

4.2.6.2 Scen1-2-8-9 Safety

The ATC operations presented in these scenarios were evaluated with regard to the safety and efficiency of the flow of traffic. Several notable observations and comparisons are described in this section.

As rated on a 7-point scale in the PRQ, with "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High," the Local controller in each scenario reported high confidence in the overall safety of operations, giving ratings of 5, 6, 5, and 6 for Scen1, Scen2, Scen8, and Scen9, respectively. The Ground controller's confidence in safety was also high for all four scenarios (rated 7, 7, 6, and 6, for Scen1, Scen2, Scen8, and Scen9, respectively).

SME Observers perceived similar levels of safety across most of these scenarios. On a 7-point scale, with "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High," the Local SME Observer rated the overall safety of the pattern sequence below average for Scen2 (rated 3) but above average for Scen1, Scen8, and Scen9 (rated 6, 5, and 6, respectively). The Ground SME Observer rated this same metric as above average for all four scenarios (rated 5, 6, 6, and 6, for Scen1, Scen2, Scen8, and Scen9, respectively).

Both SME Observers also noted that in Scen2 and Scen9 there were instances in which the controllers did not exercise 'positive control,' compromising the safety of these operations. The Local controller in Scen2 and Scen8 indicated that he provided an extra margin of spacing for UAS; however, the Local controller in Scen9 did not.

In general, the controller and SME Observer ratings related to perception of safety were above average for all scenarios, with the exception of one below average rating by the Local SME Observer who indicated some concerns in Scen2.

From an operational perspective, there are several types of incidents that adversely affect the safe, orderly, and expeditious movement of air traffic. These include MAC as well as other ACC, NMAC, OE, OD, RI, and PD. Concerning some of these measures, it is important to note that the focus of this study was to examine the potential effects of UAS operations on Class D airspace. By design, the simulation pilots, both manned and unmanned, were not the direct subject of study in this simulation. Therefore, any occurrences of pilot-induced incidents (e.g., PD, RI, or NMAC caused by pilot error or actions) are considered part of the realistic, complex situations presented to the controller participants and not reported as deficiencies or safety-related findings for the purposes of this evaluation.

Information concerning the study's valid incident safety measures are summarized in Table 43, with reported incident details provided in Table 44. All scenarios were 45 minutes in length.

In Scen1, there were three incidents attributed to ATC. All were caused by ATC not complying with the proper intersecting runway standards as prescribed in FAO JO7110.65, Sections 3-9-8 and 3-10-4, Intersecting Runway Separation, and resulted in OE. None of the OE involved UAS.

In Scen2, there were four incidents attributed to ATC. All were caused by ATC not complying with the proper intersecting runway standards as prescribed in FAO JO7110.65, Sections 3-9-

8 and 3-10-4, Intersecting Runway Separation, and resulted in OE. None of the OE involved UAS.

In Scen8, there were three incidents attributed to ATC. All were caused by ATC not complying with the proper intersecting runway standards as prescribed in FAO JO7110.65, Sections 3-9-8 and 3-10-4, Intersecting Runway Separation, and resulted in OE. One OE involved a UAS.

In Scen9, there were five incidents attributed to ATC. Four were caused by ATC not complying with the proper intersecting runway standards as prescribed in FAO JO7110.65, Sections 3-9-8 and 3-10-4, Intersecting Runway Separation, and resulted in OE. One OE involved a UAS. One NMAC also occurred and involved a UAS.

This data shows that all scenarios had a similar number of incidents, with Scen2 and Scen9 having the most. Scen8 and Scen9 had UAS-involved incidents.

Table 43: Scen1-2-8-9 Safety Metrics

	#MAC	# Other Accidents	# NMAC	# OE	# OD	# Runway Incursions	TOTAL # INCIDENTS
Scen1	0	0	0	3	0	0	**3**
Scen2	0	0	0	4	0	0	**4**
Scen8	0	0	0	3	0	0	**3**
Scen9	0	0	1	4	0	0	**5**

Table 44: Scen1-2-8-9 Incident Tables

	Incident Type	Aircraft #1	Aircraft #2	Incident Description
Scen1	OE	N744PA	TNKR911	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8/3-10-4
	OE	N744PA	N44EL	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8/3-10-4
	OE	OMEGA70	DOJ703	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8/3-10-4
Scen2	OE	N739HZ	N744PA	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8/3-10-4
	OE	RYN5	N44EL	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8/3-10-4
	OE	Slam 88	N44EL	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8/3-10-4
	OE	NASA901	N44EL	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8/3-10-4
Scen8	OE	SWA3471	Grizzly 21 (UAS)	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8/3-10-4
	OE	Slam 88	N744PA	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8/3-10-4
	OE	NASA901	N744PA	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8/3-10-4
Scen9	NMAC	N744PA	RQ11 Raven (UAS)	ATC permitted N744PA to operate within the confines of the Raven operations area. (Closest proximity was 184 feet)
	OE	N744PA	Grizzly 21 (UAS)	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8/3-10-4
	OE	N744PA	Slam 88	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8/3-10-4
	OE	RYN5	N744PA	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8/3-10-4
	OE	Slam 88	N44EL	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8/3-10-4

4.2.6.3 Scen1-2-8-9 Efficiency

Several metrics were captured to evaluate the efficiency of the operation simulated. Table 45 captures the observed occurrences of the efficiency metrics in these scenarios.

In Scen1, one pilot initiated a go around and three traffic pattern modifications were observed. There was also one re-sequenced arrival and two instances where a manned aircraft request was altered and/or cancelled for a total of seven efficiency-related occurrences.

In Scen2, one aircraft was delayed and four traffic pattern modifications were observed. There was also one re-sequenced arrival and one instance where a manned aircraft request was altered and/or cancelled for a total of seven efficiency-related occurrences.

In Scen8, four manned aircraft were delayed, one UAS was delayed, and eight traffic pattern modifications were observed. There were also two instances where a manned aircraft request was altered and/or cancelled and one instance where an UA request was altered and/or cancelled for a total of 16 efficiency-related occurrences.

In Scen9, three manned aircraft were delayed, one UAS was delayed, and two traffic pattern modifications were observed. There were also three instances where a manned aircraft request was altered and/or cancelled for a total of nine efficiency-related outcomes.

Scen8 had noticeably more efficiency-related events than Scen1, Scen2, and Scen9. SME noted that the performance characteristics of the MQ-1B Predator were at times incompatible with manned aircraft, thus contributing to inefficiencies. The specific performance characteristics at play were the MQ-1B Predator's slow pattern speed and its inability to comply with ATC instructions by visual means.

Table 45: Scen1-2-8-9 Efficiency Metrics

	Scen1	Scen2	Scen8	Scen9
Go-Arounds				
ATC Initiated Go-Arounds	0	0	0	0
Pilot Initiated Go-Arounds	1	0	0	0
Total	**1**	**0**	**0**	**0**
Delays				
Manned A/C Departure Delays	0	0	2	3
Manned Aircraft Arrival Delays	0	1	2	0
Unmanned A/C Departure Delays	0	0	0	1
Unmanned A/C Arrival Delays	0	0	1	0
Total	**0**	**1**	**5**	**4**
Traffic Pattern Modifications				
Extended Down-Winds	0	1	2	2
360° Turns	2	2	2	0
ATC Initiated Runway Changes	0	0	2	0
ATC Requested Short Approaches	0	0	1	0
ATC Requested Early Departure Turns	0	0	0	0
ATC Assigned Straight-Out/Runway Headings	1	1	1	0
Total	**3**	**4**	**8**	**2**
Miscellaneous Efficiency Measures				
Class D Airspace Denials	0	0	0	0
Re-Sequenced Arrivals	1	1	0	0
Re-Sequenced Departures	0	0	0	0
Altered and/or Cancelled Manned A/C Requests	2	1	2	3
Altered and/or Cancelled Unmanned A/C Requests	0	0	1	0
Total	**3**	**2**	**3**	**3**
TOTAL: All Efficiency-Related Occurrences	**7**	**7**	**16**	**9**

Participant input indicates that some of the observed efficiency metrics may have been directly attributed to the presence of UAS in the operations.

The Local controller indicated the UAS highly affected the traffic pattern and sequence in Scen8 (both rated a 6 on a 7-point scale, with "1" corresponding to "not at all" and "7" corresponding to "a great deal"). The Local SME Observer in Scen8 indicated that the Predator's slow speed while performing touch and gos caused the controller to extend the traffic pattern. In addition, the Local controller in Scen8 noted that a manned aircraft request was altered due to UAS operations.

The Ground controller in Scen9 indicated that the UAS had a notable effect on the ability to accommodate manned aircraft and the efficiency of manned aircraft operations (both rated 4).

The Local controller indicated that the UAS required some additional attention as compared to manned aircraft in Scen2 (rated 3).

Questionnaire responses show that the Local controller in Scen8 reported that he treated UAS differently than manned aircraft. He indicated that this was due to the fact that he was unable to instruct the UAS PIC that "[it] is number two to follow [another aircraft in the traffic pattern]." Similar to observations in other scenarios, this is a result of the fact that UAS PIC are not on board the aircraft and they currently do not have an alternate approved method to visually acquire other aircraft — and therefore cannot be instructed by ATC to follow another aircraft[12].

On a 7-point scale, with "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High," the Ground SME observer rated overall efficiency of taxiway and runway assignments as above average for Scen1, Scen2, and Scen8 and below average for Scen9 (rated as 5, 5, 5, and 2, respectively).

SME Observer ratings and controller questionnaire responses indicate that the UAS operations had a large impact on the efficiency of traffic operations in all three scenarios involving UAS. SME identified three main contributing factors. They were the requirement of the MQ-1B Predator to safely join with its chase plane (a Mooney MO20) as a flight before departing the Class D airspace. The second was the Local controller had to provide progressive pattern instructions to the MQ-1B Predator PIC while in the pattern. This is due to the inability of any UAS to comply with ATC instructions by visual means. The third was the lack of standard phraseology when providing ATC services to UAS.

4.2.6.4 Scen1-2-8-9 Communication

Voice communication is a key element of ATC. Many different communication anomalies can be indicative of traffic saturation and ATC loss of situation awareness. These types of occurrences include transposed call signs, missed transmissions, misidentified aircraft, and repeat ATC instructions. (Note: simulation pilot communication errors are not reported since they were not the subject of study.)

In Scen1, the SME Observers noted the observation of one transposed control instruction and late coordination with the JOSHUA Sector at High Desert TRACON by the Ground controller.

In Scen2, the SME Observers did not observe any communication anomalies.

In Scen8, the SME Observers did not observe any communication anomalies.

In Scen9, SME Observers observed three missed transmissions, two by the Local controller and one by the Ground controller.

[12] Reference JO 7110.65 Section 3-8-1

Overall, Scen9 (included four UAS) had more communication anomalies than Scen1, Scen2, and Scen8.

4.2.6.5 Scen1-2-8-9 Workload and Situation Awareness

In addition to the observations noted in the safety, efficiency, and communications section, other measures of workload and situation awareness were captured via the system recordings, PRQ, and WAK.

Table 46 summarizes the traffic counts for these scenarios.

Table 46: Scen1-2-8-9 Traffic Counts

	# Arrivals	# Departures	# Touch and Gos/Low Approaches	# Overflights
Scen1	15	14	10	3
Scen2	17	17	13	5
Scen8	21	22	17	6
Scen9	21	23	17	7

Table 47 and Table 48 depict subjective ratings of overall complexity and overall workload, provided by the participants and SME Observers after each scenario. These ratings were made on a Likert scale of 1-7, with "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High." As seen in Table 47 below, all individuals provided average or below average ratings for overall complexity of all four scenarios.

All individuals provided average or below average ratings for overall workload in Scen1, Scen2, and Scen8, as depicted in Table 48. The Local SME Observer rated overall workload in Scen9 as above average, while the rest of the individuals rated overall workload for this scenario as average or below.

Table 47: Scen1-2-8-9 Ratings of Overall Complexity

Overall Complexity	Local Controller	Local Control SME Observer	Ground Controller	Ground Control SME Observer
Scen1	4	4	1	3
Scen2	3	3	1	2
Scen8	4	4	3	4
Scen9	4	4	4	2

Table 48: Scen1-2-8-9 Ratings of Overall Workload

Overall Workload	Local Controller	Local Control SME Observer	Ground Controller	Ground Control SME Observer
Scen1	4	3	1	3
Scen2	4	3	1	3
Scen8	4	4	3	4
Scen9	4	5	3	2

Factors such as mental demand, effort, and the degree to which UAS required attention are some of the contributing factors to overall workload and complexity.

On a 7-point scale, with "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High," the Local controller reported average and below average ratings for effort and mental demand in Scen1 (rated 4 and 3, respectively), Scen2 (rated 2 and 3, respectively), and Scen8 (both rated 4). For Scen9, the Local controller reported above average ratings for effort and mental demand in (both rated 5).

The Local controller in Scen9 indicated that handling the UAS had a notable effect on his workload (rated 4 on a 7-point scale, with "1" corresponding to "not at all" and "7" corresponding to "a great deal").

The results support previous SME observations of increased workload in Scen9 (included four UAS).

Participants were asked to provide instantaneous workload ratings every two minutes during the run via a WAK located at each workstation. Ratings were made on a 7-point scale, with "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High." Figure 12 depicts the average of these workload ratings for each scenario by control position.

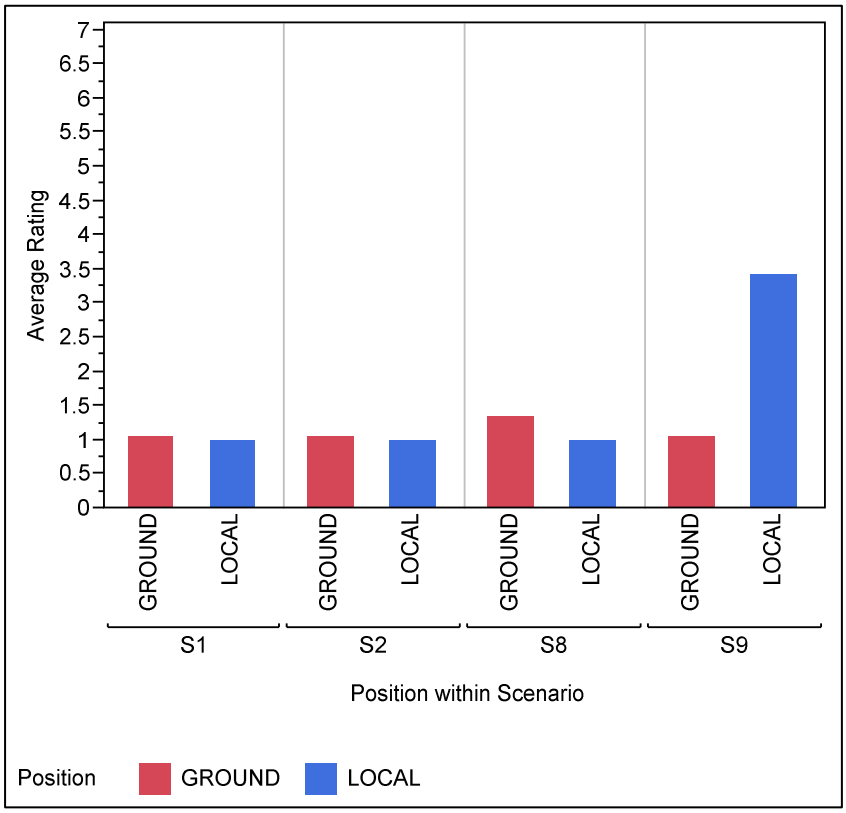

Figure 12: Scen1-2-8-9 WAK Data

In line with other workload measures reported, the Local controller's mean instantaneous workload rating was higher for Scen9 than those observed in Scen1, Scen2, and Scen8. Also consistent with other workload measures, the Ground controller's mean workload rating was below average for all four scenarios.

Though reported mean workload ratings for all scenarios were low, the highest mean workload ratings were observed by the Local controller in Scen9.

4.2.6.6 Scen1-2-8-9 Comparison Findings

A summary of observations for this comparison are listed.

- Controller and SME Observer ratings related to perception of safety were above average for all scenarios, with the exception of one below average rating by the Local SME Observer, indicating some concerns in Scen2.

- All scenarios had a similar number of safety incidents, with Scen2 and Scen9 (included four UAS and a chase aircraft for the Predator) having the most. Scen8 (included three UAS) and Scen9 had UAS-involved incidents.

- Scen8, which included the Predator operating with manned aircraft in the traffic pattern for Runway 17, had noticeably more efficiency-related events than Scen1, Scen2, and Scen9, in which case the Predator was operating on Runway 21.

- SME Observer ratings and controller questionnaire responses indicate that the UAS operations had a large impact on the efficiency of traffic operations in all three scenarios involving UAS. SMEs identified three main contributing factors. They were the requirement of the MQ-1B Predator to safely join with its chase plane (a Mooney MO20) as a flight before departing the Class D airspace. The second was the Local controller had to provide progressive pattern instructions to the MQ-1B Predator PIC while in the pattern. This is due to the inability of any UAS to comply with ATC instructions by visual means. The third was the lack of standard phraseology when providing ATC services to UAS.

- SME noted that the presence of aircraft delays, numerous traffic pattern modifications, re-sequencing of arrivals, denials of entry into Class D airspace, or denials to enter traffic patterns for practice approaches are all symptoms of an operational situation that is too complex or ATC workload that is too high. The actions taken by the controller are tools to manage traffic volume and complexity and to ensure safety.

- Scen9 had more communication anomalies than Scen1, Scen2, and Scen8.

- SME observations indicate increased workload in Scen9, which included all four UAS and a chase aircraft for the Predator.

- SME noted that UAS which required the use of the runways were much more reliant on ATC for sequencing and spacing than manned aircraft pilots. This had the potential to increase controller workload and complexity.

- Though mean instantaneous workload ratings for all scenarios were low, the highest mean workload ratings were observed by the Local controller in Scen9.

Upon examination of the complete set of data collected, the trend in findings indicates that the three scenarios with UAS (Scen2, Scen8, and Scen9) had noticeably more safety and efficiency-related incidents than the scenario with no UAS (Scen1). The scenario with all four UAS in the operation (Scen9) had the highest mean workload rating for the Local controller and also the most recorded safety incidents and communication anomalies. The scenario with three UAS in the operation (Scen8) had the most recorded efficiency-related occurrences.

4.2.7 Scenarios 1, 3, and 7

The comparative analysis scenarios each consisted of approximately 17 manned aircraft operations, to which UAS operations were incrementally added. The goal of the comparison was to identify and document the impact of the UAS operations on manned aircraft, standard ATC operations, and routine operations in Class D airspace. The comparative scenarios did not contain any off-nominal events such as lost link or in-flight emergencies. This scenario comparison "thread" contains Scenario 1 (Scen1), Scenario 3 (Scen3), and Scenario 7 (Scen7).

4.2.7.1 Scen1-3-7 Design

All scenarios were developed with the following characteristics:

Airport and Weather Conditions: Simulation start-time was mid-afternoon and VFR prevailed throughout the scenario. Winds were 210° at 9kts. The active runways were 21 and 17.

Manned Aircraft: Seventeen manned aircraft were introduced to simulate normal traffic flows at the airport. Operations included both military and civilian departures, arrivals, over-flights, and local traffic pattern work. Four additional VFR (1200 code) targets were introduced to simulate over-flight traffic above and/or adjacent to the Class D airspace. These targets did not communicate with ATC.

Special Military Operations: In addition to other manned military flights, a C17 Globemaster II (Slam 88) was added to simulate specialized military tactical maneuvers practiced by USAF crews at KVCV and similar airports.

Ground Vehicles: Two Ground vehicles were added to the scenario to replicate vehicular traffic at a typical airport. The vehicles simulated routine airfield maintenance and runway sweeping operations and communicated with ATC on the GC frequency.

Unmanned Aircraft Systems: Table 49 captures the type and number of UAS present in each scenario.

Table 49: Comparative Scenarios (Scen1, Scen3, Scen7)

	Number of UAS	UAS
Scen1	0	None
Scen3	2	AS800 JPL Blimp, A-160 Hummingbird
Scen7	3	AS800 JPL Blimp, A-160 Hummingbird, MQ-1B Predator

4.2.7.2 Scen1-3-7 Safety

The ATC operations presented in these scenarios were evaluated with regard to the safety and efficiency of the flow of traffic. Several notable observations are described in this section.

As rated on a 7-point scale in the PRQ, with “1” corresponding to “Extremely Low” and “7” corresponding to “Extremely High,” the Local controller in each scenario appeared to be highly confident in the overall safety of operations, giving ratings of 5, 6, and 5 for Scen1, Scen3, and Scen7, respectively. The Ground controller’s confidence in safety was extremely high for all three scenarios (rated 7 for all).

SME Observers generally agreed in their perceived levels of safety across these scenarios. On a 7-point scale, with “1” corresponding to “Extremely Low” and “7” corresponding to “Extremely High,” the Local SME Observer rated the overall safety of the pattern sequence above average

for all three scenarios (rated as a 6, 6, and 5 for Scen1, Scen3, and Scen7, respectively). The Ground SME Observer's ratings were average or above for this metric (rated as 5, 6, and 4, for Scen1, Scen3, and Scen7, respectively).

On the same scale, the Local SME Observer rated the overall safety and efficiency of the traffic flow as average or above (rated as 5, 6, and 4 for Scen1, Scen3, and Scen7, respectively). The Ground SME Observer's ratings were slightly above average, average, and slightly below average for these three scenarios (rated as 5, 4, and 3 for Scen1, Scen3, and Scen7, respectively).

Both SME Observers also noted that in Scen7 (which included three UAS) there were instances in which the controllers did not exercise 'positive control,' compromising the safety of these operations.

In general, SME Observer ratings related to perception of safety appear to be consistently lower for Scen7, as compared to the other two scenarios.

From an operational perspective, there are several types of incidents that adversely affect the safe, orderly, and expeditious movement of air traffic. These include MAC as well as other ACC, NMAC, OE, OD, RI, and PD. Concerning some of these measures, it is important to note that the focus of this study was to examine the potential effects of UAS operations on Class D airspace. By design, the simulation pilots, both manned and unmanned, were not the direct subject of study in this simulation. Therefore, any occurrences of pilot-induced incidents (e.g., PD, RI, or NMAC caused by pilot error or actions) are considered part of the realistic, complex situations presented to the controller participants and not reported as deficiencies or safety-related findings for the purposes of this evaluation.

Information concerning the study's valid incident safety measures are summarized in Table 50, with reported incident details provided in Table 51. All scenarios were 45 minutes in length.

In Scen1, there were three incidents attributed to ATC. All were caused by ATC not complying with the proper intersecting runway standards as prescribed in FAO JO7110.65, Sections 3-9-8 and 3-10-4, Intersecting Runway Separation, and resulted in OE. None of the OE involved UAS.

In Scen3, there was one incident attributed to ATC. This was caused by ATC not complying with the proper intersecting runway standards as prescribed in FAO JO7110.65, Sections 3-9-8 and 3-10-4, Intersecting Runway Separation, and resulted in an OE. The OE did not involve a UAS.

In Scen7, there were five incidents attributed to ATC. Three were caused by ATC not complying with the proper intersecting runway standards as prescribed in FAO JO7110.65, Sections 3-9-8 and 3-10-4, Intersecting Runway Separation, and resulted in OE. One OE involved a UAS. The other two incidents were caused by ATC's failure to coordinate use of adjacent airspace as prescribed in FAO JO7110.65, Sections 2-1-14, and resulted in OD. Neither of the OD involved a UAS.

The data shows that Scen7, with three UAS present, had noticeably more safety incidents than Scen1 (no UAS) and Scen3 (two UAS). Scen7 had a UAS-involved incident.

Table 50: Scen1-3-7 Safety Metrics

	# MAC	# Other Accidents	# NMAC	# OE	# OD	# Runway Incursions	TOTAL # INCIDENTS
Scen1	0	0	0	3	0	0	3
Scen3	0	0	0	1	0	0	1
Scen7	0	0	0	3	2	0	5

Table 51: Scen1-3-7 Incident Table

	Incident Type	Aircraft #1	Aircraft #2	Incident Description
Scen1	OE	N744PA	TNKR911	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
	OE	N744PA	N44EL	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
	OE	OMEGA70	DOJ703	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
Scen3	OE	R50095	N44EL	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
Scen7	OE	Slam 88	Grizzly 21 *(UAS)*	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
	OE	Slam 88	N44EL	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
	OE	RYN5	N744PA	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
	OD	Slam 88	n/a	ATC Failed to coordinate use of adjacent airspace * Reference FAA JO 7110.65 Section 2-1-14
	OD	Slam 88	n/a	ATC Failed to coordinate use of adjacent airspace * Reference FAA JO 7110.65 Section 2-1-14

4.2.7.3 Scen1-3-7 Efficiency

Several metrics were captured to evaluate the efficiency of the operations simulated. Table 52 captures the observed occurrences of the efficiency metrics for these scenarios.

In Scen1, one pilot initiated a go-around and three traffic pattern modifications were observed. There was also one re-sequenced arrival and two instances where a manned aircraft request was altered and/or cancelled, for a total of seven efficiency-related occurrences.

In Scen3, one manned aircraft was delayed and one traffic pattern modification was observed. There were also two instances where a manned aircraft request was altered and/or cancelled by ATC, for a total of four efficiency-related occurrences.

In Scen7, ATC initiated one go-around, three manned aircraft were delayed, and nine traffic pattern modifications were observed. There was also one manned aircraft request and one UA request that was altered and/or cancelled, for a total of 15 efficiency-related occurrences.

Scen7, with three UAS present, had noticeably more efficiency-related events than Scen1 and Scen3.

Table 52: Scen1-3-7 Efficiency Metrics

	Scen1	Scen3	Scen7
Go-Arounds			
ATC Initiated Go-Arounds	0	0	1
Pilot Initiated Go-Arounds	1	0	0
Total	**1**	**0**	**1**
Delays			
Manned A/C Departure Delays	0	1	2
Manned Aircraft Arrival Delays	0	0	1
Unmanned A/C Departure Delays	0	0	0
Unmanned A/C Arrival Delays	0	0	0
Total	**0**	**1**	**3**
Traffic Pattern Modifications			
Extended Down-Winds	0	0	4
360° Turns	2	0	0
ATC Initiated Runway Changes	0	1	3
ATC Requested Short Approaches	0	0	0
ATC Requested Early Departure Turns	0	0	0
ATC Assigned Straight-Out/Runway Headings	1	0	2
Total	**3**	**1**	**9**
Miscellaneous Efficiency Measures			
Class D Airspace Denials	0	0	0
Re-Sequenced Arrivals	1	0	0
Re-Sequenced Departures	0	0	0
Altered and/or Cancelled Manned A/C Requests	2	2	1
Altered and/or Cancelled Unmanned A/C Requests	0	0	1
Total	**3**	**2**	**2**
TOTAL: All Efficiency-Related Occurrences	**7**	**4**	**15**

Though it appears the manned aircraft delays were not directly attributed to the UAS operations in these scenarios, participant input indicated that some of the other observed efficiency measures listed above in Scen3 and Scen7 may be directly attributed to UAS present in the operations. The UAS was sent to 'High Key' in Scen7 to accommodate other aircraft in the pattern. Also, in Scen7, the Local controller indicated the UAS notably affected the traffic pattern (rated a 3 on a 7-point scale, with "1" corresponding to "not at all" and "7" corresponding to "a great deal"). He commented that he "had to call base [turn] for Predator." Similar to observations in other scenarios, this is a result of the fact that UAS PIC are not on board the aircraft and they currently do not have an alternate approved method to visually acquire and follow other aircraft[13].

[13] Reference FAA Order JO 7110.65 Section 3-8-1

The Local controller indicated the UAS had a more notable effect on the efficiency of manned aircraft operations in Scen3 as compared to Scen7 (rated a 4 for Scen3 and a 2 for Scen7). These ratings were made on a 7-point scale, with "1" corresponding to "not at all" and "7" corresponding to "a great deal." On the same scale, the Local controller also indicated a notable degree of priority handling was provided to the UAS in Scen3 (rated a 3 in Scen3).

The Ground SME observer rated overall efficiency of taxiway and runway assignments as above average for Scen1 and Scen3 and below average for Scen7 (rated as 5, 6, and 3 for Scen1, Scen3, and Scen7, respectively). The Ground SME Observer rated overall efficiency of the pattern sequence as average or above for Scen1 and Scen3 (rated as 5 and 4, respectively) and below average for Scen7 (rated as 3).

SME Observer ratings and input suggest a decrease in efficiency for Scen7 as compared to Scen1 and Scen3. SME noted that the performance characteristics of the MQ-1B Predator were at times incompatible with manned aircraft, thus contributing to inefficiencies. The specific performance characteristics at play were the MQ-1B Predator's slow pattern speed and its inability to comply with ATC instructions by visual means.

4.2.7.4 Scen1-3-7 Communication

Voice communication is a key element of ATC. Many different communication anomalies can be indicative of traffic saturation and ATC loss of situation awareness. These types of occurrences include transposed call signs, missed transmissions, misidentified aircraft, and repeat ATC instructions. (Note: simulation pilot communication errors are not reported since they were not the subject of study.)

In Scen1 (no UAS), the SME Observers noted the observation of one transposed control instruction and late coordination with the JOSHUA sector at High Desert TRACON by the Ground controller.

In Scen3 (included two UAS), the SME Observers did not observe any communication anomalies.

In Scen7 (included three UAS), SME observers noted one transposed control instruction, two misidentified aircraft, and a lack of prescribed phraseology all on the part of the Local controller. It was also observed that the Local controller did not appear to maintain correct priority of transmissions. The Local SME observer specifically noted that it appeared as though many of these anomalies were a direct result of the Local controller occasionally experiencing a loss of situation awareness.

There were noticeably more communication anomalies in Scen7 (included three UAS) than in the other two scenarios.

4.2.7.5 Scen1-3-7 Workload and Situation Awareness

In addition to the observations noted in the safety, efficiency, and communications section, other measures of workload and situation awareness were captured via the system recordings, PRQ, and WAK.

Table 53 summarizes the traffic counts for these scenarios.

Table 53: Scen1-3-7 Traffic Counts

	# Arrivals	# Departures	# Touch and Go's/Low Approaches	# Overflights
Scen1	15	14	10	3
Scen3	19	21	14	5
Scen7	18	19	12	5

Table 54 and Table 55 depict subjective ratings of overall complexity and overall workload provided by the participants and SME Observers after each scenario. These ratings were made on a Likert scale of 1-7, with "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High."

All individuals rated overall complexity as average or below in Scen1 and Scen3. The Local Controller, Local SME Observer, and Ground SME Observer all rated the overall complexity as above average in Scen7.

All individuals rated overall workload as average or below in Scen1 and Scen3. The Local Controller, Local SME Observer, and Ground SME Observer all rated the overall workload as above average in Scen7.

Table 54: Scen1-3-7 Ratings of Overall Complexity

Overall Complexity	Local Controller	Local Control SME Observer	Ground Controller	Ground Control SME Observer
Scen1	4	4	1	3
Scen3	4	3	1	2
Scen7	6	5	3	5

Table 55: Scen1-3-7 Ratings of Overall Workload

Overall Workload	Local Controller	Local Control SME Observer	Ground Controller	Ground Control SME Observer
Scen1	4	3	1	3
Scen3	4	3	1	2
Scen7	6	6	2	5

Factors such as mental demand, effort, and the degree to which UAS required attention are some of the contributing factors to overall workload and complexity.

On a 7-point scale, with "1" corresponding to "Extremely Low/Very Poor/Decreased a Great Deal/Not At All" and "7" corresponding to "Extremely High/Very Good/Increased a Great Deal/A Great Deal," the Local controller reported average or below average ratings for effort and mental demand in Scen 1 and Scen3 (rated a 4 and 3, respectively, for Scen1, and both rated as 3 for Scen3). The Local controller reported above average ratings for effort and mental demand in Scen7 (both rated a 6).

These results support previous SME observations of increased workload and complexity in Scen7 (which included three UAS).

In Scen7, the Local SME Observer noted that it appeared as though the Local controller lost situation awareness during the scenario. SME Observer input indicates that these instances of the controller 'losing the flick' may have resulted in some of the communication anomalies described previously. It was also noted that it appeared as though the Ground controller lost situation awareness at one point in Scen3.

Participants were asked to provide instantaneous workload ratings every two minutes during the run via a WAK located at each workstation. Ratings were made on a 7-point scale, with "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High." Figure 13 depicts the average of these workload ratings for each scenario by control position.

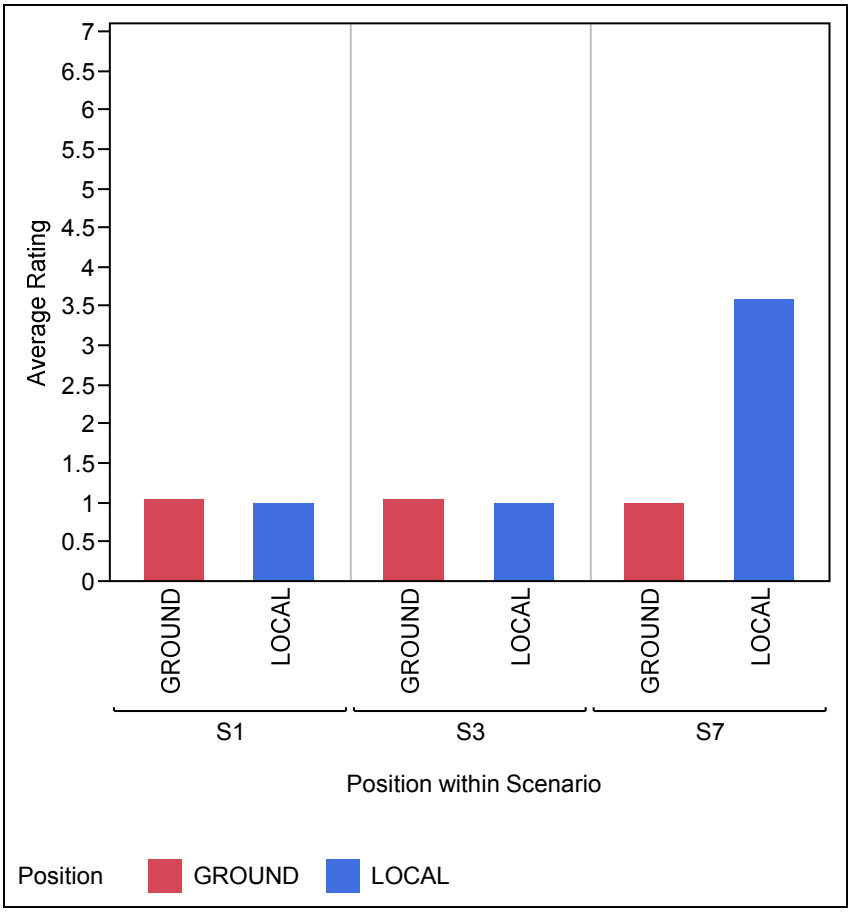

Figure 13: Scen1-3-7 WAK Data

In line with other workload measures reported, the Local controller's mean workload for Scen7 was higher than those observed in Scen1 and Scen3. The Ground controller's mean instantaneous workload was below average for all three scenarios, a finding that is also in concurrence with the previously discussed workload measures.

Though mean workload ratings for all scenarios were below average, the highest mean workload rating was observed in Scen7, which included three UAS in the operations.

4.2.7.6 Scen1-3-7 Comparison Findings

A summary of observations for this comparison are listed.

- SME Observer ratings related to perception of safety appear to be consistently lower for Scen7 (which included three UAS) as compared to both Scen1 (no UAS) and Scen3 (two UAS).

- Scen7 had noticeably more safety incidents than Scen1 and Scen3. Scen7 had a UAS-involved incident.

- Scen7 had noticeably more efficiency-related events than Scen1 and Scen3.

- SME Observer ratings suggest a decrease in efficiency for Scen7 as compared to Scen1 and Scen3. The SME Observers identified two contributing factors. The Local controller had to provide progressive pattern instructions to the MQ-1B Predator pilot while in the pattern. This is due to the inability of any UAS to comply with ATC instructions by visual means. The second contributing factor observed was the lack of standard phraseology when providing ATC services to UAS.

- There were noticeably more communication anomalies in Scen7 than in the other two scenarios.

- SME observations indicate increased workload and complexity in Scen7.

- The SME Observers noted that the presence of aircraft delays, numerous traffic pattern modifications, re-sequencing of arrivals, and denials to enter traffic patterns for practice approaches are all symptoms of an operational situation that is too complex or ATC workload that is too high. The actions taken by the controller are tools to manage traffic volume and complexity and to ensure safety.

- SME noted that UAS that required the use of the runways were much more reliant on ATC for sequencing and spacing than manned aircraft pilots. This had the potential to increase controller workload and complexity.

- Though mean instantaneous workload ratings for all scenarios were below average, the highest mean workload rating was observed in Scen7.

Upon examination of the complete set of data collected, the overall presence of UAS accounted for a notable impact on manned aircraft, standard ATC operations, and routine operations in Class D airspace. The trend in findings indicates that the scenario with three UAS (Scen7) had the most safety incidents and efficiency-related events, which contributed to a reduction in overall safety and a decrease in overall efficiency. In addition, Scen7, the scenario with the three UAS in the operation, including the MQ-1B Predator operating on Runway 21, had noticeably more communication anomalies and the highest mean rating for workload (though all mean workload ratings were below average). The SME Observers also reported observations of higher complexity, increased workload, and they generally rated their perceptions of safety lower for Scen7 (MQ-1B Predator operating on Runway 21) as compared to the other scenarios.

4.3 Descriptive Analysis Results

4.3.1 Scenario 10

In line with the overall study objectives, the goal of Scenario 10 was to examine the effects of simultaneous multiple UAS platforms with dissimilar flight characteristics on local traffic pattern operations, ATC operations, and Class D airspace. This scenario also included a scripted off-nominal event.

4.3.1.1 Scen10 Design

Scenario 10 was developed with the following characteristics:

Airport and Weather Conditions: Simulation start-time was mid-afternoon and VFR prevailed throughout the scenario. Winds were 210° at 9kts. The active runways were 21 and 17.

Manned Aircraft: Seventeen manned aircraft were introduced at random intervals to simulate normal traffic flows at the airport. Operations included both military and civilian departures, arrivals, over-flights, and local pattern work. Four additional VFR (1200 code) targets were injected to simulate over-flight traffic above and/or adjacent to the Class D airspace. These targets did not communicate with ATC.

Special Military Operations: In addition to other manned military flights, an additional C17 Globemaster II (Slam 88) was added to simulate specialized military tactical maneuvers practiced by USAF crews at KVCV and similar airports.

Ground Vehicles: Two ground vehicles were added to the scenario to replicate vehicular traffic at a typical airport. The vehicles simulated routine airfield maintenance and sweeping operations and communicated with ATC on the GC frequency.

Unmanned Aircraft Systems: Two UAS were included in this scenario — the AS800 JPL Blimp and the RQ-11 Raven.

Off Nominal Event(s): Secondary to the simultaneous multiple UAS operations, Scenario 10 also examined the effects of an RQ-11 scripted loss of its control and communication link. The COA in effect requires that if the UAS experiences a lost link condition it is to "return home." The Raven did not follow the anticipated lost link recovery procedure as required in the current COA. This type of rare, off-nominal UAS event is unofficially, but commonly referred to as, a 'fly away.' ATC was informed of the lost link by the Raven's PIC, and was advised that the aircraft's intent was unknown. ATC was subsequently updated as to the last known position of the Raven and informed that no further information was available as to the aircraft's position, route, nor altitude. ATC was later advised by the pilot that the Raven's flight had been terminated and the aircraft was recovered on the ground. The AS800 JPL Blimp was airborne throughout the scenario within the confines of the normal operations area west of runway 17.

4.3.1.2 Scen10 Safety

The ATC operations presented in this scenario were evaluated with regard to the safety and efficiency of the flow of traffic. Several notable observations are described in this section.

As rated on a 7-point scale in the PRQ, with "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High," both participants appeared to be highly confident in the safety of operations for this scenario. Although the Local and Ground controllers rated their confidence in safety as "6" and "7," respectively, data and post-analysis observations suggest some safety concerns.

In particular, the Raven fly away event seemed to notably affect the safety of the overall operation. In post-scenario discussions, the controllers stated that they never visually observed

the Raven during the fly away, nor were they able to figure out its exact location based on the information provided to them by the pilot. As such, they stated that they felt in order to safely and effectively handle the fly away event, their only option was to clear the Class D airspace of all manned aircraft and deny entry of any additional aircraft.

Another safety concern observed was when the UAS were within their own operational areas, ATC generally did not issue them traffic or safety advisories. This demonstrates a lack of proper and uniform application of 7110.65 rules[14], as multiple manned aircraft were observed flying through the active UA operating areas.

From an operational perspective, there are several types of incidents that adversely affect the safe, orderly, and expeditious movement of air traffic. These include MAC as well other ACC, NMAC, OE, OD, RI, and PD. Concerning some of these measures, it is important to note that the focus of this study was to examine the potential effects of UAS operations on Class D airspace. By design, the simulation pilots, both manned and unmanned, were not the direct subject of study in this simulation. Therefore, any occurrences of pilot-induced incidents (e.g., PD, RI, or NMAC caused by pilot error or actions) are considered part of the realistic, complex situations presented to the controller participants and not reported as deficiencies or safety-related findings for the purposes of this evaluation.

Information concerning the study's incident safety measures are summarized in Table 56, with reported incident details provided in Table 57. In this 45-minute operation, there was one ATC-related incident where ATC did not comply with the proper intersecting runway standards as prescribed in FAA Order JO7110.65T, resulting in the OE depicted in Table 56 and Table 57.

Table 56: Scen10 Safety Metrics

Metric:	MAC	Other Accident	NMAC	OE	OD	RI
Number of Incidents	0	0	0	1	0	0

[14] FAO JO7110.65 Section 2-1-21 states "Unless an aircraft is operating within Class A airspace or omission is requested by the pilot, issue traffic advisories to all aircraft (IFR or VFR) on your frequency when, in your judgment, their proximity may diminish to less than the applicable separation minima. Where no separation minima applies, such as for VFR aircraft outside of Class B/Class C airspace, or a TRSA, issue traffic advisories to those aircraft on your frequency when in your judgment their proximity warrants it."

Table 57: Scen10 Incident Table

Incident Type	Aircraft #1	Aircraft #2	Incident Description
OE	DOJ703	N744PA	Required intersecting runway separation was not provided * Reference FAA Order JO 7110.65 Section(s) 3-9-8/3-10-4

4.3.1.3 Scen10 Efficiency

Several metrics were captured to evaluate the efficiency of the operation simulated. Table 58 captures the observed occurrences of the efficiency metrics for this scenario. In the 45-minute operation, one ATC initiated a go-around, two aircraft were delayed, and three traffic pattern modifications were observed. In addition, there were three instances where manned aircraft requests were altered and/or cancelled, three Class D airspace requests denied, and two arrivals re-sequenced.

Table 58: Scen10 Efficiency Metrics

Go-Arounds	
ATC Initiated Go-Arounds	1
Pilot Initiated Go-Arounds	0
Total	1
Delays	
Manned A/C Departure Delays	0
Manned Aircraft Arrival Delays	2
Unmanned A/C Departure Delays	0
Unmanned A/C Arrival Delays	0
Total	2
Traffic Pattern Modifications	
Extended Down-Winds	1
360° Turns	1
ATC Initiated Runway Changes	1
ATC Requested Short Approaches	0
ATC Requested Early Departure Turns	0
ATC Assigned Straight-Out/Runway Headings	0
Total	3
Miscellaneous Efficiency Measures	
Class D Airspace Denials	3
Re-Sequenced Arrivals	2
Re-Sequenced Departures	0
Altered and/or Cancelled Manned A/C Requests	3
Altered and/or Cancelled Unmanned A/C Requests	0
Total	8

Analysis of the scenario suggests that several of these observed measures were a direct result of the UAS present in the operation. Specifically, in addition to affecting overall safety, the Raven fly away event also appeared to notably affect the efficiency of the operation. This is supported by the controllers' PRQ responses. On a 7-point Likert scale, with "1" corresponding to "not at all" and "7" corresponding to "a great deal," both the Local and Ground controllers rated the degree to which UAS affected the traffic pattern, sequence, and capacity a "7." They stated that this was due to the Raven fly away and they were "unable to have aircraft in the Class Delta" airspace.

On the same scale, the Local controller also rated the degree to which airborne UAS operations affected the efficiency of manned aircraft operations a "7." The Ground controller rated the degree to which the Raven fly away affected the manageability of the operations a "7" as well.

These ratings indicate that UAS affected the efficiency of operations a great deal in this scenario.

During the debriefing for this scenario, both controllers stated they felt when the Raven initially went lost link, the situation was manageable since they expected the aircraft to fly its known lost link pattern. However, when they were ultimately notified of the fly away circumstances, they no longer felt it was something they could safely and effectively handle with other aircraft in the airspace. This resulted in the subsequent 'sterilization' of the Class D airspace, with the exception of the JPL Blimp, which ATC felt could continue its operations based on the last known location of the Raven. As described in this section, the airspace sterilization had a substantial impact on the overall efficiency of the operations for this scenario.

4.3.1.4 Scen10 Communication

Voice communication is a key element of ATC. Many different communication anomalies can be indicative of traffic saturation and ATC loss of situation awareness. These types of occurrences include transposed call signs, missed transmissions, misidentified aircraft, and repeat ATC instructions. In this scenario, there were no recorded occurrences. (Note: Simulation pilot communication errors are not reported since they were not the subject of study.)

However, the SME Observers reported that in some instances, the air traffic controllers used nonstandard phraseology in situations involving the UAS. They added that while this type of phraseology is sometimes necessary, it can lead to confusion, adding risk to the safety of operations. This occurred specifically in the scenario during the Raven fly away event while ATC was coordinating with the High Desert TRACON to clear manned aircraft from the Class D airspace. Observances such as this demonstrate the potential need to examine standards for UAS-specific phraseology.

Another important observation with regard to communications in this scenario was the lack of ATC radio frequency use, or availability, by some UAS PICs. Common throughout the study was the lack of advisories issued to the UAS PIC that operated without direct ATC radio frequency contact (the Raven and Blimp operators utilized cell phones/landlines to communicate with ATC). It was observed that it was difficult to issue advisories to these aircraft, but it is also assumed that had communications been available to these participants via ATC radio frequency, advisories would have been issued more frequently.

4.3.1.5 Scen10 Workload and Situation Awareness

In addition to the observations noted in the safety, efficiency, and communications section, other measures of workload and situation awareness were captured via the system recordings, PRQ, and WAK. Table 59 summarizes the traffic counts for this scenario.

Table 59: Scen10 Traffic Count

	Arrivals	Departures	Touch and Gos/Low Approaches	Overflights
Count	8	7	4	5

This scenario featured two active UAS, including a Raven, fly away event. SME observed that after being notified of the Raven fly away, ATC's workload initially appeared to increase while they attempted to sterilize the airspace. However, once all aircraft were instructed to exit the Class D airspace, and coordination with High Desert TRACON was completed to keep aircraft from reentering this airspace, workload seemed to return to average levels. Although ATC explained that their decision to continue to allow the JPL to operate was based on the location of its operations area versus the last known location of the Raven, the SME Observers felt that this decision demonstrated a lack of situation awareness by the air traffic controllers.

After each run, participants and SME Observers were asked to provide subjective ratings about their assessment of their overall workload and situation awareness throughout the scenario by making ratings on a Likert scale of 1-7, where "1" corresponds to "Extremely Low" and "7" responds to "Extremely High." As seen in Table 60, the Local controller reported an average overall workload and complexity. The SME observing him felt that he experienced a just below average overall workload and complexity. The Ground controller reported a very low overall workload and a just below average complexity. The Ground SME felt that the Ground controller experienced an average overall workload and a just above average overall complexity.

Table 60: Scen10 Ratings of Overall Workload and Complexity

		Position			
		Local Controller	Local Control SME Observer	Ground Controller	Ground Control SME Observer
Metric:	Overall Complexity	4	3	3	5
	Overall Workload	4	3	2	4

Factors such as mental demand, effort, and the degree to which UAS required attention are some of the contributing factors to overall workload and complexity. Table 61 captures the PRQ responses pertaining to these factors for this scenario utilizing the Likert scales of 1-7, where "1" corresponds to "Extremely Low/Very Poor/Decreased a Great Deal/Not At All" and "7" corresponds to "Extremely High/Very Good/Increased a Great Deal/A Great Deal." On the scale with "1" corresponding to "Very Poor" and "7" corresponding to "Very Good," the Local controller self-rated his performance a "6" or "good." The Ground controller self-rated his performance a "7" or "very good."

On the scale with "1" corresponding to "Extremely Low" and "7" corresponding to "a great deal," the Local controller indicated that the UAS had very little effect on his mental demand, physical demand, temporal demand, effort, and frustration. The Ground controller felt that UAS had no effect on his mental demand, physical demand, temporal demand, and frustration. He did feel his effort during the scenario was just above average, since he assisted with UAS operations other than Ground Control operations. He reported that he "called radar to Class D and advised when they would accept aircraft into the airspace again."

On the scale with “1” corresponding to “not at all” and “7” corresponding to “a great deal,” the Local controller felt that the UAS had a notable effect on his workload. He also felt that the UAS required a great deal of additional attention as compared to manned aircraft. This supports previous observations suggesting the Raven fly away increased air traffic controller workload.

Participants were also asked to provide subjective ratings about the degree to which the REHOST display helped them maintain traffic awareness on the scale where “1” corresponds to “not at all” and “7” corresponds to “a great deal.” The REHOST had a notable effect on the ability of the air traffic controllers to maintain situation awareness, as both air traffic controllers rated this as “3.”

Table 61: Scen10 PRQ Workload and Situation Awareness

	Position	
	Local Controller	Ground Controller
Mental Demand:	2	1
Physical Demand:	2	1
Temporal Demand:	2	1
Performance:	6	7
Effort:	2	3
Frustration:	2	1
Amount of coordination with GC or LCL:	4	4
Degree to which staffing GC affected workload (LCL Only):	1	N/A
Assist with UAS operations other than GC (GC Only):	N/A	Yes, called radar to close Class "D" and would advise when we would accept aircraft again
If yes to having assisted with any UAS, did the assistance negatively affect your ability to accomplish your primary GC duties (GC Only):	N/A	No
Degree to which UAS contributed workload:	4	N/A
Degree to which UAS required additional attention:	7	N/A
Degree to which REHOST helped maintain traffic awareness:	3	3

Participants were alao asked to provide instantaneous workload ratings every two minutes during the run via a WAK located at each workstation. Graphed over time, the responses for this scenario are depicted in Figure 14.

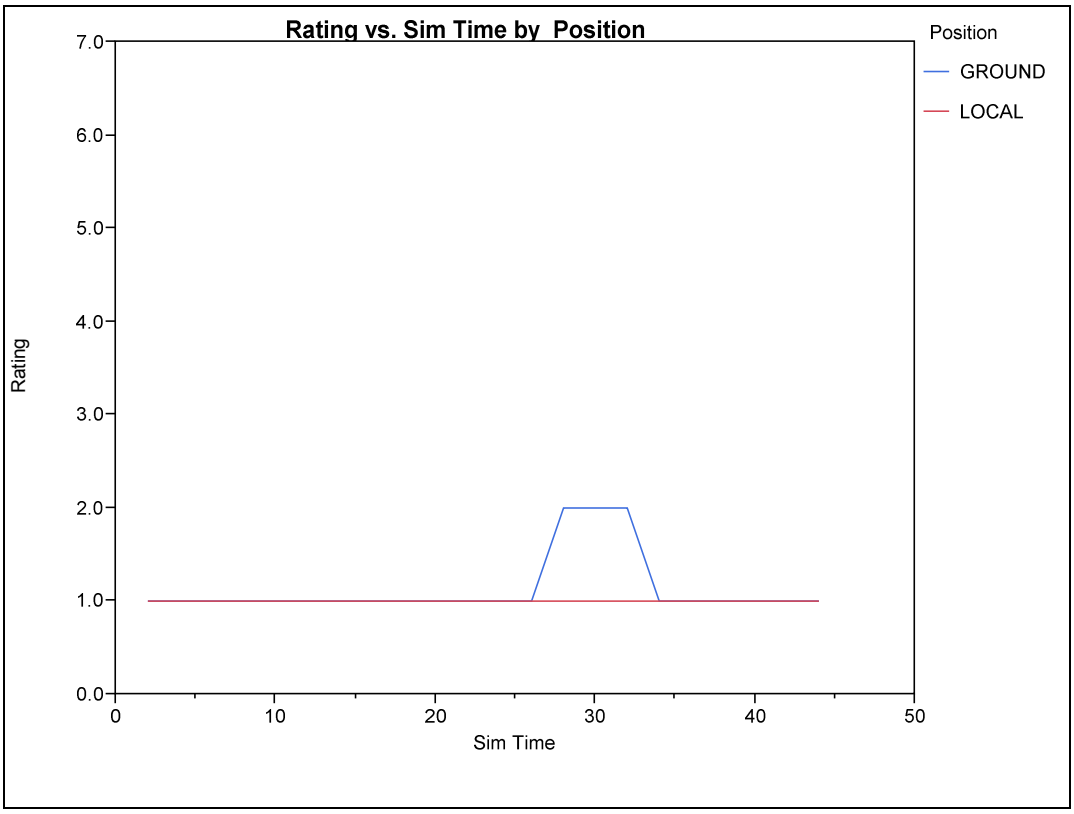

Figure 14: Scen10 WAK Data

The air traffic controllers' self-reported instantaneous workload throughout this scenario was very low. The small increase noted in the Ground controller's ratings coincides with the occurrence of the Raven reporting a lost link at 25 minutes into the scenario and then subsequently reporting a fly away at the 27th minute. This supports previous observations and comments indicating that air traffic controller workload slightly increased immediately following the incident as they sterilized the Class D airspace but then returned to previous levels following completion of the sterilization.

4.3.1.6 Scen10 SME Observations

In addition to collecting the data discussed above, the SME analysis team made supplementary observations during their post-study analysis. These observations capture events, occurrences, and their effects on the scenario which were not recorded elsewhere.

The SME Observers recognized the need for Standard Operating Procedures (SOP) for Class D operations to be developed to address situations for UAS lost link and fly away events. They suggested that these SOP be included in all COA that permit UAS operations at any towered airport so the facility is prepared should a situation like this occur. Along the same lines, it was noted that the air traffic controllers in this scenario were not even aware that an event such as this could occur. It is important that proper training also be provided to the air traffic controllers who are working UAS at every facility so they are fully aware of the potential issues that may arise.

The SME Observers noted the lack of standard ATC phraseology when controlling UAS, especially during the lost link/fly away event present in this scenario. It was observed that this non-standard phraseology can contribute to an increased risk to safety.

The SME Observers felt it was important that segregation standards and criteria for the placement of UAS operation areas in Class D airspace be developed and implemented. This issue, as identified previously, was highlighted in this scenario when a departing aircraft flew directly through the JPL operations area. It was suggested by the observers that UAS operation areas be moved to a location where they would not directly conflict with the typical airport operations — such as on or near the final approach course, departure course, or in or near the legs of the standard traffic patterns.

SME noted that UA pilots that required use of the runways were much more reliant on ATC for sequencing and separation than manned aircraft pilots.

The final observation of note in this scenario is the issue of responsibility concerning the Raven operator's compliance with see and avoid requirements. Per current COA requirements, the PIC and visual observers must be able to see the aircraft and the surrounding airspace throughout the entire flight. In the simulated fly away event, it is reasonable to assume that the pilot and visual observer lost the ability to see the aircraft. From the ATC perspective, the air traffic controllers in the simulated tower were unable to see the Raven operations, even with the assistance of (simulation) binoculars. It is reasonable to assume that the visual observers of other UA, and the pilots of manned aircraft, would also have a difficult time visually observing the Raven. Therefore, in addition to the clear safety concerns previously expressed, there is uncertainty regarding who is complying with visual see and avoid requirements of the COA and Federal Air Regulations during normal and abnormal UAS flight operations, and how this is being achieved. The safety and integrity of Class D airspace relies heavily on VFR and compliance with see and avoid requirements.

4.3.1.7 Scen10 Findings

Upon examination of the complete set of data collected, the simulated operation presented in this scenario does not appear to be feasible with regard to the safe and efficient flow of traffic.

4.3.2 Scenario 11

In line with the overall study objectives, the goal of Scenario 11 was to examine the effects of simultaneous multiple UAS platforms with dissimilar flight characteristics on local traffic pattern operations, ATC operations, and Class D airspace. This scenario also included a scripted off nominal event.

4.3.2.1 Scen11 Design

Scenario 11 was developed with the following characteristics:

Airport and Weather Conditions: Simulation start-time was mid-afternoon and VFR prevailed throughout the scenario. Winds were 210° at 9kts. The active runways were 21 and 17.

Manned Aircraft: Seventeen manned aircraft were introduced at random intervals to simulate normal traffic flows at the airport. Operations included both military and civilian departures, arrivals, over-flights, and local pattern work. Four additional VFR (1200 code) targets were injected to simulate over-flight traffic above and/or adjacent to the Class D airspace. These targets did not communicate with ATC.

Special Military Operations: In addition to other manned military flights, an additional C17 Globemaster II (Slam 88) was added to simulate specialized military tactical maneuvers practiced by USAF crews at KVCV and similar airports.

Ground Vehicles: Two ground vehicles were added to the scenario to replicate vehicular traffic at a typical airport. The vehicles simulated routine airfield maintenance and sweeping operations and communicated with ATC on the GC frequency.

Unmanned Aircraft Systems: Two UAS were included in this scenario — the AS800 JPL Blimp and the A-160 Hummingbird.

Off Nominal Event(s): Secondary to the simultaneous multiple UAS operations, Scenario 11 examined the effects of the A-160 experiencing a loss of its control and communication link. The lost link event occurred at approximately 15 ½ minutes into the scenario. The A-160 immediately began its lost link procedure and proceeded directly to the Warrior Ramp. As per scenario scripting, ATC was immediately notified of the lost link event and was informed of the aircraft's intent. The AS800 JPL Blimp was airborne throughout the scenario within the confines of the normal operations area west of Runway 17.

4.3.2.2 Scen11 Safety

The ATC operations presented in this scenario were evaluated with regard to the safety and efficiency of the flow of traffic. Several notable observations are described in this section.

Although the A-160 (Mariner 1) in this scenario experienced lost link, it did not appear to affect the confidence in safety or the workload of the controllers. As rated on a 7-point Likert scale in the PRQ, with a "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High," both participants appeared to be confident in the safety of operations for this scenario. The Local and Ground controllers rated their confidence levels as 5 and 6, respectively. Both Local and Ground SME Observers also rated the safety and efficiency of traffic flow as well as the safety of the pattern sequence as high (both SME observers rated both metrics as 6).

From an operational perspective, there are several types of incidents that adversely affect the safe, orderly, and expeditious movement of air traffic. These include MAC as well as other ACC, NMAC, OE, OD, RI, and PD. Concerning some of these measures, it is important to note that the focus of this study was to examine the potential effects of UAS operations on Class D airspace. By design, the simulation pilots, both manned and unmanned, were not the direct subject of study in this simulation. Therefore, any occurrences of pilot-induced incidents (e.g., PD, RI, or NMAC caused by pilot error or actions) are considered part of the realistic, complex situations presented to the controller participants and not reported as deficiencies or safety-related findings for the purposes of this evaluation.

Information concerning the study's valid incident safety measures are summarized in Table 62, with reported incident details provided in Table 63. In this 45-minute scenario, ATC did not comply with the proper intersecting runway standards as prescribed in the FAO JO7110.65, Sections 3-9-8 and 3-10-4, Intersecting Runway Separation, resulting in the two OE depicted in Table 62 and Table 63.

Table 62: Scen11 Safety Metrics

Metric:	MAC	Other Accidents	NMAC	OE	OD	RI
Number of Incidents	0	0	0	2	0	0

Table 63: Scen11 Incident Table

Incident Type	Aircraft #1	Aircraft #2	Incident Description
OE	R50095	N744PA	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
OE	NASA901	N44EL	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4

4.3.2.3 Scen11 Efficiency

Several metrics were captured to evaluate the efficiency of the operation. Table 64 captures the observed efficiency metrics for this scenario. In the 45-minute scenario, four aircraft delays and five traffic pattern modifications were observed.

Table 64: Scen11 Efficiency Metrics

Go-Arounds	
ATC Initiated Go-Arounds	0
Pilot Initiated Go-Arounds	0
Total	0
Delays	
Manned A/C Departure Delays	2
Manned Aircraft Arrival Delays	2
Unmanned A/C Departure Delays	0
Unmanned A/C Arrival Delays	0
Total	4
Traffic Pattern Modifications	
Extended Down-Winds	2
360° Turns	1
ATC Initiated Runway Changes	1
ATC Requested Short Approaches	0
ATC Requested Early Departure Turns	0
ATC Assigned Straight-Out/Runway Headings	1
Total	5
Miscellaneous Efficiency Measures	
Class D Airspace Denials	0
Re-Sequenced Arrivals	0
Re-Sequenced Departures	0
Altered and/or Cancelled Manned A/C Requests	0
Altered and/or Cancelled Unmanned A/C Requests	0
Total	0

Participant responses on the PRQ indicated that the UAS had some effect on the efficiency of the operations for this scenario. On a 7-point Likert scale, with a "1" corresponding to "not at all" and "7" corresponding to "a great deal," the Local controller reported the UAS minimally affected the capacity, the sequence of traffic, and his ability to accommodate manned aircraft (all rated as 2). However, according to the Local controller, the UAS did appear to have a considerable effect on the traffic pattern (rated as 5), and he indicated that he provided substantial priority of handling to the UAS as compared to manned aircraft (rated as 6).

Ratings from the Ground controller indicated UAS had no effect on the efficiency of ground operations or his ability to accommodate manned aircraft in his role. In the post scenario debrief, one of the participants commented on the lost link event, stating that "the situation was handled like any emergency situation and the UAS was treated no different than a manned flight." The Local controller also noted that as a result of Mariner 1 going lost link, the traffic patterns of other manned traffic were extended to ensure safe operations.

4.3.2.4 Scen11 Communication

Voice communication is a key element of ATC. Many different communication anomalies can be indicative of traffic saturation and ATC loss of situation awareness. These types of occurrences include transposed call signs, missed transmissions, misidentified aircraft, and repeat ATC instructions. In this scenario, there were no recorded occurrences. (Note: simulation pilot communication errors are not reported since they were not the subject of study.)

4.3.2.5 Scen11 Workload and Situation Awareness

In addition to the observations noted in the safety, efficiency, and communications sections, other measures of workload and situation awareness were captured via the system recordings, PRQ, and WAK. Table 65 summarizes traffic count data for this scenario.

Table 65: Scen11 Traffic Count

	Arrivals	Departures	Touch and Go's/ Low Approaches	Overflights
Count:	19	17	13	5

After each run, participants and SME Observers were asked to provide subjective ratings about their assessment of overall workload and situation awareness on a 7-point Likert scale, where "1" corresponds to "Extremely Low" and "7" responds to "Extremely High."

The Local controller rated overall complexity below average (rated as 3) and overall workload as average (rated as 4). The Local SME Observer noted that they observed the Local controller's overall workload and complexity as average (rating for both was 4).

The Ground controller rated overall workload and complexity as above average (both rated as 5) while the SME Observer for this position rated them both as below average (both rated as 3). Table 66 captures the responses.

Table 66: Scen11 Ratings of Overall Workload and Complexity

		Position			
		Local Controller	Local Control SME Observer	Ground Controller	Ground Control SME Observer
Metric:	Overall Complexity	3	4	5	3
	Overall Workload	4	4	5	3

Factors such as mental demand, effort, and the degree to which UAS required attention are some of the contributing factors to overall workload and complexity. Table 67 captures the PRQ responses pertaining to these factors.

On a scale with "1" equal to "Very Poor" and "7" corresponding to "Very Good," the Local and Ground controllers self-rated their performance on the higher end for this scenario (rated 5 and 7, respectively).

On a scale with "1" equal to "Extremely Low" and "7" corresponding to "Extremely High," both controllers rated their mental demand, physical demand, temporal demand, effort, and frustration as average or below.

However, on a scale with "1" equal to "not at all" and "7" corresponding to "a great deal," the Local controller indicated the UAS notably contributed to his workload (rated as 4), but he indicated the UAS only required minimal additional attention as compared to manned aircraft (rated as 2).

The REHOST display appeared to provide substantial benefit to the Local controller for maintaining situation awareness, rated as a 6 on a scale with "1" equal to "not at all" and "7" corresponding to "a great deal."

Table 67: Scen11 PRQ Workload and Situation Awareness

		Position	
		Local Controller	Ground Controller
Metric:	Mental Demand:	3	2
	Physical Demand:	3	1
	Temporal Demand:	3	2
	Performance:	5	7
	Effort:	2	4
	Frustration:	2	2
	Amount of coordination with GC or LCL:	4	4
	Degree to which staffing GC affected workload (LCL Only):	4	N/A
	Assist with UAS operations other than GC (GC Only):	N/A	No
	If yes to having assisted with any UAS, did the assistance negatively affect your ability to accomplish your primary GC duties (GC Only):	N/A	N/A
	Degree to which UAS contributed workload:	4	N/A
	Degree to which UAS required additional attention:	2	N/A
	Degree to which REHOST helped maintain traffic awareness:	6	Not Rated

Furthermore, participants were asked to provide instantaneous workload ratings every two minutes during the run via a WAK located at each workstation. Graphed over time, the responses for this scenario are depicted in Figure 15.

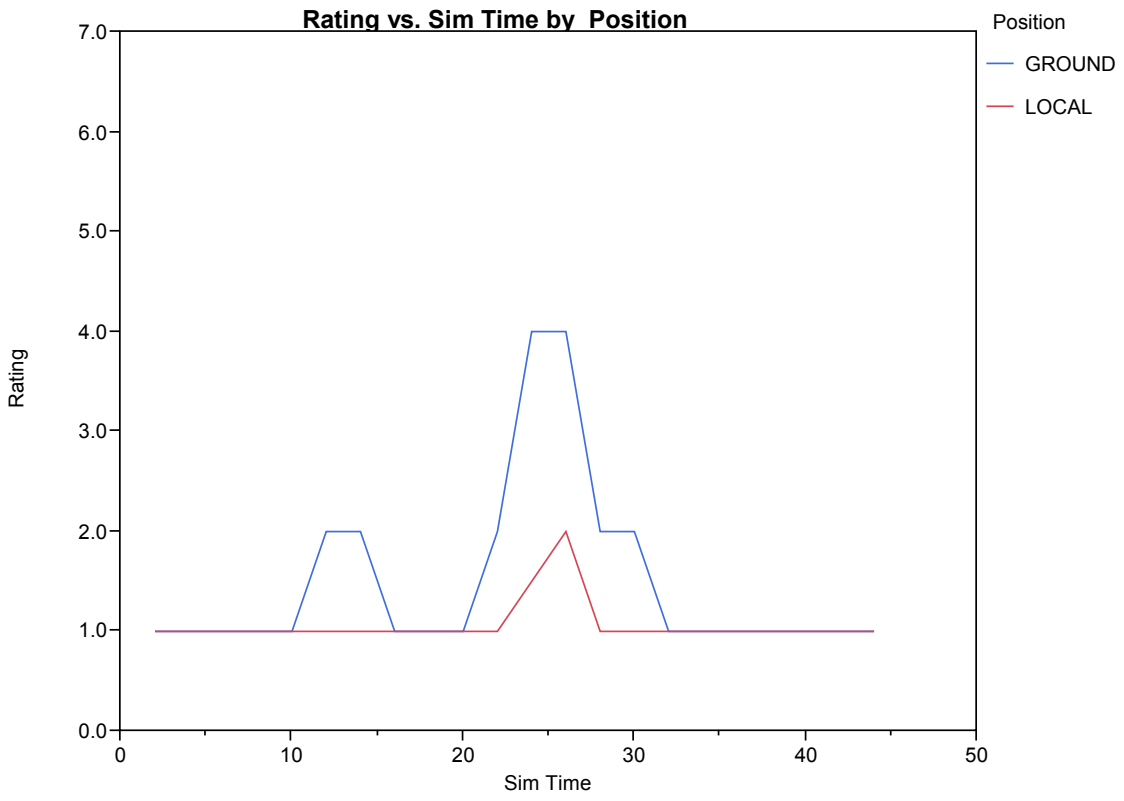

Figure 15: Scen11 WAK Data

As depicted in the graph, the Local controller generally self-rated his instantaneous workload throughout the scenario as minimum. The Ground controller's ratings were average or below. Both sets of ratings showed an elevation surrounding the Mariner 1's lost link event (the Ground controller's increase was more prominent) which began at approximately 15 ½ minutes into the scenario and lasted until about the 22nd minute. This observation logically suggests that the event may have triggered an increase in controller workload.

4.3.2.6 Scen11 SME Observations

In addition to collecting the data discussed above, the SME analysis team made supplementary observations during their post-study analysis. These observations capture events, occurrences, and their effects on the scenario which were not recorded elsewhere.

For this scenario, there were no additional SME observations noted.

4.3.2.7 Scen11 Findings

Upon examination of the complete set of data collected, the ATC operation simulated in this scenario does not appear to be feasible with regard to the safe and efficient flow of air traffic.

4.3.3 Scenario 12

In line with the overall study objectives, the goal of Scenario 12 was to examine the effects of simultaneous multiple UAS platforms with dissimilar flight characteristics on local traffic pattern operations, ATC operations, and Class D airspace. This scenario also included a scripted off nominal event.

4.3.3.1 Scen12 Design

Scenario 12 was developed with the following characteristics:

Airport and Weather Conditions: Simulation start-time was mid-afternoon and VFR prevailed throughout the scenario. Winds were 210° at 9kts. The active runways were 21 and 17.

Manned Aircraft: Seventeen manned aircraft were introduced at random intervals to simulate normal traffic flows at the airport. Operations included both military and civilian departures, arrivals, over-flights, and local pattern work. Four additional VFR (1200 code) targets were injected to simulate over-flight traffic above and/or adjacent to the Class D airspace. These targets did not communicate with ATC.

*Special Military Operations***:** In addition to other manned military flights, an additional C17 Globemaster II (Slam 88) was added to simulate specialized military tactical maneuvers practiced by USAF crews at KVCV and similar airports.

Ground Vehicles: Two ground vehicles were added to the scenario to replicate vehicular traffic at a typical airport. The vehicles simulated routine airfield maintenance and sweeping operations and communicated with ATC on the GC frequency.

Unmanned Aircraft Systems: Two UAS were included in this scenario — the AS800 JPL Blimp and the MQ1B Predator. Although not a UAS, the Predator Chase aircraft (a manned, Mooney MO20) was included in the scenario to simulate the requirements of the current COA.

Off Nominal Event(s): Secondary to the multiple UAS traffic pattern operations, Scenario 12 also examined the effects of an airborne runway change request. The MQ-1B Predator requested a scripted runway change while operating within the closed traffic patterns in Class D airspace. The Predator and chase aircraft then departed the Class D airspace to the north as a flight. The AS800 JPL Blimp was airborne throughout the scenario within the confines of its normal operations area west of Runway 17.

4.3.3.2 Scen12 Safety

The ATC operations presented in this scenario were evaluated with regard to the safety and efficiency of the flow of traffic. Notable observations are described in this section.

Rated on a 7-point Likert scale in the PRQ, with a “1” corresponding to “Extremely Low” and “7” corresponding to “Extremely High,” the Local and Ground controllers rated their confidence level for the safety of operations as very high (rated 6 by both).

The Local and Ground SME Observers also reported high levels of perceived safety for this operation. Specifically, the Local SME Observer rated both the safety of the pattern sequence and overall traffic flow a 6, while the Ground SME Observer rated them 5, or above average. The data and observations for this scenario appear to be in line with these opinions.

The planned event for this scenario involved Grizzly 21 flying an abbreviated left-turn closed traffic pattern to Runway 21. After a touch and go maneuver at midfield, Grizzly 21 requested a right-turn closed traffic pattern to Runway 17 for some additional touch and gos. SME Observers indicated that the situation appeared to have been handled safely without system impact.

From an operational perspective, there are several types of incidents that adversely affect the safe, orderly, and expeditious movement of air traffic. These include MAC as well as other ACC, NMAC, OE, OD, RI, and PD. Concerning some of these measures, it is important to note that the focus of this study was to examine the potential effects of UAS operations on Class D airspace. By design, the simulation pilots, both manned and unmanned, were not the direct subject of study in this simulation. Therefore, any occurrences of pilot-induced incidents (e.g., PD, RI, or NMAC caused by pilot error or actions) are considered part of the realistic, complex situations presented to the controller participants and not reported as deficiencies or safety-related findings for the purposes of this evaluation.

Information concerning the study's valid incident safety measures are summarized in Table 68, with reported incident details provided in Table 69.

In the 45-minute scenario, there were three incidents attributed to ATC. Specifically, there were three OE where ATC did not comply with the proper intersecting runway standards as prescribed in FAO JO7110.65, Sections 3-9-8 and 3-10-4, Intersecting Runway Separation, resulting in the OE depicted in Table 68 and Table 69.

Table 68: Scen12 Safety Metrics

Metric:	MAC	Other Accidents	NMAC	OE	OD	RI
Number of Incidents	0	0	0	3	0	0

Table 69: Scen12 Incident Table

Incident Type	Aircraft #1	Aircraft #2	Incident Description
OE	OMEGA70	N739HZ	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
OE	NASA901	N44EL	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
OE	N744PA	N44EL	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4

4.3.3.3 Scen12 Efficiency

Several metrics were captured to evaluate the efficiency of the operation simulated. Table 70 captures the observed occurrences of the efficiency metrics for this scenario. In the 45-minute scenario, one go-around maneuver, two aircraft delays, and two traffic pattern modifications were observed. In addition, there was one re-sequenced arrival.

Table 70: Scen12 Efficiency Metrics

Go-Arounds	
ATC Initiated Go-Arounds	0
Pilot Initiated Go-Arounds	1
Total	1
Delays	
Manned A/C Departure Delays	0
Manned Aircraft Arrival Delays	2
Unmanned A/C Departure Delays	0
Unmanned A/C Arrival Delays	0
Total	2
Traffic Pattern Modifications	
Extended Down-Winds	0
360° Turns	1
ATC Initiated Runway Changes	1
ATC Requested Short Approaches	0
ATC Requested Early Departure Turns	0
ATC Assigned Straight-Out/Runway Headings	0
Total	2
Miscellaneous Efficiency Measures	
Class D Airspace Denials	0
Re-Sequenced Arrivals	1
Re-Sequenced Departures	0
Altered and/or Cancelled Manned A/C Requests	0
Altered and/or Cancelled Unmanned A/C Requests	0
Total	1

On a scale 7-point scale, with a "1" corresponding to "not at all" and "7" corresponding to "a great deal," the Local controller reported that UAS operations had a minimal effect on the efficiency of manned aircraft operations (rated a 2). He indicated that the UAS had little or no effect on the traffic pattern, sequence, and capacity (rated 2, 2, and 1, respectively). The Local controller also reported he did not provide priority handling to the UAS as compared to manned aircraft, and that the UAS had little impact on his ability to accommodate manned aircraft (rated as 2). The Ground controller, in his role, had minimal direct interaction with the UAS and reported the UAS had no effect at all on the same metrics.

SME Observers also rated the overall efficiency of the pattern sequence and overall efficiency of taxiway and efficiency of taxiway runway assignments as high.

On a scale 7-point scale, with a "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High," the Local SME Observer rated the overall efficiency of pattern sequence and taxi and runway assignments as very high (both rated 6). The Ground SME Observer rated the same metrics as average and above average (rated as 4 and 5, respectively).

4.3.3.4 Scen12 Communication

Voice communication is a key element of ATC. Many different communication anomalies can be indicative of traffic saturation and ATC loss of situation awareness. These types of occurrences include transposed call signs, missed transmissions, misidentified aircraft, and repeat ATC instructions. In this scenario, there were three instances of missed transmissions. (Note: simulation pilot communication errors are not reported since they were not the subject of study.)

4.3.3.5 Scen12 Workload and Situation Awareness

In addition to the observations noted in the safety, efficiency, and communications sections, other measures of workload and situation awareness were captured via the system recordings, PRQ, and WAK. Table 71 summarizes traffic count data for this scenario.

Table 71: Scen12 Traffic Count

	Arrivals	Departures	Touch and Go's/ Low Approaches	Overflights
Count:	17	17	12	5

After each run, participants and SME Observers were asked to provide subjective ratings about their assessment of workload and situation awareness by making ratings on a Likert scale of 1-7, where "1" corresponds to "Extremely Low" and "7" corresponds to "Extremely High."

The Local controller and the SME Observer for this position indicated average ratings of overall workload and complexity. The Ground controller and SME Observer rated overall workload and complexity for this position as well below average. Table 72 captures the responses.

Table 72: Scen12 Ratings of Overall Workload and Complexity

		Position			
		Local Controller	Local SME Observer	Ground Controller	Ground SME Observer
Metric:	Overall Complexity	4	4	2	2
	Overall Workload	4	4	2	2

Factors such as mental demand, effort, and the degree to which UAS required attention are some of the contributing factors to overall workload and complexity. Table 73 captures the PRQ responses pertaining to these factors for this scenario.

On a scale with “1” equal to “Very Poor” and “7” corresponding to “Very Good,” the Local and Ground controllers self-rated their performance on the high end for this scenario (rated 7 and 6, respectively).

On a scale with “1” equal to “Extremely Low” and “7” corresponding to “Extremely High,” the Local controller rated mental demand, physical demand, temporal demand, effort, and frustration as average or below. The Ground controller rated the same metrics as well below average to extremely low.

On a scale with “1” equal to “not at all” and “7” corresponding to “a great deal,” the Local controller indicated the UAS noticeably contributed to workload (rated as 3), but the UAS required only minimal additional attention as compared to manned aircraft (rated as 2). The Ground controller indicated the UAS minimally contributed to his workload (rated as 2) and that the UAS required no additional attention as compared to manned aircraft.

The controllers reported they did not treat Grizzly 21 any different because of the chase plane. The Local controller also reported that while Grizzly 21’s runway change did affect his management of traffic (rated as 3), it did not cause a negative impact to operations on the runway.

Participants were also asked to provide subjective ratings about the degree to which the REHOST display helped them maintain traffic awareness on the scale where “1” corresponds to “not at all” and the “7” corresponds to “a great deal.” Both the Local and Ground controllers indicated significant benefit from the system (they rated it as 7 and 5, respectively).

Table 73: Scen12 PRQ Workload and Situation Awareness

		Position	
		Local Controller	Ground Controller
Metric:	Mental Demand:	4	1
	Physical Demand:	2	1
	Temporal Demand:	3	1
	Performance:	7	6
	Effort:	4	2
	Frustration:	1	1
	Amount of coordination with GC or LCL:	3	4
	Degree to which staffing GC affected workload (LCL Only):	2	N/A
	Assist with UAS operations other than GC (GC Only):	N/A	No
	If yes to having assisted with any UAS, did the assistance negatively affect your ability to accomplish your primary GC duties (GC Only):	N/A	N/A
	Degree to which UAS contributed workload:	3	2
	Degree to which UAS required additional attention:	2	1
	Degree to which REHOST helped maintain traffic awareness:	7	5

Participants were also asked to provide instantaneous workload ratings every two minutes during the run via a WAK located at each workstation. Graphed over time, the responses for this scenario are depicted in Figure 16.

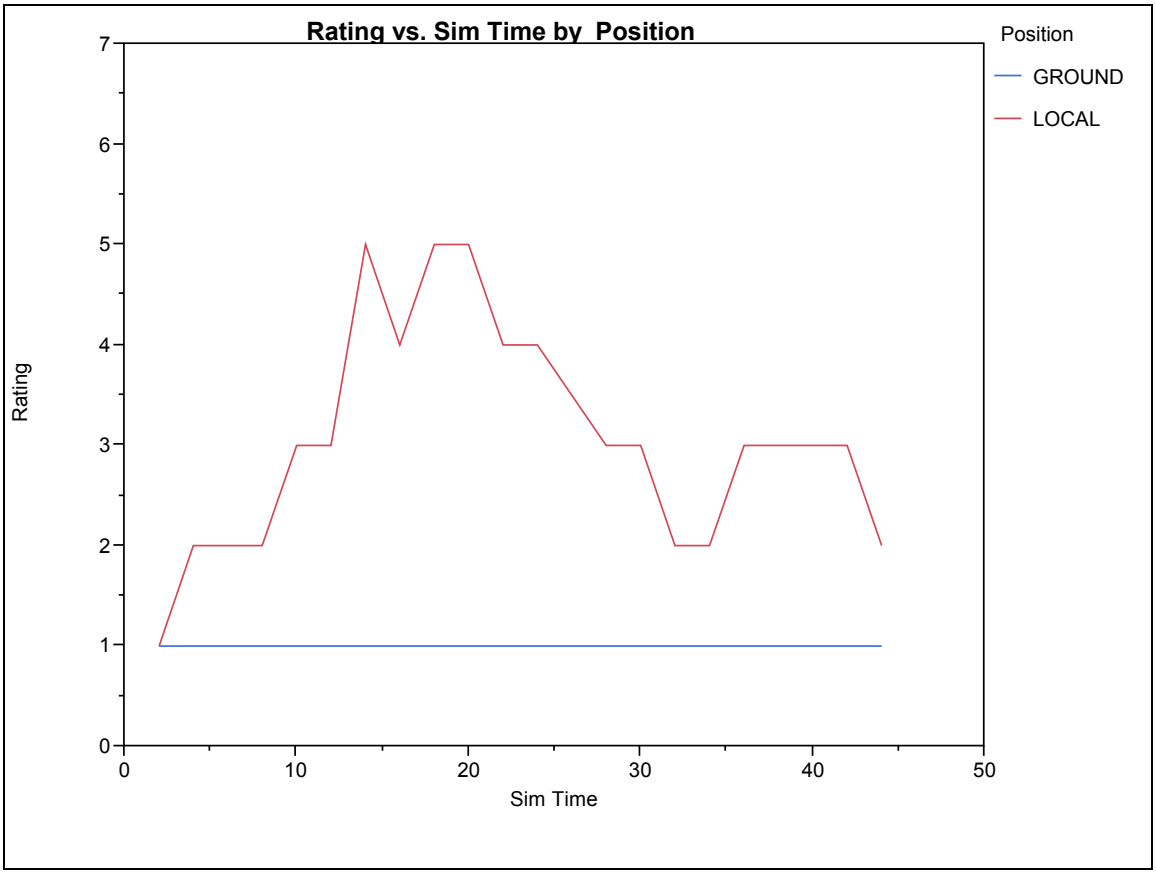

Figure 16: Scen12 WAK Data

In line with questionnaire responses, the Ground controller's self-reported instantaneous workload was consistently minimal throughout the scenario. The Local controller's ratings varied over time but appeared to remain manageable throughout the scenario. The rise in the Local controller's ratings appears to coincide with Grizzly 21's request for a runway change at approximately 11 minutes into the scenario, logically suggesting the event triggered an increase in controller workload.

4.3.3.6 Scen12 SME Observations

In addition to collecting the data discussed above, the SME analysis team made supplementary observations during their post-study analysis. These observations capture events, occurrences, and their effects on the scenario which were not recorded elsewhere.

SME noted that UAS that required the use of the runways were much more reliant on ATC for sequencing and spacing than manned aircraft pilots. This had the potential to increase controller workload and complexity.

4.3.3.7 Scen12 Findings

Upon examination of the complete set of data collected, the ATC operation simulated in this scenario does not appear to be feasible with regard to the safe and efficient flow of air traffic.

4.3.4 Scenario 13

In line with the overall study objectives, the goal of Scenario 13 was to examine the effects of simultaneous multiple UAS platforms with dissimilar flight characteristics on local traffic pattern operations, ATC operations, and Class D airspace. This scenario also included off-nominal events.

4.3.4.1 Scen13 Design

Scenario 13 was developed with the following characteristics:

Airport and Weather Conditions: Simulation start-time was mid-afternoon, and Visual Flight Rules (VFR) prevailed throughout the scenario. Winds were 210° at 9kts. The active runways were 21 and 17.

Manned Aircraft: Seventeen manned aircraft were included to simulate normal traffic flows at the airport. Operations included both military and civilian departures, arrivals, over-flights, and local pattern work. Four additional VFR (1200 code) targets were introduced to simulate over-flight traffic above and/or adjacent to the Class D airspace, and did not communicate with ATC.

Special Military Operations: In addition to other manned military flights, an additional C17 Globemaster II (Slam 88), was added to simulate specialized military tactical maneuvers practiced by USAF crews at KVCV and similar airports.

Ground Vehicles: Two ground vehicles were added to the scenario to replicate vehicular traffic at a typical airport. The vehicles simulated routine airfield maintenance and runway sweeping operations, and communicated with ATC on the GC frequency.

Unmanned Aircraft Systems: Three UAS were included in this scenario; the AS800 JPL Blimp, and two MQ-1B Predators.

Off Nominal Event(s): Secondary to the simultaneous multiple UAS operations, Scenario 13 also examined the effects of simultaneous multiple UAS platforms operating in the same runway traffic pattern. In this case two MQ-1B Predators were introduced and requested closed traffic for Runway 21.

4.3.4.2 Scen13 Safety

The ATC operations presented in this scenario were evaluated with regards to the safety and efficiency of the flow of traffic. Notable observations are described in this section.

As rated post run on a 7 point scale, with a “1” corresponding to “Extremely Low’ and “7” corresponding to “Extremely High”, both participants and SME observers appeared to be confident in the safety of operations for this scenario. The Local and Ground controllers rated

their confidence levels for safe operations as just above average and extremely high, respectively. Both SME observers also rated the overall safety of pattern sequence as very high (both rated as 6). The Local SME Observer gave a very high rating for the safety and efficiency of the flow of traffic, whereas the Ground SME Observer gave an average rating. He also noted the operations in this scenario were safe but less than efficient due to untimely clearances.

Although controllers and SME felt confident in the safety and efficiency of operations in this scenario, data and observations indicated some safety concerns.

Both controllers noted that they did not provide an extra margin of spacing and/or separation for UAS nor did they treat the UAS any differently than a manned aircraft.

SME Observers also observed ATC's disregard for JPL operating within its operational area. Manned aircraft flew in close proximity to this area with no issuance of traffic or safety advisories.

From an operational perspective, there are several types of incidents that adversely affect the safe, orderly and expeditious movement of air traffic. These include MAC, other ACC, NMAC, OE, OD, RI, and PD. Concerning some of these measures, it is important to note that focus of this study was to examine the potential effects of UAS operations on Class D airspace. By design, the simulation pilots, both manned and unmanned, were confederates in this simulation (i.e., not the direct subjects of study). Therefore, any occurrences of pilot-induced incidents (e.g., PD, RI, or NMAC caused by pilot error or actions) are considered part of the realistic, complex situations presented to the controller participants and not reported as deficiencies or safety related findings for the purposes of this evaluation.

Information concerning the study's incident safety measures are summarized in Table 74, with reported incident details provided in Table 75. In this 45-minute operation, there were five ATC related incidents where ATC did not comply with the proper intersecting runway standards as prescribed in the FAO JO7110.65, resulting in the OE depicted in Table 74 and Table 75. Three of these OE involved UAS.

Table 74: Scen13 Safety Metrics

Metric:	MAC	Other Accidents	NMAC	OE	OD	RI
Number of Incidents	0	0	0	5	0	0

Table 75: Scen13 Incident Table

Incident Type	Aircraft #1	Aircraft #2	Incident Description
OE	NASA901	Grizzly 22 *(UAS)*	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section 3-9-8
OE	N744PA	Grizzly 21 *(UAS)*	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section 3-9-8
OE	SWA3471	Grizzly 22 *(UAS)*	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section 3-9-8
OE	RYN5	N44EL	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section 3-9-8
OE	Slam 88	N44EL	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section 3-9-8

4.3.4.3 Scen13 Efficiency

Several metrics were captured to evaluate the efficiency of the operation simulated. Table 76 captures the observed metrics for this scenario. In the 45-minute operation, seven A/C delays and eleven traffic pattern modifications were observed. In addition, there were two go-arounds: one pilot-initiated, one ATC-initiated.

The majority of the seven delays that took place in this scenario were due to the two Predators that were operating simultaneously in the traffic pattern with manned aircraft. SME observed ATC making an attempt to resequence one of the two Predators in the traffic pattern ahead of manned aircraft. As a result, extended downwinds and 360 degree turns were issued to manned and unmanned aircraft in the traffic patterns in an attempt to sequence them. Manned aircraft also experienced a delay due to an inbound Predator on Runway 21.

Table 76: Scen13 Efficiency Metrics

Go-Arounds	
ATC Initiated Go-Arounds	1
Pilot Initiated Go-Arounds	1
Total	2
Delays	
Manned A/C Departure Delays	4
Manned Aircraft Arrival Delays	1
Unmanned A/C Departure Delays	1
Unmanned A/C Arrival Delays	1
Total	7
Traffic Pattern Modifications	
Extended Down-Winds	7
360° Turns	4
ATC Initiated Runway Changes	0
ATC Requested Short Approaches	0
ATC Requested Early Departure Turns	0
ATC Assigned Straight-Out/Runway Headings	0
Total	11
Miscellaneous Efficiency Measures	
Class D Airspace Denials	0
Re-Sequenced Arrivals	0
Re-Sequenced Departures	0
Altered and/or Cancelled Manned A/C Requests	0
Altered and/or Cancelled Unmanned A/C Requests	0
Total	0

Participant responses on the PRQ indicated that the UAS, in general, had an effect on the efficiency of the operations during this scenario. On a 7-point scale, with "1" corresponding to "Not at All" and "7" corresponding to "A Great Deal," the Local controller reported that the UAS had a notable effect on the traffic pattern and minimal effect on the capacity. He also reported that the UAS had a notable effect on the sequence of traffic and stated that he was "unable to tell UAS to follow so had to readjust sequencing and had to call the UAS base turn." The Ground controller had a different perception and felt that that the UAS had a considerable effect on the sequence of traffic and on the traffic pattern but did not affect the capacity of traffic.

In addition to the effect on efficiency, the simultaneous Predator operations also appeared to have an effect on the overall manageability of operations for this scenario. The Local controller indicated that UAS operations had a notable effect on his ability to efficiently accommodate manned aircraft operations. Also, both the Local and Ground controllers indicated that

simultaneous Predator operations had a notable effect on the manageability of the overall operations. The Ground controller reported that manned aircraft touch and go operations were affected by the Predator operations on the same runway, but the Local controller did not agree with this observation.

4.3.4.4 Scen13 Communication

Voice communication is a key element of ATC. Many different communication anomalies can be indicative of traffic saturation and ATC loss of situation awareness. These types of occurrences include transposed call signs, missed transmissions, misidentified aircraft, and repeat ATC instructions.

In this scenario, there was one missed transmission by the Local controller and two missed transmissions by the Ground controller. Besides the missed transmissions there were no other recorded occurrences of communication problems. (Note: simulation pilot communication errors are not reported since they were not the subjects of study.)

4.3.4.5 Scen13 Workload and Situation Awareness

In addition to the observations noted in the safety, efficiency, and communications sections, other measures of workload and situation awareness were captured via the system recordings, PRQ, and WAK.
Table 77 summarizes traffic count data for this scenario.

Table 77: Scen13 Traffic Count

	Arrivals	Departures	Touch and Go's/ Low Approaches	Overflights
Count:	27	25	19	4

After each run, the participants and SME Observers were asked to provide subjective ratings about their assessment of workload and situation awareness by marking ratings on a Likert scale of 1-7, where “1” corresponds to “Extremely Low” and the “7” corresponds to “Extremely High”.

The Local participant indicated that he experienced an average overall complexity and a just above average overall workload. In alignment with his ratings, responses given by the Local SME Observer indicate that it appeared as though the Local controller experienced an average overall workload and an above average overall complexity.

The Ground controller rated overall complexity and overall workload as very low (both rated 2). The Ground SME Observer rated the participant’s overall workload and overall complexity as average (both rated 4). Table 78 captures the responses.

Although the controllers reported very low to just above average ratings for workload, it appeared that the presence of two Predators in the pattern increased the workload of the

controllers. Numerous instructions were given in order to work the UAS into the traffic pattern with manned aircraft. An example of this is ATC's decision to sequence the Predator to position number 1 in the traffic pattern in front of manned aircraft N44EL. As a result, there were several instances in which re-sequencing of manned and unmanned aircraft were necessary. It was noted by controllers in the daily debrief that once one Predator landed, it made things easier.

Table 78: Scen13 Ratings of Overall Workload and Complexity

		Position			
		Local Controller	Local SME Observer	Ground Controller	Ground SME Observer
Metric:	Overall Complexity	4	5	2	4
	Overall Workload	5	4	2	4

Factors such as mental demand, effort, and the degree in which UAS required attention are some of the contributing factors to overall workload and complexity. Table 79 captures the PRQ responses pertaining to these factors.

On a scale with "1" equal to "Very Poor" and "7" corresponding to "Very Good", the Local and Ground controllers self-rated their performance on the high end of the ratings scale for this scenario (rated 6 and 7 respectively).

On a scale with "1" equal to "Extremely Low" and "7" corresponding to "Extremely High", the Local controller rated his physical demand as very low and his frustration as just below average; furthermore, he rated his mental demand, temporal demand and effort as average. The Ground controller rated his mental demand, temporal demand, and effort as very low and rated his physical demand and frustration as extremely low.

Participants were also asked to provide subjective ratings about the degree to which the REHOST display helped them maintain traffic awareness on the scale where "1" corresponds to "Not at all" and the "7" corresponds to "A great deal." The Local controller indicated situation awareness significantly benefited from the system, but the Ground controller indicated that the benefit of using REHOST was minimal.

Table 79: Scen13 PRQ Workload and Situation Awareness

		Position	
		Local Controller	Ground Controller
Metric:	Mental Demand:	4	2
	Physical Demand:	2	1
	Temporal Demand:	4	2
	Performance:	6	7
	Effort:	4	2
	Frustration:	3	1
	Amount of coordination with GC or LCL:	4	4
	Degree to which staffing GC affected workload (LCL Only):	2	x
	Assist with UAS operations other than GC (GC Only):	x	No
	If yes to having assisted with any UAS, did the assistance negatively affect your ability to accomplish your primary GC duties (GC Only):	x	x
	Degree to which UAS contributed workload:	5	1
	Degree to which UAS required additional attention:	5	1
	Degree to which REHOST helped maintain traffic awareness:	5	1

Participants were asked to provide instantaneous workload ratings every two minutes during the run via a WAK located at each workstation. Graphed over time, the responses for this scenario are depicted in Figure 17.

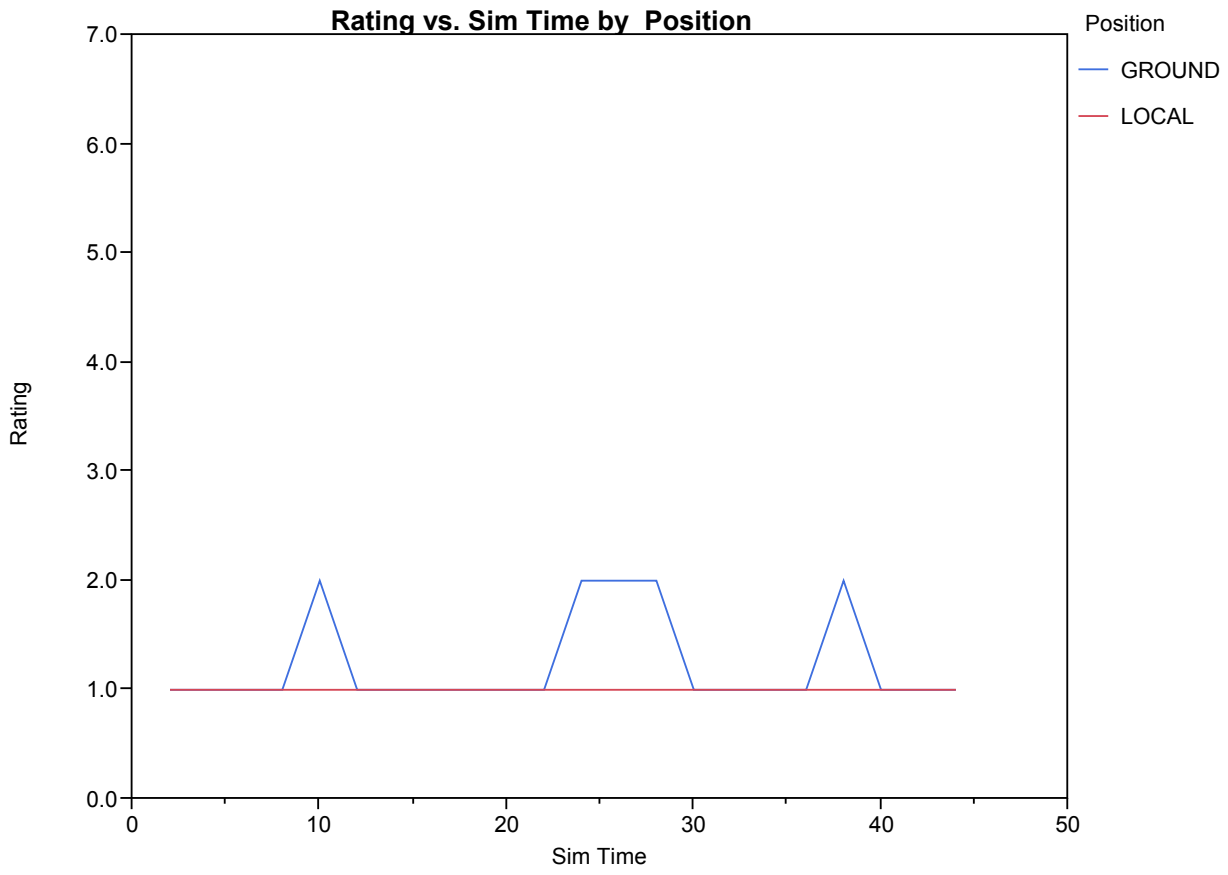

Figure 17: Scen13 WAK Data

Contrary to questionnaire responses, the Local controller's self-reported workload throughout the scenario appeared to be rather low. However, the Ground controller's rather low self-reported workload throughout the scenario was in line with questionnaire responses. The first of the spikes in the graph approximately coincides with the time at which the second Predator aircraft departed at 6 minutes. This supports previous SME observations and comments that the presence of multiple Predator aircraft in the scenario increased the controllers' workload. The remaining small peaks in the graph on the side of the Ground controller may be attributed to normal fluctuations in workload for the controller due to regular variations in traffic operations, as well as added workload associated with the presence of multiple Predator aircraft.

4.3.4.6 Scen13 SME Comments

SME Observers noted that ATC generally will hold, spin, or delay, in any way possible, manned aircraft in order to accommodate a UAS being made first for the runway. The reason for them doing so is not known; however, SME Observers think that it may be because UAS cannot be instructed to follow another aircraft whereas manned aircraft can. SME noted that UAS that required the use of the runways were much more reliant on ATC for sequencing and spacing than manned aircraft pilots. This had the potential to increase controller workload and complexity.

This was especially noted with two Predators operating simultaneously in the Runway 21 traffic pattern.

It can be difficult for other aircraft to follow UAS in a traffic pattern while maintaining separation because the flight characteristics and capabilities of the UAS may not be known to manned aircraft pilots. Also, when two Predators are in the pattern they are both totally reliant on ATC for sequencing and spacing behind other aircraft.

These points collectively bring up the question of whose responsibility it is to meet see and avoid requirements when UAS are extended beyond the visual range of a ground observer. Often in times of traffic pattern work, there is no clear definition as to who is complying with see and avoid responsibilities.

From this simulated experience, it appears that, at minimum, the COA for UAS in the same or nearby airspace need to be examined together for possible safety concerns and harmonized/de-conflicted as necessary.

4.3.4.7 Scen13 Findings

Upon examination of the complete set of data collected, the ATC operation simulated in this scenario does not appear to be feasible with regard to the safe and efficient flow of air traffic.

4.3.5 Scenario 14

In line with the overall study objectives, the goal of Scenario 14 was to examine the effects of simultaneous multiple UAS platforms with dissimilar flight characteristics on local traffic pattern operations, ATC operations, and Class D airspace.

The scenario also included off-nominal events.

4.3.5.1 Scen14 Design

Scenario 14 was developed with the following characteristics:

Airport and Weather Conditions: Simulation start-time was mid-afternoon, and Visual Flight Rules (VFR) prevailed throughout the scenario. Winds were 210° at 9kts. The active runways were 21 and 17.

Manned Aircraft: Seventeen manned aircraft were included to simulate normal traffic flows at the airport. Operations included both military and civilian departures, arrivals, over-flights, and local pattern work. Four additional VFR (1200 code) targets were introduced to simulate over-flight traffic above and/or adjacent to the Class D airspace, and did not communicate with ATC.

Special Military Operations: In addition to other manned military flights, an additional C17 Globemaster II (Slam 88), was added to simulate specialized military tactical maneuvers practiced by USAF crews at KVCV and similar airports.

Ground Vehicles: Two ground vehicles were added to the scenario to replicate vehicular traffic at a typical airport. The vehicles simulated routine airfield maintenance and runway sweeping operations, and communicated with ATC on the GC frequency.

Unmanned Aircraft Systems: Three UAS were included in this scenario: the AS800 JPL Blimp, RQ-11 Raven, and the A-160 Hummingbird. The approved operating area for the A-160 was 2-3 miles north of Runway 21 and east of the extended centerline of Runway 17, surface to 5,000' MSL. The approved operating area of the AS800 JPL Blimp was north of Runway 21 and west of Runway 17, at or below 700' AGL. The approved operating area for the RQ-11 Raven was southeast of Runway 21 over the old housing area, at or below 400' AGL.

Off Nominal Event(s): Secondary to the multiple UAS traffic pattern operations, Scenario 14 examined the effects of the AS800 JPL Blimp as it experienced a spill-out. The JPL Blimp was airborne throughout the entire scenario and by design, the spill-out was simulated as a pilot error. This resulted in the JPL blimp exiting the confines of the normal operations area. The blimp continued to fly across Runway 17 before it corrected back into its delegated airspace. As scripted, the JPL operators were instructed not to inform ATC of the event until the aircraft initiated its correction maneuver back into its normal operations airspace.

4.3.5.2 Scen14 Safety

The ATC operations presented in this scenario were evaluated with regard to the safety and efficiency of the flow of traffic. Several notable observations are described in this section.

As rated on a 7-point scale in the PRQ, with a "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High," both participants appeared to be extremely confident in the safety of operations for this scenario. Both Local and Ground controllers rated their confidence levels as 7. Although the participants believed the operation to be safe, data and post analysis observations indicated some safety concerns.

In accordance with FAA VFR flight rules, FAA policies on Class D airspace management and the provisions of the COA, the UAS operating areas within the Class D airspace are not "sterilized" areas where other aircraft are prohibited from flying. Following FAA JO7110.65, ATC allowed manned aircraft to fly through the active UAS operating areas. In this scenario for example, Runway 17 manned aircraft departures routinely flew through the JPL operational area which in the opinion of the SME Observers created potential risk to safety. In this scenario, N44EL, which was in a left closed traffic pattern for Runway 21, was observed flying through the Raven operational area on a continual basis. In accordance with FAA JO7110.65T, ATC should issue traffic advisories to all aircraft involved when in their judgment proximity warrants it. In this scenario, traffic advisories were not issued to manned or unmanned aircraft when in the judgment of SME observers they should have been.

From an operational perspective, there are several types of incidents that adversely affect the safe, orderly and expeditious movement of air traffic. These include MAC, other ACC, NMAC, OE, OD, RI, and PD. Concerning some of these measures, it is important to note that focus of this study was to examine the potential effects of UAS operations on Class D airspace. By design, the simulation pilots, both manned and unmanned, were confederates in this simulation (i.e., not the direct subjects of study). Therefore, any occurrences of pilot-induced incidents (e.g.,

PD, RI or NMAC caused by pilot error or actions) are considered part of the realistic, complex situations presented to the controller participants and not reported as deficiencies or safety related findings for the purposes of this evaluation.

Information concerning the study's incident safety measures are summarized in Table 80, with reported incident details provided in Table 81. In this 45-minute scenario, there were two OE where ATC did not comply with the proper intersecting runway standards as prescribed in FAO JO7110.65, Sections 3-9-8.

Table 80: Scen14 Safety Metrics

Metric:	MAC	Other Accidents	NMAC	OE	OD	RI
Number of Incidents	0	0	0	2	0	0

Table 81: Scen14 Incident Table

Incident Type	Aircraft #1	Aircraft #2	Incident Description
OE	N739HZ	N744PA	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section 3-9-8
OE	RYN5	N44EL	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section 3-9-8

4.3.5.3 Scen14 Efficiency

Several metrics were captured to evaluate the efficiency of the operation simulated. These included go-arounds, delays, traffic pattern modifications, re-sequencing, etc. In the 45-minute operation, three aircraft delays and three traffic pattern modifications were observed. Table 82 captures the observed efficiency metrics for this scenario.

Table 82: Scen14 Efficiency Metrics

Go-Arounds	
ATC Initiated Go-Arounds	0
Pilot Initiated Go-Arounds	0
Total	0
Delays	
Manned A/C Departure Delays	2
Manned Aircraft Arrival Delays	1
Unmanned A/C Departure Delays	0
Unmanned A/C Arrival Delays	0
Total	3
Traffic Pattern Modifications	
Extended Down-Winds	2
360° Turns	1
ATC Initiated Runway Changes	0
ATC Requested Short Approaches	0
ATC Requested Early Departure Turns	0
ATC Assigned Straight-Out/Runway Headings	0
Total	3
Miscellaneous Efficiency Measures	
Class D Airspace Denials	0
Re-Sequenced Arrivals	0
Re-Sequenced Departures	0
Altered and/or Cancelled Manned A/C Requests	0
Altered and/or Cancelled Unmanned A/C Requests	0
Total	0

The efficiency of the operation for this scenario appears to be affected by the presence of two UAS in the traffic pattern. On a 7 point scale, with a "1" corresponding to "Not at All" and "7" corresponding to "A Great Deal," the Local controller reported that the UAS had a moderate effect on his ability to accommodate manned aircraft (rated as 3). This controller also noted that the UAS required significant additional attention as compared to manned aircraft (rated a 5). The Ground controller reported that the UAS had a moderate effect on the traffic pattern (rated a 4 on the same scale).

SME observations during this scenario reported that Omega 70 received an excessive ground delay waiting to depart Runway 17. According to conjecture based on post-run SME analysis, ATC merely forgot about Omega 70 waiting to depart at the far end of Runway 17 which is not easily visible from the tower cab.

4.3.5.4 Scen14 Communication

Voice communication is a key element of ATC. Many different communication anomalies can be indicative of traffic saturation and ATC loss of situation awareness. These types of occurrences include transposed call signs, missed transmissions, misidentified aircraft, and repeat ATC instructions.

During this scenario, the SME Observers reported that in some instances, the controllers used nonstandard phraseology in situations involving the UAS. They also noted that it was necessary for ATC to do so, demonstrating and suggesting the need to examine standards for UAS-specific phraseology. As an example, once ATC realized that JPL had exited its operational area, they had a difficult time describing the problem on frequency. This is directly attributed to a lack of standard phraseology and clearly demonstrates the need for such. For example, ATC called JPL's ops area the "runway safety zone" when trying to describe the situation to N44EL.

4.3.5.5 Scen14 Workload and Situation Awareness

In addition to the observations noted in the safety, efficiency, and communications section, other measures of workload and situation awareness were captured via the system recordings, PRQ, and WAK. Table 83 summarizes the traffic count data for this scenario.

Table 83: Scen14 Traffic Count

	Arrivals	Departures	Touch and Go's/ Low Approaches	Overflights
Count:	17	18	13	7

After each run, participants and SME Observers were asked to provide subjective ratings about their assessment of workload and situation awareness by marking ratings on a Likert scale of 1-7, where the "1" corresponds to "Extremely Low" and the "7" corresponds to "Extremely High."

As seen depicted in Table 84, the Local controller rated his overall complexity and workload as average. The Local SME Observer also rated the controller's overall complexity as average, but rated his overall workload as just below average. The Ground controller rated his overall complexity and workload as just below average and the SME Observer observing him rated his overall workload and complexity as average.

Post run, SME's observed the JPL Blimp clearly cross Runway 17 and Runway 21 before ATC recognized that it was no longer within its operational area. This was indicative of the "spill-out" that is described in the scenario design. SME's could not attribute ATC's lack of attention to any noticeable distraction or complex traffic situation and surmised that it was attributed to a lack of situation awareness. In contrast, neither the Local nor Ground controller reported losing situation awareness. Also, they rated the degree to which the Blimp "spill-out" affected the manageability of the overall operations as minimal to not at all. The "spill-out" also did not appear to have an effect on the controller's workload.

Table 84: Scen14 Ratings of Overall Workload and Complexity

		Position			
		Local Controller	Local SME Observer	Ground Controller	Ground SME Observer
Metric:	Overall Complexity	4	4	3	4
	Overall Workload	4	3	3	4

Factors such as mental demand, effort, and the degree to which UAS required attention are some of the contributing factors to overall workload and complexity. Table 85 captures the PRQ responses pertaining to these factors.

On the scale with "1" equal to "Very Poor" and "7" corresponding to "Very Good", both controllers rated their performance for this scenario as very good.

On a scale with "1" equal to "Extremely Low" and "7" corresponding to "Extremely High", the Local controller rated his frustration level as extremely low. He also rated his mental, physical, and temporal demand as very low and his effort as just below average. The Ground controller also had low ratings for these metrics. He rated his physical demand and frustration as extremely low, his mental demand and temporal demand as very low and his effort as average.

On a scale with "1" corresponding to "Not at All" and "7"corresponding to "A Great Deal", the Local controller felt that the UAS had a notable effect on his workload and required a considerable amount of attention. Although the Ground controller noted that he performed duties outside of his role as the Ground controller and assisted the Local controller in observing the JPL operate outside of its area and calling operations for more information, he felt that the UAS did not require any additional attention.

Participants were also asked to provide subjective ratings about the degree to which the REHOST display helped them maintain traffic awareness on the scale where "1" corresponds to "Not at all" and the "7" corresponds to "A great Deal." The Local controller felt that REHOST helped him substantially in maintaining situation awareness whereas the Ground controller, who was not as reliant upon the REHOST to perform his duties, felt that it had a notable effect in helping him.

Table 85: Scen14 PRQ Workload and Situation Awareness

		Position	
		Local Controller	Ground Controller
Metric:	Mental Demand:	2	2
	Physical Demand:	2	1
	Temporal Demand:	2	2
	Performance:	7	7
	Effort:	3	4
	Frustration:	1	1
	Amount of coordination with GC or LCL:	4	3
	Degree to which staffing GC affected workload (LCL Only):	2	N/A
	Assist with UAS operations other than GC (GC Only):	N/A	Yes, Observed JPL out of area, called ops for information.
	If yes to having assisted with any UAS, did the assistance negatively affect your ability to accomplish your primary GC duties (GC Only):	N/A	No
	Degree to which UAS contributed workload:	4	N/A
	Degree to which UAS required additional attention:	5	1
	Degree to which REHOST helped maintain traffic awareness:	5	3

Participants were asked to provide instantaneous workload ratings every two minutes during the run via a WAK located at each workstation. Graphed over time, the responses for this scenario are depicted in Figure 18.

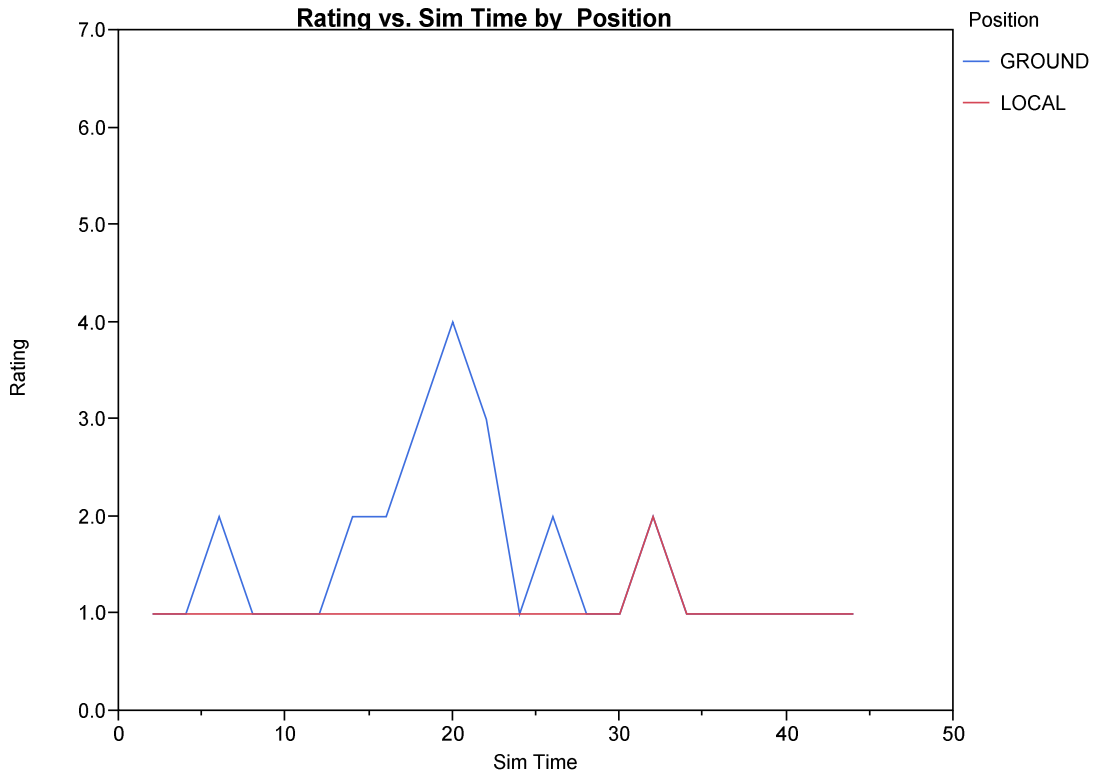

Figure 18: Scen14 WAK Data

In line with the questionnaire data, the controllers' self-reported workload throughout this scenario was lower than average. The multiple small peaks in the graph on the side of the ground controller may be attributed to normal fluctuations in workload for the controller due to regular variations in traffic operations. The large peak, however, coincides in time to the occurrence of the JPL Spill Out during this scenario. The Spill Out occurred at approximately 11 minutes and ended when the aircraft returned to its operational area at approximately 16 minutes. As discussed previously, ATC had difficulty communicating the Spill Out over frequency due to the lack of standard phraseology. This peak in the graph suggests that this difficulty, coupled with the procedures associated with handling the Spill Out, may have increased the controller's workload.

4.3.5.6 Scen14 SME Observations

In addition to collecting the data discussed above, the SME analysis team made supplementary observations during their post-study analysis. These observations capture events, occurrences, and their effects on the scenario which were not recorded elsewhere.

In this scenario, no additional SME observations were captured.

4.3.5.7 Scen14 Findings

Upon examination of the complete set of data collected, the ATC operation simulated in this scenario does not appear to be feasible with regard to the safe and efficient flow of air traffic.

4.3.6 Scenario 15

In line with the overall study objectives, the goal of Scenario 15 was to examine the effects of simultaneous multiple UAS platforms with dissimilar flight characteristics on local traffic pattern operations and Class D airspace. This scenario also included a (scripted) off-nominal event.

4.3.6.1 Scen15 Design

Scenario 15 was developed with the following characteristics:

Airport and Weather Conditions: Simulation start-time was mid-afternoon and VFR prevailed throughout the scenario. Winds were 210° at 9kts. The active runways were 21 and 17.

Manned Aircraft: Seventeen manned aircraft were introduced at random intervals to simulate normal traffic flows at the airport. Operations included both military and civilian departures, arrivals, over-flights, and local pattern work. Four additional VFR (1200 code) targets were injected to simulate over-flight traffic above and/or adjacent to the Class D airspace. These targets did not communicate with ATC.

Special Military Operations: In addition to other manned military flights, an additional C17 Globemaster II (Slam 88) was added to simulate specialized military tactical maneuvers practiced by USAF crews at KVCV and similar airports.

Ground Vehicles: Two ground vehicles were added to the scenario to replicate vehicular traffic at a typical airport. The vehicles simulated routine airfield maintenance and sweeping operations and communicated with ATC on the GC frequency.

Unmanned Aircraft Systems: Two UAS were included in this scenario — the A-160 Hummingbird and the MQ-1B Predator.

Off Nominal Event(s): Secondary to the simultaneous multiple UAS traffic pattern operations, Scenario 15 also examined the effects of a UAS lost link event. The MQ-1B Predator experienced a (scripted) loss of its control and communication link while in the Runway 21 traffic pattern. By design, ATC was immediately notified of the lost link by the Predator flight crew. As required by the current COA, the aircraft complied with the operator's standard lost link procedure, which was to climb to 5500' MSL and proceed to a holding area/orbit point northeast of the runways. Furthermore, at the time of the Predator lost link, the A-160 Hummingbird was operational within its defined operating area northeast of the airport. Due to the fact that the MQ-1B's lost link procedure conflicted with the standard operations area for the A-160, a potential conflict situation was created between the two aircraft.

4.3.6.2 Scen15 Safety

The ATC operations presented in this scenario were evaluated with regard to the safety and efficiency of the flow of traffic. Several notable observations are described in this section.

Rated on a 7-point scale in the PRQ, with "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High," the Ground air traffic controller appeared to be highly confident in the safety of operations (rated 7). The Local controller reported his confidence in safety as average for this scenario (rated 4). The Local controller also reported that he provided an extra margin of spacing for the UAS and treated the UAS differently than manned aircraft.

Though the participants reported average to high confidence in the overall safety of this operation, the data and post-analysis observations appear to suggest some safety concerns.

In this scenario, the MQ-1B Predator (Grizzly 21) experienced a lost link event which conflicted with the A-160's (Mariner 1) area of operations. Grizzly 21 executed its lost link mission, climbed to 5000 ft. MSL and continued toward its holding area/orbit point. In order to de-conflict the two UAS, ATC forced Mariner 1 to land and end its flight. Today, manned aircraft pilots are able to separate themselves visually under VFR rules whereas for UAS this is not possible. As such, ATC SME analysis noted that requiring the A-160 to land would likely not have been necessary had either aircraft been manned. This is one very important air traffic example of why UAS cannot be treated the same as any manned flight unconditionally. From a safety perspective, the SME Observers also noted a lack of wake turbulence separation between DOJ703 and N744PA.

From an operational perspective, there are several types of incidents that adversely affect the safe, orderly, and expeditious movement of air traffic. These include MAC as well as other ACC, NMAC, OE, OD, RI, and PD. Concerning some of these measures, it is important to note that the focus of this study was to examine the potential effects of UAS operations on Class D airspace. By design, the simulation pilots, both manned and unmanned, were not the direct subject of study in this simulation. Therefore, any occurrences of pilot-induced incidents (e.g., PD, RI, or NMAC caused by pilot error or actions) are considered part of the realistic, complex situations presented to the controller participants and not reported as deficiencies or safety-related findings for the purposes of this evaluation.

Information concerning the study's incident safety measures is summarized in Table 86, with reported incident details provided in Table 87. In this 45-minute scenario, ATC did not comply with the proper intersecting runway standards as prescribed in FAO JO7110.65, Sections 3-9-8 and 3-10-4, Intersecting Runway Separation, resulting in the two OE depicted in Table 86 and Table 87.

Table 86: Scen15 Safety Metrics

Metric:	MAC	Other Accidents	NMAC	OE	OD	RI
Number of Incidents	0	0	0	2	0	0

Table 87: Scen15 Incident Table

Incident Type	Aircraft #1	Aircraft #2	Incident Description
OE	R50095	N744PA	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section 3-9-8 and 3-10-4
OE	DOJ703	N744PA	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section 3-9-8 and 3-10-4

4.3.6.3 Scen15 Efficiency

Several metrics were captured to evaluate the efficiency of the operation simulated. Table 88 captures the observed occurrences of the efficiency metrics for this scenario. In the 45-minute scenario, there were five aircraft delays and three traffic pattern modifications observed. In addition, there were two incidents of manned aircraft and two incidents of UA having altered and/or cancelled requests that were due to the presence of UAS in the scenario.

Table 88: Scen15 Efficiency Metrics

Go-Arounds	
ATC Initiated Go-Arounds	0
Pilot Initiated Go-Arounds	0
Total	0
Delays	
Manned A/C Departure Delays	2
Manned Aircraft Arrival Delays	0
Unmanned A/C Departure Delays	2
Unmanned A/C Arrival Delays	1
Total	5
Traffic Pattern Modifications	
Extended Down-Winds	1
360° Turns	1
ATC Initiated Runway Changes	1
ATC Requested Short Approaches	0
ATC Requested Early Departure Turns	0
ATC Assigned Straight-Out/Runway Headings	0
Total	3
Miscellaneous Efficiency Measures	
Class D Airspace Denials	0
Re-Sequenced Arrivals	0
Re-Sequenced Departures	0
Altered and/or Cancelled Manned A/C Requests	2
Altered and/or Cancelled Unmanned A/C Requests	2
Total	4

The efficiency of the operation for this scenario appeared to be directly affected by the presence of UAS in the traffic pattern. For example, during this scenario, Grizzly 21 was moved to the High Key loiter point to hold. The air traffic controllers indicated this was done to segregate the UAS from needing to sequence behind two manned aircraft (N744PA and N44EL) in the traffic pattern to RWY21. This segregation maneuver precluded ATC from requiring the UAS to visually follow manned aircraft on final approach, as that maneuver is currently not feasible with UAS. It also resulted in an arrival delay for Grizzly 21. Analysis of the data indicates that the presence of the UAS in the traffic pattern caused most of the departure delays and traffic modifications in this scenario.

The Local controller's PRQ responses also substantiated that the UAS had a notable effect on the efficiency of operations. On a 7-point Likert scale, with "1" corresponding to "not at all" and "7" corresponding to "a great deal," the Local controller reported that the UAS greatly affected the traffic pattern, sequence, and capacity (all rated 7). On the same scale, the Local controller also reported that the UAS substantially impacted his ability to accommodate manned aircraft (rated a

6). Similarly, the Local controller reported that UAS operations adversely affected the efficiency of manned aircraft operations (rated a 6). The Local controller also reported having provided priority handling to the UAS a great deal (rated a 7). It should also be noted that the Local controller reported having employed the use of extended patterns in this scenario.

Since the Ground controller had very limited interaction with the UAS in this scenario, his efficiency ratings on the same topics were overall consistently neutral.

4.3.6.4 Scen15 Communication

Voice communication is a key element of ATC. Many different communication anomalies can be indicative of traffic saturation and ATC loss of situation awareness. These types of occurrences include transposed call signs, missed transmissions, misidentified aircraft, and repeat ATC instructions. In this scenario, there was one instance of a transposed instruction (call sign), one missed transmission, and one misidentified aircraft. (Note: simulation pilot communication errors are not reported since they were not the subject of study.)

During this scenario, the SME Observers reported that in some instances, the air traffic controllers used nonstandard phraseology in situations involving the UAS. SME Observers also noted that it was necessary for ATC to do so, demonstrating and suggesting the need to examine standards for UAS-specific ATC phraseology.

4.3.6.5 Scen15 Workload and Situation Awareness

In addition to the observations noted in the safety, efficiency, and communications section, other measures of workload and situation awareness were captured via the system recordings, PRQ, and WAK. Table 89 summarizes the traffic counts for this scenario.

Table 89: Scen15 Traffic Count

	Arrivals	Departures	Touch and Go's/ Low Approaches	Overflights
Count	22	23	18	4

After each run, the participants and SME Observers were asked to provide subjective ratings about their assessment of workload and situation awareness by marking ratings on a Likert scale, with ratings going from 1-7, where “1” corresponds to “Extremely Low” and “7” corresponds to “Extremely High.”

The Local controller and Local SME Observer indicated average to just above average ratings for overall workload and complexity. Both the Ground controller and Ground SME Observer reported below average ratings for these metrics. Table 90 captures the responses.

Table 90: Scen15 Ratings of Overall Workload and Complexity

		Position			
		Local Controller	Local Control SME Observer	Ground Controller	Ground Control SME Observer
Metric:	Overall Complexity	5	5	2	2
	Overall Workload	5	4	3	2

Factors such as mental demand, effort, and the degree to which UAS required attention are some of the contributing factors to overall workload and complexity. Table 91 captures the PRQ responses pertaining to these factors.

On a scale with “1” equal to “Very Poor” and “7” corresponding to “Very Good,” the Local and Ground controllers self-rated their performance for this scenario above average and very good (rated 5 and 7, respectively).

For this scenario, the Local controller rated several of the contributing factors on the high end of the scale. Specifically, the Local controller's ratings indicate that the UAS required a great deal of additional attention as compared to manned aircraft (rated 7 on a Likert scale, with “1” equal to “not at all” and “7” corresponding to “a great deal”). On the same scale, the Local controller indicated that airborne UAS operations contributed a great deal to his workload, which in turn likely contributed to above average ratings for temporal and mental demand (both rated as 5 on a Likert scale, with “1” equal to “Extremely Low” and “7” corresponding to “Extremely High”).

The Ground controller rated most of the contributing factors well below average, which is consistent with the fact that he had limited direct exposure with the UAS in this scenario. He indicated that in his role, the UAS did not contribute to his workload at all and required no additional attention as compared to manned aircraft.

The participants were also asked to provide subjective ratings concerning the degree to which the REHOST display helped them maintain traffic awareness. On the scale where “1” corresponds to “not at all” and “7” corresponds to “a great deal,” both the Local and Ground controller indicated a high situation awareness benefit from the system (rated 6 and 5, respectively).

Table 91: Scen15 PRQ Workload and Situation Awareness

		Position	
		Local Controller	Ground Controller
Metric:	Mental Demand:	5	3
	Physical Demand:	2	1
	Temporal Demand:	5	2
	Performance:	5	7
	Effort:	3	2
	Frustration:	3	1
	Amount of coordination with GC or LCL:	2	4
	Degree to which staffing GC affected workload (LCL Only):	2	N/A
	Assist with UAS operations other than GC (GC Only):	N/A	No
	If yes to having assisted with any UAS, did the assistance negatively affect your ability to accomplish your primary GC duties (GC Only):	N/A	N/A
	Degree to which UAS contributed workload:	7	1
	Degree to which UAS required additional attention:	7	1
	Degree to which REHOST helped maintain traffic awareness:	6	5

In questions specific to this scenario, it appears that for the Local controller, Grizzly 21's lost link event not only affected the overall manageability of operations, but also specifically affected the Mariner and other manned aircraft operations a great deal. Specifically, rated on a scale with "1" corresponding to "not at all" and "7" corresponding to "a great deal," these observations were rated as 6, 7, and 6, respectively, by the Local controller. The Local controller also reported that being aware of Grizzly 21's planned lost link procedure ahead of time (i.e., there was a predictability factor) greatly affected his ability to handle the situation.

The Ground controller reported that the effect the lost link event had on the manageability of operations was average (rated 4). It also appears that for Ground control, the lost link event had little effect on other manned aircraft operations (rated 2). However, the Ground controller reported that the lost link event did affect the Mariner 1 operations a great deal (rated 7). Similar to the Local controller, the Ground controller reported that his knowledge of the planned lost link procedure ahead of time positively affected his ability to handle the situation (rated a 7).

Furthermore, participants were asked to provide instantaneous workload ratings every two minutes during the run via a WAK located at each workstation. Graphed over time, the responses for this scenario are depicted in Figure 19.

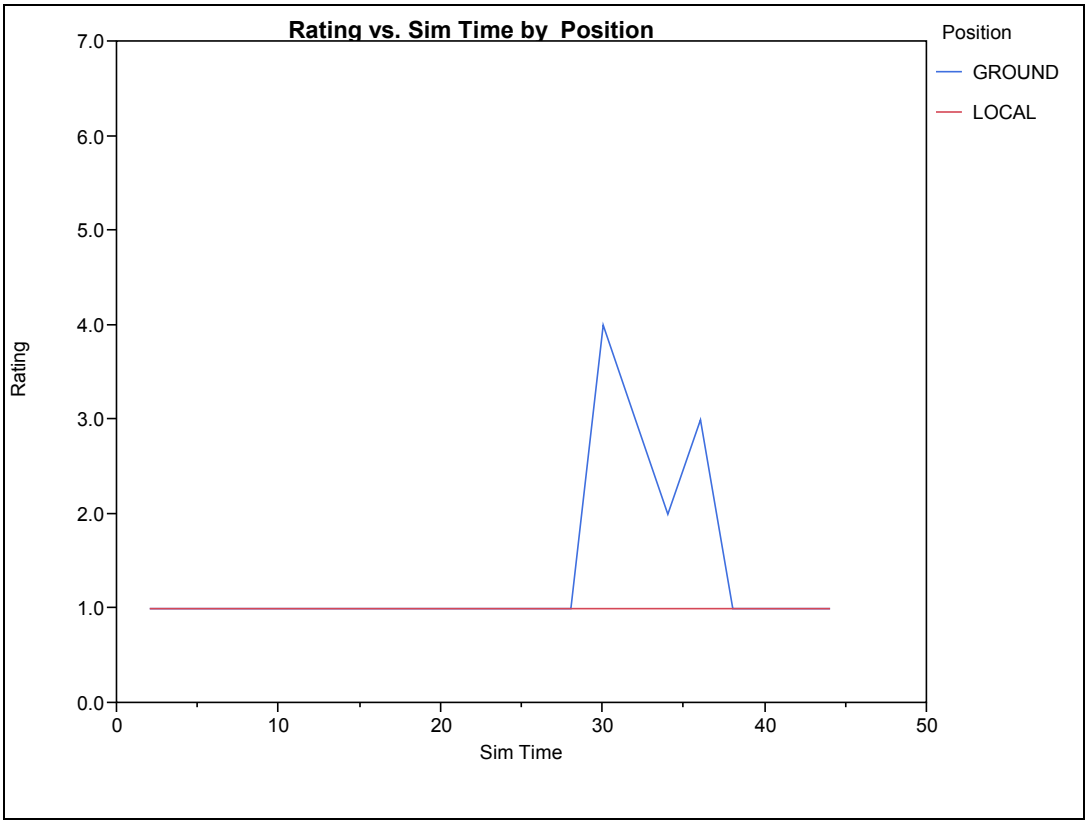

Figure 19: Scen15 WAK Data

As depicted in the graph, the Local controller consistently reported his instantaneous workload at the very low end of the scale throughout the scenario. The Ground controller's workload was reportedly more variable, though still at the low end of the scale. Peak ratings of average and slightly below average are noted around the 30th and 37th minutes. These elevated ratings could be attributed to the Grizzly 21's lost link event, which began approximately 26 minutes into the scenario. However, it should be noted that the Ground controller had very little interaction with the UAS in this scenario, so his ratings may be more of a depiction of what was happening overall in the tower cab. Furthermore, the low ratings from both air traffic controllers do not, in general, coincide well with what they reported in their PRQ after the scenario's conclusion, or with what was observed through post-simulation analysis by the SME Observers and research team.

4.3.6.6 Scen15 SME Observations

In addition to collecting the data discussed above, the SME analysis team made supplementary observations during their post-study analysis. These observations capture events, occurrences, and their effects on the scenario which were not recorded elsewhere.

In this scenario, to accommodate sequencing of all aircraft to Runway 21, ATC instructed Grizzly 21 to hold at the High Key loiter point. The participants explained that this is done in order to segregate the UAS from manned aircraft in the traffic pattern. No chase plane was present; therefore, ground observers would be used to comply with the COA. The SME Observers believed it reasonable to conclude that High Key, three to four miles northeast of Runway 21, is beyond the visual range of the visual observer(s). This raises the issue of where the responsibility for see-and-avoid lies for the UAS while in orbit at High Key.

As previously mentioned, Grizzly 21 incurred a lost link event while Mariner 1 was operating in its designated area. The A-160 operating area inherently conflicts with Grizzly 21's lost link mission. This raises a major concern for multiple UAS operating in the same airspace. In the observed case, to maintain safety, ATC instructed Mariner to land due to the fact that Grizzly 21 could no longer comply with visual see-and-avoid requirements while in a lost link configuration. From this simulated experience, it appears that at minimum, the COAs for UAS in the same or nearby airspace need to be examined together for possible safety concerns and harmonized/de-conflicted, as necessary. In a more extreme, but distinctly possible case, loss of link for both aircraft could simultaneously occur during simultaneous UAS operations. In this arguably rare case, to mitigate the risk of collision of two (or more) UAS in lost link status, each lost link procedure would need to be preemptively de-conflicted from all others at all times, under every possible dynamic configuration of their flights in the area, whether by standardization of lost link procedures or other acceptable mitigation means. Considering the current airspace operational environment and the current capabilities of UAS, this will be challenging to achieve in an overlapping, dynamic flight environment.

As such, concerning the observed operations in this scenario, the SME Observers maintain that, in the current day Class D environment, UAS operating areas and basic procedures need to be de-conflicted and segregated from each other — from manned aircraft operations and from standard traffic patterns.

SME noted that UAS which required the use of the runways were much more reliant on ATC for sequencing and spacing than manned aircraft pilots. This had the potential to increase controller workload and complexity.

4.3.6.7 Scen15 Findings

Upon examination of the complete set of data collected, the ATC operation simulated in this scenario does not appear to be feasible with regard to the safe and efficient flow of air traffic.

4.3.7 Scenario 16

In line with the overall study objectives, the goal of Scenario 16 was to examine the effects of simultaneous multiple UAS platforms with dissimilar flight characteristics on local traffic pattern operations, ATC operations, and Class D airspace. The scenario also included off-nominal events.

4.3.7.1 Scen16 Design

Scenario 16 was developed with the following characteristics:

Airport and Weather Conditions: Simulation start-time was mid-afternoon, and Visual Flight Rules (VFR) prevailed throughout the scenario. Winds were 210° at 9kts. The active runways were 21 and 17.

Manned Aircraft: Seventeen manned aircraft were included to simulate normal traffic flows at the airport. Operations included both military and civilian departures, arrivals, over-flights, and local pattern work. Four additional VFR (1200 code) targets were introduced to simulate over-flight traffic above and/or adjacent to the Class D airspace, and did not communicate with ATC.

Special Military Operations: In addition to other manned military flights, an additional C17 Globemaster II (Slam 88), was added to simulate specialized military tactical maneuvers practiced by USAF crews at KVCV and similar airports.

Ground Vehicles: Two ground vehicles were added to the scenario to replicate vehicular traffic at a typical airport. The vehicles simulated routine airfield maintenance and runway sweeping operations, and communicated with ATC on the GC frequency.

Unmanned Aircraft Systems: Two UAS were included in this scenario; the A-160 Hummingbird, and the MQ-1B Predator. The approved operating area for the A-160 was 2-3 miles north of Runway 21 and east of the extended centerline of Runway 17, surface to 5,000' MSL. The approved operating area for the MQ-1B Predator was Class D airspace including traffic patterns to both runways.

Off Nominal Event(s): Secondary to the simultaneous multiple UAS operations, Scenario 16 also examined the effects of an A-160 scripted Lost Link procedure at approximately 30 minutes into the scenario and proceeded directly to the Warrior Ramp. As per scenario scripting, ATC was immediately notified of the lost link and was informed of the aircraft's intent. Concurrently, the remaining UAS (MQ-1B Predator) was operating in the runway 21 touch & go pattern.

4.3.7.2 Scen16 Safety

The ATC operations presented in this scenario were evaluated with regards to the safety and efficiency of the flow of traffic. Several notable observations are described in this section.

Approximately 19 minutes into the scenario, SMEs determined that the operation presented in this scenario had reached a point in which the safety and efficiency of the flow of traffic was compromised.

As rated on a 7-point scale in the PRQ, with a "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High," both participants appeared to be confident in the safety of operations for this scenario. The Local and Ground controllers rated their confidence levels as 5 and 7 respectively. Although the participants believed the operation to be safe, data and post analysis observations indicated there were some safety concerns.

The Local controller did not self-report a loss of "situation awareness"; however, it was determined through post-study analysis that the controller had appeared to lose situation awareness, causing an unnecessary spike in workload. A major contributing factor was the assumed lost link of the Predator A. The Predator A made a 360 degree turn in the traffic pattern without warning, when this occurred ATC did not contact the Predator pilot before assuming that the Predator A had gone lost link. In response, the Local controller attempted to sterilize the Class D airspace by removing one manned aircraft (N744PA) and attempting to remove another manned aircraft (N44EL) from the Class D airspace. These actions led to an OE between DOJ703 and N44EL.

From an operational perspective, there are several types of incidents that adversely affect the safe, orderly and expeditious movement of air traffic. These include MAC, other ACC, NMAC, OE, OD, RI, and PD. Concerning some of these measures, it is important to note that focus of this study was to examine the potential effects of UAS operations on Class D airspace. By design, the simulation pilots, both manned and unmanned, were confederates in this simulation (i.e., not the direct subjects of study). Therefore, any occurrences of pilot-induced incidents (e.g., PD, RI or NMAC caused by pilot error or actions) are considered part of the realistic, complex situations presented to the controller participants and not reported as deficiencies or safety related findings for the purposes of this evaluation.

Information concerning the study's incident safety measures are summarized in Table 92, with reported incident details provided in Table 93. In the 45-minutes operation, there were five ATC related incidents where ATC did not comply with the proper intersecting runway standards as prescribed in the FAO JO7110.65, resulting in the OE depicted in Table 92 and Table 93.

Table 92: Scen16 Safety Metrics

Metric:	MAC	Other Accidents	NMAC	OE	OD	RI
Number of Incidents	0	0	0	5	0	0

Table 93: Scen16 Incident Table

Incident Type	Aircraft #1	Aircraft #2	Incident Description
OE	DOJ703	N44EL	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section 3-9-8
OE	RYN5	Grizzly 21 *(UAS)*	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section 3-9-8
OE	N744PA	Grizzly 21 *(UAS)*	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section 3-9-8
OE	Grizzly 21 *(UAS)*	Slam 88	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section 3-9-8
OE	Grizzly 21 *(UAS)*	NASA901	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section 3-9-8

Operational errors observed in this scenario can be attributed to the misapplication of anticipated separation on crossing runways. SMEs observed ATC failing to provide traffic and safety advisories to UAS in particular during a situation in which N744PA was instructed to turn north, away from the A-160 Hummingbird. In response N744PA turned south, directly into the path of the A-160 Hummingbird, causing a safety alert situation. It is the responsibility of ATC to provide advisories to UAS as well as other aircraft; therefore, they should not rely solely on manned aircraft to maneuver when a UAS is involved.

4.3.7.3 Scen16 Efficiency

Several metrics were captured to evaluate the efficiency of the operation simulated. Table 94 captures the observed occurrences of the efficiency metrics for this scenario. In the 45-minute operation, six aircraft delays and nine traffic pattern modifications were observed. In addition, there was one Class D clearance denial and one re-sequenced arrival of N744PA to Runway 17.

There was also one altered manned aircraft request. Table 94 captures the observed efficiency metrics for this scenario.

Table 94: Scen16 Efficiency Metrics

Go-Arounds	
ATC Initiated Go-Arounds	1
Pilot Initiated Go-Arounds	1
Total	2
Delays	
Manned A/C Departure Delays	2
Manned Aircraft Arrival Delays	2
Unmanned A/C Departure Delays	1
Unmanned A/C Arrival Delays	1
Total	6
Traffic Pattern Modifications	
Extended Down-Winds	4
360° Turns	3
ATC Initiated Runway Changes	0
ATC Requested Short Approaches	0
ATC Requested Early Departure Turns	1
ATC Assigned Straight-Out/Runway Headings	1
Total	9
Miscellaneous Efficiency Measures	
Class D Airspace Denials	1
Re-Sequenced Arrivals	1
Re-Sequenced Departures	0
Altered and/or Cancelled Manned A/C Requests	1
Altered and/or Cancelled Unmanned A/C Requests	0
Total	3

The efficiency of the operation for this scenario appeared to be directly affected by the presence of two UAS in the traffic pattern. There were 20 total efficiency-related events.

On a 7 point scale, with a "1" corresponding to "Not at All" and "7" corresponding to "A Great Deal," the Local controller reported that the UAS had a notable effect on the traffic pattern, sequence, and capacity (all rated 3). The Ground controller, however, in his role which had limited to no interaction with the UAS, reported that the UAS had no effect at all on manned aircraft ground operations, the traffic pattern, sequence, or capacity (all rated 1).

This scenario also included a planned simulated A-160 lost link. The Local controller stated the A-160 lost link had a moderate effect on the manageability of overall ops (rating of 3 on a 7 point scale where "1" is " Not at All" and "7" is "A Great Deal"), while the Ground controller reported no effect (rating of 1). This moderate effect may be attributed to the Local controller's

understanding of the lost link procedure. The Local controller stated: "If A-160 flies lost link, it remains clear of Runway 17 and Runway 21." The Local controller noted that the A-160 lost link had no effect at all on manned aircraft operations on Runway 17 or on other manned aircraft Class D operations (both rated a 1 on the same 7 point scale mentioned above). SME noted that the ATC participants stated that they had never seen an A-160 Hummingbird experience lost link before and were not sure what to expect when it actually occurred.

4.3.7.4 Scen16 Communication

Voice communication is a key element of air traffic control. Many different communication anomalies can be indicative of traffic saturation and ATC loss of situation awareness. These types include transposed call signs, missed transmissions, misidentified aircraft, and repeat ATC instructions.

In this scenario, the SME analysis team observed one excessive instruction, three missed transmissions, and one repeat transmission. All of these instances occurred on the Local control frequency and there were no observed communication anomalies on Ground control. (Note: simulation pilot communication errors are not reported since they were not the subjects of study.)

In post study analysis, SME also observed that use of standard phraseology, as prescribed in the FAO JO7110.65, was not always adhered to. It appeared that as traffic increased, approximately 19 minutes into the scenario, the use of prescribed ATC phraseology decreased.

4.3.7.5 Scen16 Workload and Situation Awareness

In addition to the observations noted in the safety, efficiency, and communication sections, other measures of workload and situation awareness were captured via the system recordings, PRQ and WAK. Table 95 summarizes the traffic counts for this scenario.

Table 95: Scen16 Traffic Count

	Arrivals	Departures	Touch and Go's/ Low Approaches	Overflights
Count	21	18	14	4

After each run, participants and SME Observers were asked to provide subjective ratings about their assessment of workload and situation awareness by marking ratings on a Likert scale of 1-7, where the "1" corresponds to "Extremely Low" and the "7" corresponds to "Extremely High."

The Local controller reported experiencing extremely high workload and complexity (both rated as 7); whereas the Local SME Observer indicated that the Local controller experienced just above average overall complexity and workload (both rated as 5). Ratings given by the Ground

controller were average in respect to overall complexity and just below average for workload (4 and 3 respectively). The Ground SME observer indicated that the Ground controller experienced very low overall complexity and workload (both rated as 2). Table 96 captures the responses.

Table 96: Scen16 Ratings of Overall Workload and Complexity

		Position			
		Local Controller	Local Control SME Observer	Ground Controller	Ground Control SME Observer
Metric:	Overall Complexity	7	5	4	2
	Overall Workload	7	5	3	2

Factors such as mental demand, effort, and the degree in which UAS required attention are some of the contributing factors to overall workload and complexity. Table 97 captures the PRQ responses pertaining to these factors.

On a scale with "1" equal to "Very Poor" and "7" corresponding to "Very Good", the Local controller rated his performance as very good and the Ground controller rated his performance as just above average.

On the scale with "1" equal to "Extremely Low" and "7" corresponding to "Extremely High", the Local controller rated his physical demand as just below average and his temporal demand as very high. He rated his mental demand, effort and frustration as extremely high. The Ground controller rated his mental demand, physical demand, temporal demand, effort and frustration as extremely low for this scenario.

In alignment with his ratings, the Local controller rated the degree in which UAS required additional attention as very high (rated 6) on a scale with "1" equal to "Not at All" and "7" corresponding to "A Great Deal." He also noted that the UAS required a great deal of additional attention. In contrast the Ground controller rated the degree in with the UAS affected his workload and the degree in which the UAS required additional attention as extremely low (rated 1) since he has minimal interaction with the UAS.

Participants were also asked to provide subjective ratings about the degree to which the REHOST display helped them maintain traffic awareness on the scale where "1" corresponds to "Not at all" and the "7" corresponds to "A great deal." The Local controller's situation awareness benefited considerably from the system. The Ground controller indicated that his benefit of using REHOST was minimal.

Table 97: Scen16 PRQ Workload and Situation Awareness

		Position	
		Local Controller	Ground Controller
Metric:	Mental Demand:	7	1
	Physical Demand:	3	1
	Temporal Demand:	6	1
	Performance:	5	7
	Effort:	7	1
	Frustration:	7	1
	Amount of coordination with GC or LCL:	2	4
	Degree to which staffing GC affected workload (LCL Only):	1	N/A
	Assist with UAS operations other than GC (GC Only):	N/A	No
	If yes to having assisted with any UAS, did the assistance negatively affect your ability to accomplish your primary GC duties (GC Only):	N/A	N/A
	Degree to which UAS contributed workload:	6	1
	Degree to which UAS required additional attention:	7	1
	Degree to which REHOST helped maintain traffic awareness:	6	Not Rated

Evidence supporting the Local controller's higher than average rating is the controller's comments that although he did not reach a saturation point, he came very close to reaching it. The SME analysis team determined that the Local controller lost situation awareness when the Predator unexpectedly made a 360 degree turn on downwind. The controller's failure to contact the Predator pilot resulted in unnecessary instruction and an OE as described in the safety section.

Participants were asked to provide instantaneous workload ratings every two minutes during the run via a WAK located at each workstation. Graphed over time the responses for this scenario are depicted in Figure 20.

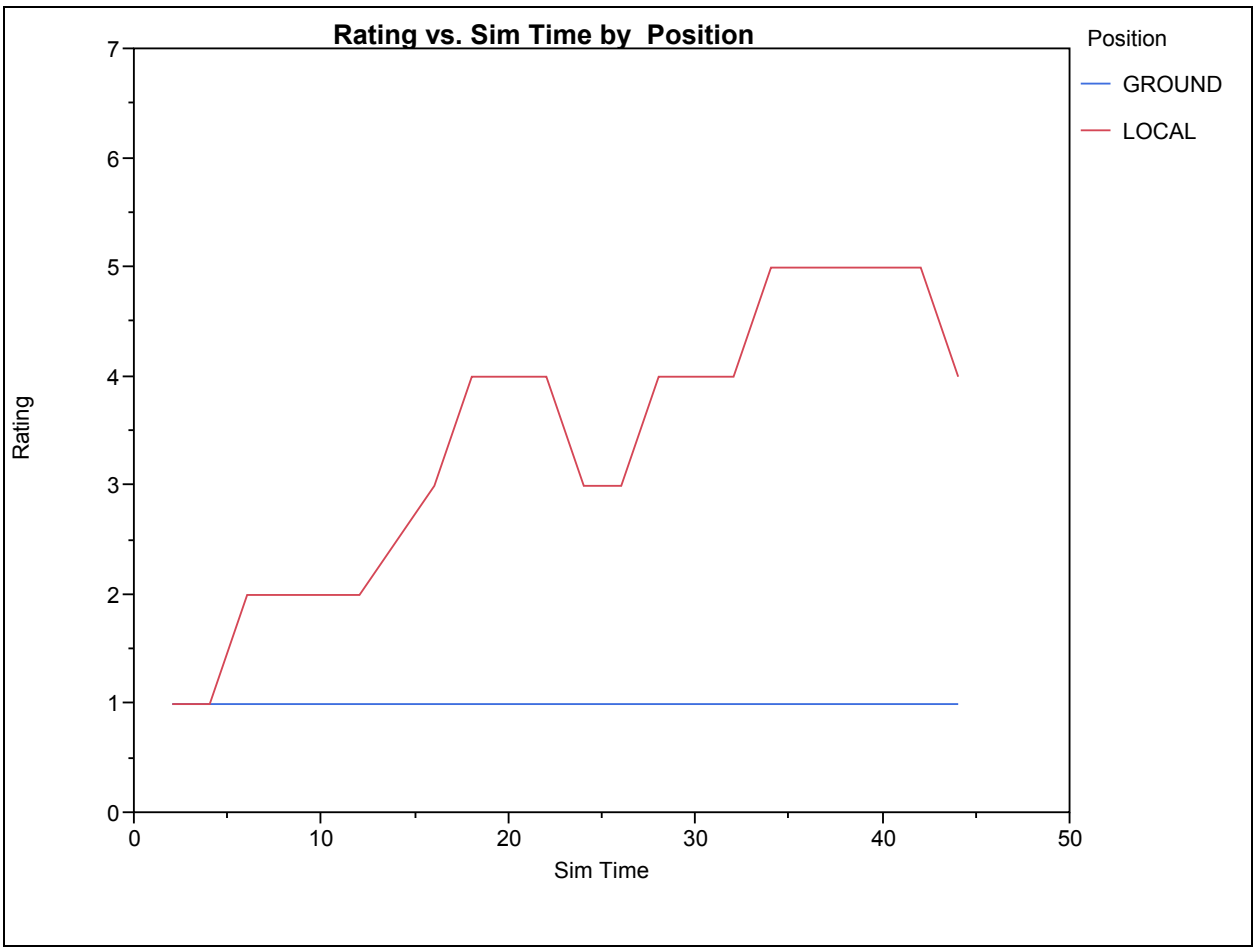

Figure 20: Scen16 WAK Data

In line with questionnaire data, the Local controller's self-reported workload throughout this scenario was rather high, while the Ground controller's self-reported workload throughout was rather low. In addition, these elevated workload ratings by the Local controller also support questionnaire items in which this controller reported elevated mental and temporal demand as well as increased effort and frustration. Although it is clear from the figure that the Local controller's workload was elevated throughout most of the scenario, the final spike in the graph appears to roughly coincide with the occurrence of the A-160 lost link lasting from approximately 31 minutes to 37 minutes, suggesting that this lost link further increased the Local controller's already elevated workload level.

4.3.7.6 Scen16 SME Observations

In addition to collecting the data discussed above, the SME analysis team made supplementary observations during their post study analysis. These observations capture events, occurrences, and their effect on the scenario which were not recorded elsewhere.

SME noted that UAS that required the use of the runways were much more reliant on ATC for sequencing and spacing than manned aircraft pilots. This had the potential to increase controller workload and complexity.

It appeared that ATC had to be cognizant as to what could and could not be done when making decisions involving UAS. In post-study analysis, it was noted by SME that ATC often overcompensated when working with UAS because of a lack of familiarity or training with UAS. Supporting evidence of this is the ATC participants' remarks that "they don't know everything that can go wrong with UAS." SME noted that it appeared as though the controller had difficulty maintaining situation awareness throughout the scenario.

The increased cognitive activity of ATC when dealing with UAS could also be attributed to the fact that VFR tower controllers rely heavily on the pilot's ability to see and avoid, see and follow, and see and make pattern adjustments. When a UAS is present, it changes ATC's decision making process because of the inability of the UAS to comply with ATC instructions by visual means. ATC compensates for this by making all pattern decisions for the UAS pilot when other aircraft are present and sequencing is necessary. This is contrary to the long established procedures set up for Class D operations that rely heavily on the pilot's ability to follow basic VFR. This has the potential to add to controllers' workload and affect the controllers' situation awareness.

4.3.7.7 Scen16 Findings

Upon examination of the complete set of data collected, the ATC operation simulated in this scenario does not appear to be feasible with regard to the safe and efficient flow of air traffic.

4.3.8 Scenario 17

In line with the overall study objectives, the goal of Scenario 17 was to examine the effects of simultaneous multiple UAS platforms with dissimilar flight characteristics on local traffic pattern operations, ATC operations, and Class D airspace. This scenario also included a (scripted) off-nominal event.

4.3.8.1 Scen17 Design

Scenario 17 was developed with the following characteristics:

Airport and Weather Conditions: Simulation start-time was mid-afternoon, and Visual Flight Rules (VFR) prevailed throughout the scenario. Winds were 210° at 9kts. The active runways were 21 and 17.

Manned Aircraft: Seventeen manned aircraft were included to simulate normal traffic flows at the airport. Operations included both military and civilian departures, arrivals, over-flights, and local pattern work. Four additional VFR (1200 code) targets were introduced to simulate over-flight traffic above and/or adjacent to the Class D airspace, and did not communicate with ATC.

Special Military Operations: In addition to other manned military flights, an additional C17 Globemaster II (Slam 88), was added to simulate specialized military tactical maneuvers practiced by USAF crews at KVCV and similar airports.

Ground Vehicles: Two ground vehicles were added to the scenario to replicate vehicular traffic at a typical airport. The vehicles simulated routine airfield maintenance and runway sweeping operations, and communicated with ATC on the GC frequency.

Unmanned Aircraft Systems: Three UAS were included in this scenario; the AS800 JPL Blimp, RQ-11 Raven, and the MQ-1B Predator. The approved operating area of the JPL Blimp was north of Runway 21 and west of Runway 17, at or below 700' AGL. The approved operating area for the Raven was southeast of Runway 21 over the old housing area, at or below 400' AGL. The approved operating area for the MQ-1B Predator was Class D airspace including traffic patterns to both runways. Although not a UAS, the Predator Chase aircraft, a manned Mooney MO20, was included in the scenario to simulate the requirements of the current COA.

Off Nominal Event(s): Secondary to the simultaneous multiple UAS traffic pattern operations, Scenario 17 examined the effects of an airborne runway change request, by the MQ-1B Predator. The Predator initially departed and requested closed traffic for Runway17, and after one touch and go, requested a runway change to Runway21. After several touch and go maneuvers to Runway 21, the Predator joined with its manned chase aircraft (a MO20), and the flights departed the Class D airspace to the north east, en route to the Edwards Airspace Complex.

4.3.8.2 Scen17 Safety

The ATC operations presented in this scenario were evaluated with regards to the safety and efficiency of the flow of traffic. Several notable observations are described in this section.

As rated on a 7-point scale, in the PRQ, with a "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High," both participants appeared to be confident in the safety of operations for this scenario. The Local and Ground controllers rated their confidence levels for a safe operation as 5 and 7 respectively. Although the participants believed the operation to be safe, data and post analysis observations raised some safety concerns.

A safety concern was observed when the Blimp and the Raven UAS were within their own operational areas. ATC generally did not issue them traffic or safety advisories. This demonstrates a lack of proper and uniform application of 7110.65 rules as multiple manned aircraft were observed flying through the active UA operating areas.

The active Raven ops area is located in close proximity to the Runway 21 traffic pattern; therefore any aircraft that execute touch and gos or depart Runway 21 fly in close proximity or through this area. There were several occasions of manned and unmanned aircraft flying through the Raven ops area without ATC issuing any traffic advisories as required by FAAO 7110.65[15] or restrictions. In one instance, SME observers determined the close proximity between the Predator and Raven constituted a NMAC event. Slam 88 was also observed flying through Raven's operational area with no safety or traffic advisory issued[16].

ATC was observed not applying wake turbulence separation standards[17] for a Predator following Slam 88, a heavy C17. SME noted that at present, no specific wake turbulence standards for

[15] See FAAO 7110.65 section 2-1-21.
[16] Ibid.
[17] See FAAO 7110.65 section 2-1-19.

UAS have been tested; only guidelines have been provided for controllers to use the most conservative manned aircraft wake turbulence procedures available. ATC appeared to be unsure of procedures for handling UAS based on SME observing the controller issuing instructions to a Predator UA to visually follow another manned aircraft. ATC did not advise Raven of Slam 88's flight as Slam 88 flew through the Raven UA Operations area, and no wake turbulence advisory[18] was issued. ATC also did not advise Slam 88 of the location of the Raven operations area, or the potential for traffic, before flying through the area.

From an operational perspective, there are several types of incidents that adversely affect the safe, orderly and expeditious movement of air traffic. These include MAC, other ACC, NMAC, OE, OD, RI, and PD. Concerning some of these measures, it is important to note that focus of this study was to examine the potential effects of UAS operations on Class D airspace. By design, the simulation pilots, both manned and unmanned, were confederates in this simulation (i.e., not the direct subjects of study). Therefore, any occurrences of pilot-induced incidents (e.g., PD, RI, or NMAC caused by pilot error or actions) are considered part of the realistic, complex situations presented to the controller participants and not reported as deficiencies or safety related findings for the purposes of this evaluation.

Information concerning the study's incident safety measures are summarized in Table 98, with reported incident details provided in Table 99.

In this 45-minute operation, there were five incidents attributed to ATC including one NMAC. Three of the remaining four incidents were a result of ATC not complying with the proper intersecting runway standards as prescribed in the FAO JO7110.65, resulting in the OE depicted in Table 98 and Table 99. The final incident occurred when ATC did not comply with wake turbulence separation standards as prescribed in the FAO JO7110.65.

Table 98: Scen17 Safety Metrics

Metric:	MAC	Other Accidents	NMAC	OE	OD	RI
Number of Incidents	0	0	1	4	0	0

[18] See FAAO 7110.65 section 2-1-20.

Table 99: Scen17 Incident Table

Incident Type	Aircraft #1	Aircraft #2	Incident Description
NMAC	Grizzly 21 *(UAS)*	RQ11 Raven (UAS)	ATC permitted Grizzly 21 to operate within the confines of the Raven Operations Area
OE	Slam 88	N90PH	Wake turbulence separation for intersection departures was not provided * Reference FAA JO 7110.65 Section 3-9-7
OE	R50095	N44EL	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section 3-9-8
OE	DOJ703	N44EL	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section 3-9-8
OE	Slam 88	N44EL	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section 3-9-8

4.3.8.3 Scen17 Efficiency

Several metrics were captured to evaluate the efficiency of the operation simulated. Table 100 captures the observed occurrences of the efficiency metrics for this scenario. In the 45-minute operation, six a/c delays and 10 traffic pattern modifications were observed. In addition, a manned aircraft request was altered and/or cancelled. Although these measures were observed and recorded throughout the scenario, not all of them can be directly attributed to UAS operations.

Table 100: Scen17 Efficiency Metrics

Go-Arounds	
ATC Initiated Go-Arounds	0
Pilot Initiated Go-Arounds	0
Total	0
Delays	
Manned A/C Departure Delays	2
Manned Aircraft Arrival Delays	2
Unmanned A/C Departure Delays	0
Unmanned A/C Arrival Delays	2
Total	6
Traffic Pattern Modifications	
Extended Down-Winds	1
360° Turns	1
ATC Initiated Runway Changes	0
ATC Requested Short Approaches	0
ATC Requested Early Departure Turns	0
ATC Assigned Straight-Out/Runway Headings	8
Total	10
Miscellaneous Efficiency Measures	
Class D Airspace Denials	0
Re-Sequenced Arrivals	0
Re-Sequenced Departures	0
Altered and/or Cancelled Manned A/C Requests	1
Altered and/or Cancelled Unmanned A/C Requests	0
Total	1

Participant responses on the PRQ indicated that the UAS in general, had some effect on the efficiency of the operations of this scenario. On a 7-point scale, with a "1" corresponding to "Not at All" and "7" corresponding to "A Great Deal", the Local controller rated the effect of the UAS on the sequence or capacity of traffic as 1, indicating that UAS operations did not affect them at all. The Local controller also rated the degree to which UAS affected traffic pattern a 5 as an indication that the UAS had a significant effect. He stated that he had to "Call base leg of the UAS so the traffic pattern was extended". In addition, the Local controller reported that airborne UAS operations had a notable effect on his ability to efficiently accommodate manned aircraft, and the Ground controller reported there was no effect at all (rated as 1). It should also be noted that the Local controller reported having employed the use of extended patterns. He stated, "Patterns are always extended when UAS are in the pattern because you have to call turns to base, which cause delays to all traffic in the pattern." This was reiterated in debrief sessions where controllers several times stated that having UAS in a traffic pattern adds to delays in the system. The need to call pattern turns for the UAS detracts from ATC's attention and delays

other aircraft in the pattern. The sole cause of this is due to there being no pilot on board the aircraft, which equates to no ability for the aircraft to operate in a visual environment. Furthermore, because of the incompatibility of the UAS flight characteristics with manned aircraft, often times delaying tactics such as extended flight legs, 360 degree turns, etc. are necessary, which lead to both manned and unmanned flight delays.

In this scenario, there were several delays due to traffic in the pattern, not just UAS. However one manned a/c departure delay (Omega 70) was caused by UAS. It's departure was delayed at least 15 minutes due to ATC, who diverted attention away from Omega70 while communicating with Grizzly 21 as it was attempting to join up with its chase aircraft. However, the Local controller noted on the PRQ that he did not treat the Predator any differently when there was a chase plane. Furthermore, the Local controller indicated that manned aircraft touch and go operations were not affected by the Predator operations on the same runway. Furthermore, the Predator runway change did not affect the manageability of the overall operations (rated 1).

4.3.8.4 Scen17 Communication

Voice communication is a key element of air traffic control. Many different communication anomalies can be indicative of traffic saturation and ATC loss of situation awareness. These types of occurrences include transposed call signs, missed transmissions, misidentified aircraft, and repeat ATC instructions. In this scenario, there were two missed transmissions by the local controller, and one missed transmission by the ground controller. (Note: simulation pilot communication errors are not reported since they were not the subjects of study.)

During this scenario, the SME Observers reported that in some instances, the controllers used nonstandard phraseology in situations involving the UAS. They also noted that it was necessary for ATC to do so, demonstrating and suggesting the need to examine standards for UAS-specific phraseology. This occurred specifically when the Local controller had a great deal of difficulty describing the area in which the Raven was operating.

4.3.8.5 Scen17 Workload and Situation Awareness

In addition to the observations noted in the safety, efficiency, and communication sections, other measures of workload and situation awareness were captured via the system recordings, PRQ, and WAK. Table 101 summarizes traffic count data for this scenario.

Table 101: Scen17 Traffic Count

	Arrivals	Departures	Touch and Go's/ Low Approaches	Overflights
Count	17	17	13	6

This scenario included three UAS and a chase plane for the Predator. On the PRQ, the controllers reported they did not treat the Predator any differently when a chase plane was present.

After each run, participants and SME Observers were asked to provide subjective ratings about their assessment of workload and situation awareness by marking ratings on a Likert scale of 1-7, where "1" corresponds to "Extremely Low" and the "7" responds to "Extremely High."

The Local controller indicated that he experienced a very high overall complexity and a just above average overall workload. The Local SME observer indicated that the Local controller experienced a just above average overall workload and an average overall complexity. The SME Observer indicated that the Local controller seemed to experience above average overall workload and average overall complexity. The Ground SME observer noted he observed the Local controller appearing to "lose the flick" when the Local controller tried to let Slam 88 do a Runway 35 operation and abeam approach. The Ground SME observer further observed that the Local controller "didn't seem to have a good, organized plan, which caused extra transmissions."

In contrast, the Ground controller indicated that he experienced a very low overall complexity and an extremely low overall workload. The Ground SME observer indicated that the Ground controller experienced an average overall workload and overall complexity. Table 102 captures their responses.

Table 102: Scen17 Ratings of Workload and Complexity

		Position			
		Local Controller	Local SME Observer	Ground Controller	Ground SME Observer
Metric:	Overall Complexity	6	4	2	4
	Overall Workload	5	5	1	4

Factors such as mental demand, effort, and the degree in which UAS required attention are some of the contributing factors to overall workload and complexity. Table 6 captures the PRQ responses pertaining to these factors.

On a scale with "1" equal to "Very Poor" and "7" corresponding to "Very Good", the Local and the Ground controllers self-rated their performance as very good for this scenario.

On a scale with "1" equal to "Extremely Low" and "7" corresponding to "Extremely High", the Local controller rated his frustration as not at all, temporal demand as very low and physical demand as just below average. He rated his mental demand and effort level as just above average. The Ground controller rated mental demand, physical demand, temporal demand, effort, and frustration as extremely low.

On a scale with "1" equal to "Not at All" and "7" corresponding to "A Great Deal," the Local controller indicated that the degree in which UAS contributed to workload and the degree in which the UAS required additional attention as compared to manned aircraft was average. In

contrast, the Ground controller indicated the UAS did not contribute to his workload at all, and that the UAS required minimal additional attention as compared to manned aircraft.

Participants were also asked to provide subjective ratings about the degree to which the REHOST display helped them maintain traffic awareness on the scale where "1" corresponds to "Not at all" and the "7" corresponds to "A great Deal". The Local controller indicated situation awareness greatly benefited from the system; whereas the Ground controller did not find that REHOST was applicable to his duties in this scenario.

Table 103: Scenario 17 PRQ Workload and Situation Awareness

		Position	
		Local Controller	Ground Controller
Metric:	Mental Demand:	5	1
	Physical Demand:	3	1
	Temporal Demand:	2	1
	Performance:	7	7
	Effort:	5	1
	Frustration:	1	1
	Amount of coordination with GC or LCL:	3	4
	Degree to which staffing GC affected workload (LCL Only):	2	N/A
	Assist with UAS operations other than GC (GC Only):	N/A	No
	If yes to having assisted with any UAS, did the assistance negatively affect your ability to accomplish your primary GC duties (GC Only):	N/A	N/A
	Degree to which UAS contributed workload:	4	1
	Degree to which UAS required additional attention:	4	1
	Degree to which REHOST helped maintain traffic awareness:	7	Not Rated

Participants were asked to provide instantaneous workload ratings every two minutes during the run via a WAK located at each workstation. Graphed over time, the responses for this scenario are depicted in Figure 21.

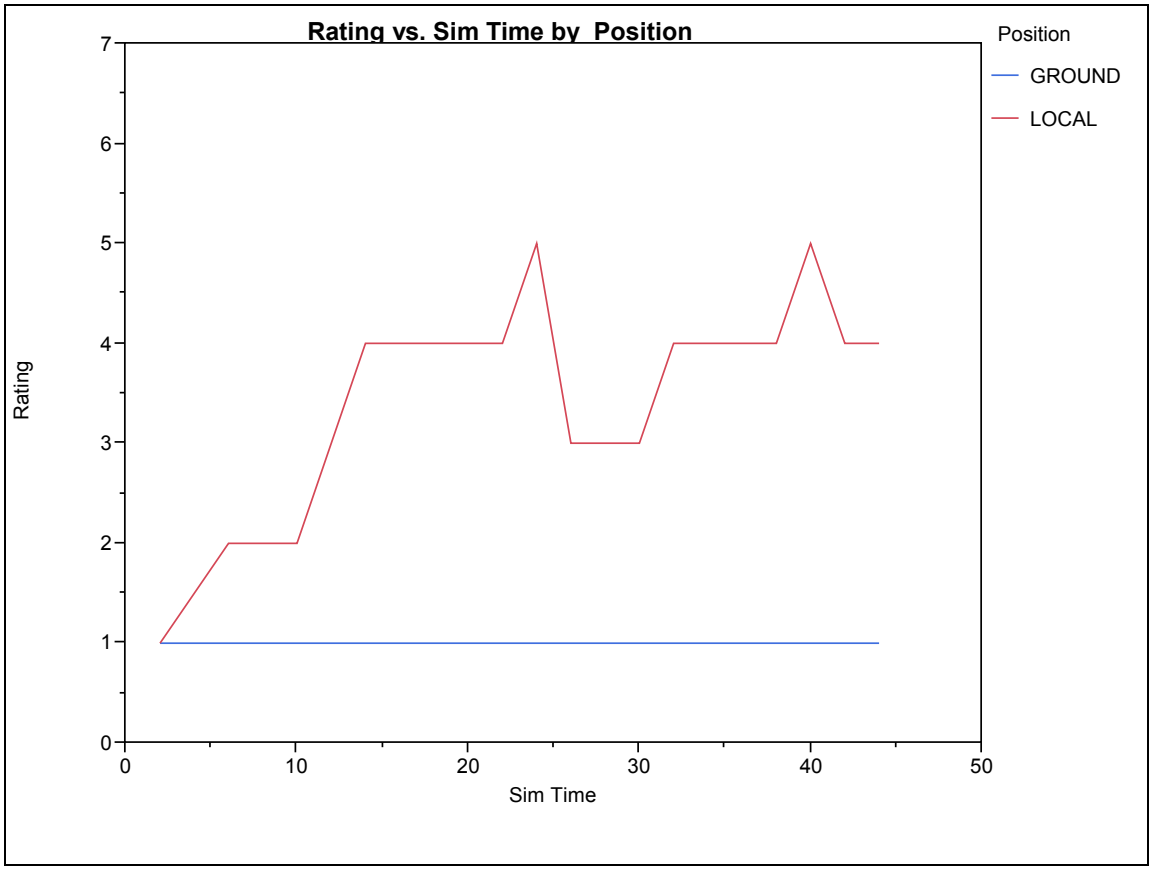

Figure 21: Scenario 17 WAK Data

In line with questionnaire data, the Local controller's self-reported workload throughout this scenario was rather high, while the Ground controller's self-reported workload throughout was rather low. In addition, these elevated workload ratings by the Local controller also support questionnaire items in which this controller reported elevated mental demand and increased effort. Although it is clear from the figure that the Local controller's workload was elevated throughout most of the scenario, the first spike in the graph appears as though it may have coincided with the Predator's request for a runway change at approximately 14 minutes. Although it is not specifically spelled out in the questionnaire data, this request may have contributed to added workload on the part of the Local controller.

4.3.8.6 Scen17 SME Observations

In addition to collecting data discussed above, the SME analysis team made supplementary observations during their post-study analysis. These observations capture events, occurrences, and their effects on the scenario which were not recorded elsewhere.

Touch and go traffic for Runway 21 routinely flew through the Raven operations area with no restrictions or traffic advisories. SME Observers inferred that although the Raven visual ground observer may have the Raven in sight, they may not be able to see other aircraft and determine if there is a conflict with the UAS. Additionally, the airborne visual observer for the Predator, located 3-4 miles northeast of the airport, may have difficulty providing see and avoid services to

the pilot of the Predator while flying through the Raven operations area because the Raven may be difficult to see.

Another observation was that the Raven pilot and the ground observer have no capability to monitor ATC frequencies. Raven ops can only be notified by ATC via telephone, which can be burdensome at times. This can make it difficult for ATC to provide timely information.

SME noted that there is a need to establish standardized phraseology and ATC procedures for handling UAS. SME's also noted that it is critical to safety that specific wake turbulence standards for UAS be developed, tested and implemented as soon as possible.

SME noted that UAS that required the use of the runways were much more reliant on ATC for sequencing and spacing than manned aircraft pilots. This had the potential to increase controller workload and complexity.

From this simulated experience, it appears that at minimum, the COA for UAS in the same or nearby airspace need to be examined together for possible safety concerns and harmonized/de-conflicted as necessary.

4.3.8.7 Scenario Findings

Upon examination of the complete set of data collected, the ATC operation simulated in this scenario does not appear to be feasible with regard to the safe and efficient flow of air traffic.

4.3.9 Scenario 18

In line with the overall study objectives, the goal of Scenario 18 was to examine the effects of simultaneous multiple UAS platforms with dissimilar flight characteristics on local traffic pattern operations, ATC operations, and Class D airspace.

The scenario also included off-nominal events.

4.3.9.1 Scen18 Design

Scenario 18 was developed with the following characteristics:

Airport and Weather Conditions: Simulation start-time was mid-afternoon, and Visual Flight Rules (VFR) prevailed throughout the scenario. Winds were 210° at 9kts. The active runways were 21 and 17.

Manned Aircraft: Seventeen manned aircraft were included to simulate normal traffic flows at the airport. Operations included both military and civilian departures, arrivals, over-flights, and local pattern work. Four additional VFR (1200 code) targets were introduced to simulate over-flight traffic above and/or adjacent to the Class D airspace, and did not communicate with ATC.

Special Military Operations: In addition to other manned military flights, an additional C17 Globemaster II (Slam 88), was added to simulate specialized military tactical maneuvers practiced by USAF crews at KVCV and similar airports.

Ground Vehicles: Two ground vehicles were added to the scenario to replicate vehicular traffic at a typical airport. The vehicles simulated routine airfield maintenance and runway sweeping operations, and communicated with ATC on the GC frequency.

Unmanned Aircraft Systems: Four UAS were included in this scenario: the AS800 JPL Blimp, RQ-11 Raven, A-160 Hummingbird, and MQ-1B Predator. Although not a UAS, the Predator Chase aircraft, a manned Mooney MO20, was included in the scenario to simulate the requirements of the current COA. The approved operating area for the A-160 was 2-3 miles north of Runway 21 and east of the extended centerline of Runway 17, surface to 5,000' MSL. The approved operating area for the MQ-1B Predator was Class D airspace including traffic patterns to both runways. The approved operating area of the JPL Blimp was north of Runway 21 and west of Runway 17, at or below 700' AGL. The approved operating area for the Raven was southeast of Runway 21 over the old housing area, at or below 400' AGL.

Off Nominal Event(s): Secondary to the simultaneous multiple UAS operations, Scenario 17 examined the effects of an A-160 "Spill-Out" from their normal operations area. By design, the pilot of the A-160 was instructed not to notify ATC of the Spill-Out, unless specifically questioned by the Local Controller. At the time of the planned Spill-Out, the MQ-1B Predator was in the Runway 21 closed traffic pattern. After completing the requested number of touch and gos, the Predator and the Predator Chase departed the Class D airspace, and proceeded as a flight to the Edwards Complex.

4.3.9.2 Scen18 Safety

The ATC operations presented in this scenario were evaluated with regards to the safety and efficiency of the flow of traffic. Several notable observations are described in this section.

As rated on a 7-point scale in the PRQ, with "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High," both participants appeared to be confident in the safety of operations for this scenario. The Local and Ground controllers rated their confidence levels as 5 and 7, respectively. Although the participants believed the operation to be safe, the SME Observers both rated the safety and efficiency of the overall traffic flow a 2 on the same 7-point scale. In addition, data and post-study analysis by the research team indicated some safety concerns.

Post-study analysis by the SME team revealed the occurrence of a midair collision between the Raven and Slam 88. Further analysis suggested that this midair collision may have been caused by multiple contributing factors. For example, Class D COA currently require UAS to be segregated from manned aircraft, but do not outline any standards or procedures to maintain this segregation. As such, no restrictions were given to Slam 88 or the Raven in this scenario to prevent this breakdown in safety. In addition, it appeared evident to the SME analysis team that the location of the Raven operations area seemed to be located in too close of a proximity to the runway to allow for safe and efficient Runway 21 operations while the Raven is in flight. Another contributing factor was believed to be the physical size of the Raven. Due to its size, the Raven UAS was too small to be visually acquired by tower controllers. Therefore, maintaining awareness of its location was difficult.

This incident led the SME team to deem these operations as unmanageable in regard to safe and efficient traffic flow. The final factor that the SME team felt played a role in the midair collision was the lack of ATC training on UAS, in regard to both their operations as well as their specific flight characteristics. As referenced above, the plan in Class D to segregate UAS from manned aircraft does not guarantee safe operations, or even guarantee that the operations are entirely segregated. SME also observed that it appeared as though ATC did not understand the severity of the effect of wake turbulence on UAS operations. In this scenario, Slam 88 was approved to routinely overfly both the JPL and the Raven operations areas without restriction or traffic advisories.

From an operational perspective, there are several types of incidents that adversely affect the safe, orderly and expeditious movement of air traffic. These include MAC, other ACC, NMAC, OE, OD, RI, and PD. Concerning some of these measures, it is important to note that focus of this study was to examine the potential effects of UAS operations on Class D airspace. By design, the simulation pilots, both manned and unmanned, were confederates in this simulation (i.e., not the direct subjects of study). Therefore, any occurrences of pilot-induced incidents (e.g., PDs, RI, or NMAC caused by pilot error or actions) are considered part of the realistic, complex situations presented to the controller participants and not reported as deficiencies or safety related findings for the purposes of this evaluation.

Information concerning the study's incident safety measures are summarized in Table 104, with reported incident details provided in Table 105.

In this 45-minute operation, ATC did not comply with the proper intersecting runway standards as prescribed in the FAO JO7110.65T[19], resulting in the four OE depicted in Table 104 and Table 105. In addition, the previously mentioned MAC is also depicted in Table 104 and Table 105

Table 104: Scen18 Safety Metrics

Metric:	MAC	Other Accidents	NMAC	OE	OD	RI
Number of Incidents:	1	0	0	4	0	0

[19] See FAO JO7110.65 paragraph 3-9-8.

Table 105: Scen18 Incident Table

Incident Type	Aircraft #1	Aircraft #2	Incident Description
MAC	Slam 88	RQ11 Raven (UAS)	ATC permitted Slam 88 to operate within the confines of the Raven Operations Area
OE	Slam 88	N90PH	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section 3-9-8
OE	Slam 88	Grizzly 21 *(UAS)*	Wake turbulence separation for intersection departures was not provided * Reference FAA JO 7110.65 Section 3-9-7
OE	Slam 88	N44EL	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section 3-9-8
OE	RYN5	N44EL	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section 3-9-8

4.3.9.3 Scen18 Efficiency

Several metrics were captured to evaluate the efficiency of the operation. These included go-around maneuvers, delays, traffic pattern modifications, re-sequencing, etc. In the 45-minute operation, one pilot-initiated go around, four aircraft delays, and 11 traffic pattern modifications were observed. In addition, one manned aircraft request was denied and/or cancelled and there were two re-sequenced arrivals. Table 106 captures the observed efficiency metrics for this scenario.

Table 106: Scen18 Efficiency Metrics

Go-Arounds	
ATC Initiated Go-Arounds	0
Pilot Initiated Go-Arounds	1
Total	1
Delays	
Manned A/C Departure Delays	1
Manned Aircraft Arrival Delays	1
Unmanned A/C Departure Delays	1
Unmanned A/C Arrival Delays	1
Total	4
Traffic Pattern Modifications	
Extended Down-Winds	5
360° Turns	3
ATC Initiated Runway Changes	2
ATC Requested Short Approaches	0
ATC Requested Early Departure Turns	0
ATC Assigned Straight-Out/Runway Headings	1
Total	11
Miscellaneous Efficiency Measures	
Class D Airspace Denials	0
Re-Sequenced Arrivals	2
Re-Sequenced Departures	0
Altered and/or Cancelled Manned A/C Requests	1
Altered and/or Cancelled Unmanned A/C Requests	0
Total	3

It appears as though at least some of these measures were a direct result of the UAS operations being conducted in this scenario. For example, according to SME observations, it seemed as though many of the extended downwinds and 360 degree turns were a direct result of attempts to sequence the Predator with manned aircraft. It also appeared as though the operations in the Runway 21 traffic pattern, including the Predator, increased the workload of the Local controller and prevented him from initially noticing the A-160 spill-out either out the window or on the REHOST.

These observations were further supported by PRQ ratings by the Local controller, who rated the effect of UAS on the traffic pattern and sequence as considerable (both rated 5 and 6, respectively, on a 7-point scale, with "1" corresponding to "Not at All" and "7" corresponding to "A Great Deal"). The Local controller also rated the degree to which UAS required additional attention as considerable (rated 5 on the same 7-point scale).

4.3.9.4 Scen18 Communication

Voice communication is a key element of air traffic control. Many different communication anomalies can be indicative of traffic saturation and ATC loss of situation awareness. These

types of occurrences include transposed call signs, missed transmissions, misidentified aircraft, and repeat ATC instructions.

In this scenario, the SME analysis team observed one missed transmission by the local controller. (Note: simulation pilot communication errors are not reported since they were not the subjects of study).

Another important observation in regards to communication in this scenario is the lack of ATC radio frequency use by UAS PIC. Common throughout the simulation and specific to this scenario, was the lack of issued advisories to UAS operating in the areas with no direct ATC radio frequency contact.

4.3.9.5 Scen18 Workload and Situation Awareness

In addition to the observations noted in the safety, efficiency, and communication sections, other measures of workload and situation awareness were captured via the system recordings, PRQ, and WAK. Table 107 summarizes the traffic counts for this scenario.

Table 107: Scen18 Traffic Count

	Arrivals	Departures	Touch and Go's/ Low Approaches	Overflights
Count:	18	20	14	7

This scenario featured 4 active UAS and an A-160 "Spill-Out" event. SME observation found that the workload of the Local controller increased due to the Predator operating in the traffic pattern. Since UAS PICs are not on board the aircraft, and they currently do not have an alternate approved method to visually acquire and follow other aircraft[20], additional workload is imposed on ATC to sequence them in a traffic pattern. SME noted that UAS that required the use of the runways were much more reliant on ATC for sequencing and spacing than manned aircraft pilots. This had the potential to increase controller workload and complexity. For example, ATC is required to call turns to the UAS when operating in the traffic pattern with other aircraft. ATC must also estimate proper safe operating distance near or behind other aircraft the UAS are following. It was observed that these additional duties increased the controller's workload so much that he did not observe the A-160 leave its operational area and cross the Runway 17 center line. The Local controller was unaware of the "Spill-Out" until he was advised of it by the Ground controller, who noticed it first after it occurred.

After being made aware of the spill-out the Local controller stated that his workload increased initially while trying to get caught up on the situation. However, after verifying the altitudes of both the A-160 and other manned aircraft in the area, to assure there would be no losses of separation, workload returned to average levels and traffic continued as normal. The Ground

[20] Reference JO 7110.65 Section 3-8-1

controller also agreed that his workload was initially increased after the incident as a result of assisting the Local controller in handling the situation.

In addition to the increased workload throughout this scenario, SME observations also determined that it appeared as though the Ground controller 'lost the flick' at one point during the scenario. This occurred when Sweeper 2 asked to cross a runway with N44EL on final approach. The controller then had to issue a 360 turn to remedy the situation. Once the issue was resolved, it appeared as though he relied on the use of the REHOST to help him regain adequate situation awareness.

After each run, participants and SME Observers were asked to provide subjective ratings about their assessment of their overall workload and situation awareness throughout the scenario by marking ratings on a Likert scale of 1-7, where "1" corresponds to "Extremely Low" and "7" corresponds to "Extremely High." As seen in Table 108, both the Local controller and SME Observer felt that overall the workload was average throughout the scenario, while the Ground Controller felt the workload was very low and the SME observer felt the workload was extremely low. However, the Local controller felt the complexity was very low during this scenario while the Ground Controller felt it was just above average.

Table 108: Scen18 Ratings of Overall Workload and Complexity

		Position			
		Local Controller	Local SME Observer	Ground Controller	Ground SME Observer
Metric:	Overall Complexity	2	4	5	1
	Overall Workload	4	4	2	1

Factors such as mental demand, effort, and the degree in which UAS required attention are some of the contributing factors to overall workload and complexity. Table 109 captures the responses pertaining to these factors.

On a scale with "1" equal to "Very Poor" and "7" corresponding to "Very Good", the Local and Ground controllers self-rated their performance as good for this scenario (both rated 6).

On a scale with "1" equal to "Extremely Low" and "7" corresponding to "Extremely High", the Local controller rated his frustration as extremely low and his physical and temporal demand as minimal; His mental demand and effort were notably affected. The Local controller also reported that the UAS required a considerable amount of attention and had a notable effect on his workload. This supports previous observations suggesting the presence of the Predator in the traffic pattern and the A-160 "Spill-Out" increased the controller workload.

The Ground controller rated his physical demand, temporal demand, and frustration as extremely low and mental demand and effort were minimally affected. He further indicated that taxiing the

UAS did not contribute to his workload at all, and that the UAS was not given any additional attention as compared to manned aircraft.

By design, the Ground control position was always staffed for this study. On the PRQ, however, the Ground controller reported he did not assist with UAS operations other than for ground control operations; the SME observed him consistently assisting the Local controller with the position of aircraft and situation awareness when UAS were present.

Participants were also asked to provide subjective ratings about the degree to which the REHOST display helped them maintain traffic awareness on the scale where "1" corresponds to "Not at all" and the "7" corresponds to "A great Deal." The Local controller indicated that REHOST had a notable effect on his situation awareness, whereas the Ground controller indicated that REHOST had a considerable effect on his situation and traffic awareness. It was beneficial to him since his workload was slightly elevated due to the off-nominal events that occurred in this scenario.

Table 109: Scen18 PRQ Workload and Situation Awareness

		Position	
		Local Controller	Ground Controller
Metric:	Mental Demand:	3	2
	Physical Demand:	2	1
	Temporal Demand:	2	1
	Performance:	6	6
	Effort:	3	2
	Frustration:	1	1
	Amount of coordination with GC or LCL:	3	3
	Degree to which staffing GC affected workload (LCL Only):	2	NA
	Assist with UAS operations other than GC (GC Only):	NA	No
	If yes to having assisted with any UAS, did the assistance negatively affect your ability to accomplish your primary GC duties (GC Only):	NA	N/A
	Degree to which UAS contributed workload:	4	1
	Degree to which UAS required additional attention:	5	1
	Degree to which REHOST helped maintain traffic awareness:	4	6

Participants were asked to provide instantaneous workload ratings every two minutes during the run via a WAK located at each workstation. Graphed over time, the responses for this scenario are depicted in Figure 22.

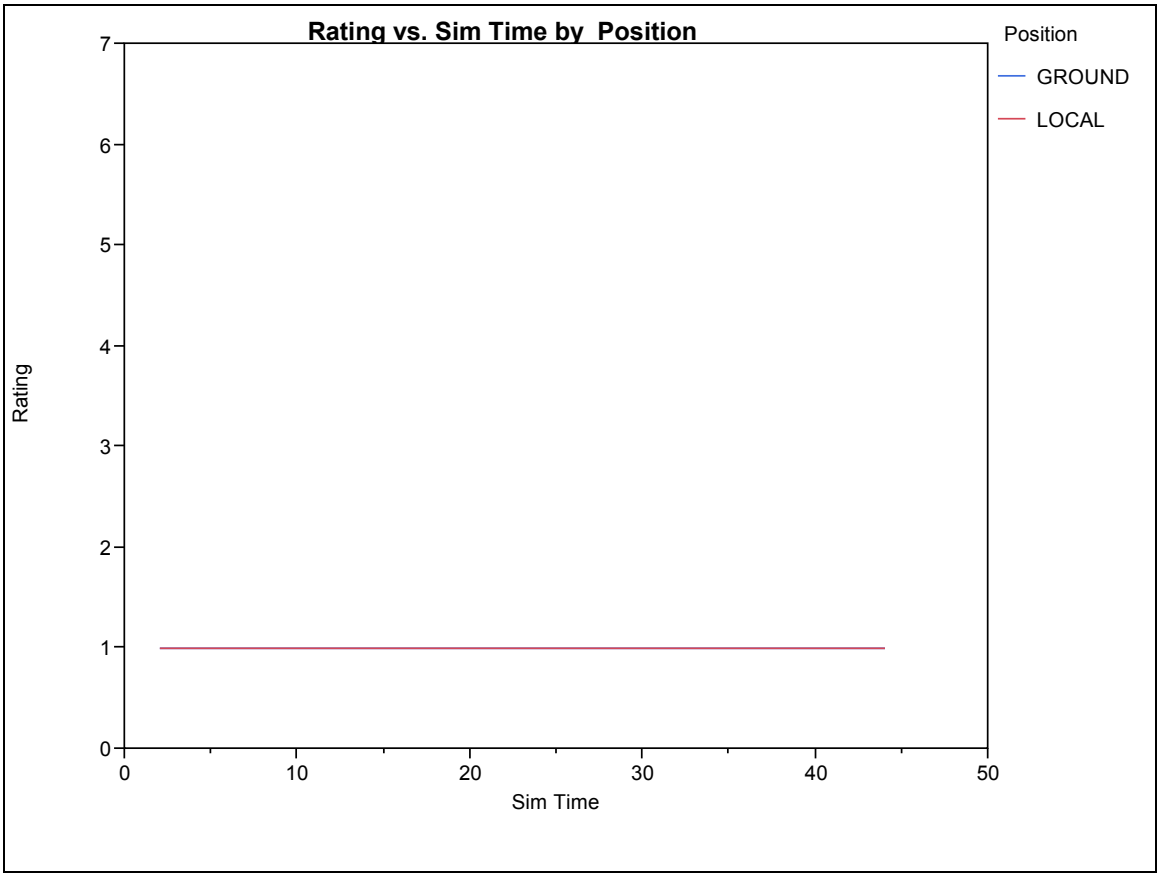

Figure 22: Scen18 WAK Data

Contrary to questionnaire responses of a self-reported increase in workload for the local controller during the A-160 spill-out, the WAK data shows self-reported ratings of workload to be consistently very low throughout the duration of the scenario. These results are inexplicable. However, the low workload ratings throughout this scenario for the Ground controller are in line with his questionnaire responses.

4.3.9.6 Scen18 SME Observations

In addition to collecting the data discussed above, the SME analysis team made supplementary observations during their post-study analysis. These observations capture events, occurrences, and their effects on the scenario which were not recorded elsewhere.

The sole defined purpose of the chase aircraft and/or ground observer is to prevent collisions (i.e., provide see and avoid capability). However, the question of who is responsible for collision avoidance, when a UAS is moved beyond the visual range of the ground observer, arose in this scenario.

The answers to these questions must be clearly defined and resolved before permitting multiple simultaneous UAS operations in Class D airspace.

SME Observers felt it was important that UAS-specific segregation standards and criteria for the placement of UAS operation areas in Class D airspace be identified and uniformly implemented

throughout the NAS. This issue, as identified previously, became apparent when a departing aircraft flew directly through the Raven Ops area, causing a midair collision. It is suggested that the operational areas be moved to a location where they will not directly affect or be affected by routine traffic pattern operations.

SME also suggested that discussions take place regarding the need for any special handling for UAS that are too small in size to be continuously seen.

4.3.9.7 Scen18 Findings

Upon examination of the complete set of data collected, the ATC operation simulated in this scenario does not appear to be feasible with regard to the safe and efficient flow of air traffic.

4.3.10 Scenario 19

In line with the overall study objectives, the goal of Scenario 19 was to examine the effects of simultaneous multiple UAS platforms with dissimilar flight characteristics on local traffic pattern operations, ATC operations, and Class D airspace. Scenario 19 examined the effect the Predator and chase aircraft had on traffic while returning from the Edwards Complex. The AS800 JPL Blimp was airborne during the entire scenario.

4.3.10.1 Scen19 Design

Scenario 19 was developed with the following characteristics:

Airport and Weather Conditions: Simulation start-time was mid-afternoon and VFR prevailed throughout the scenario. Winds were 210° at 9kts. The active runways were 21 and 17.

Manned Aircraft: Seventeen manned aircraft were introduced at random intervals to simulate normal traffic flows at the airport. Operations included both military and civilian departures, arrivals, over-flights, and local pattern work. Four additional VFR (1200 code) targets were injected to simulate over-flight traffic above and/or adjacent to the Class D airspace. These targets did not communicate with ATC.

*Special Military Operations***:** In addition to other manned military flights, an additional C17 Globemaster II (Slam 88) was added to simulate specialized military tactical maneuvers practiced by USAF crews at KVCV and similar airports.

Ground Vehicles: Two ground vehicles were added to the scenario to replicate vehicular traffic at a typical airport. Vehicular activity simulated routine airfield maintenance and sweeping operations and communicated with ATC on the GC frequency.

Unmanned Aircraft Systems: Two UAS were included in this scenario — the AS800 JPL Blimp and the MQ-1B Predator. Although not a UAS, the Predator chase aircraft, a manned Mooney MO20, was included in the scenario to simulate the airborne observer requirements of the current COA.

4.3.10.2 Scen19 Safety

The ATC operations presented in this scenario were evaluated with regard to the safety and efficiency of the flow of traffic. Applicable observations are described in this section.

As rated on a 7-point scale in the PRQ, with "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High," the Ground controller rated his confidence in the safety of operations as 7, or extremely high. The Local controller rated his confidence as 4, or average. SME Observers noted that, in general, normal traffic pattern operations prevailed throughout this scenario.

From an operational perspective, there are several types of incidents that adversely affect the safe, orderly, and expeditious movement of air traffic. These include MAC as well as other ACC, NMAC, OE, OD, RI, and PD. Concerning some of these measures, it is important to note that the focus of this study was to examine the potential effects of UAS operations on Class D airspace. By design, the simulation pilots, both manned and unmanned, were not the direct subject of study in this simulation. Therefore, any occurrences of pilot-induced incidents (e.g., PD, RI, or NMAC caused by pilot error or actions) are considered part of the realistic, complex situations presented to the controller participants and not reported as deficiencies or safety-related findings for the purposes of this evaluation.

Information concerning the study's incident safety measures are summarized in Table 110, with reported incident details provided in Table 111. In this 45-minute scenario, there were five ATC-related incidents where ATC did not comply with the proper intersecting runway standards as prescribed in FAO JO7110.65, Sections 3-9-8 and 3-10-4, Intersecting Runway Separation, resulting in the OE depicted in Table 110 and Table 111.

Table 110: Scen19 Safety Metrics

Metric:	MAC	Other Accidents	NMAC	OE	OD	RI
Number of Incidents	0	0	0	5	0	0

Table 111: Scen19 Incident Table

Incident Type	Aircraft #1	Aircraft #2	Incident Description
OE	SWA3471	N44EL	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
OE	N744PA	N44EL	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
OE	N744PA	N44EL	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
OE	N744PA	N44EL	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
OE	N744PA	N44EL	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4

4.3.10.3 Scen19 Efficiency

Several metrics were captured to evaluate the efficiency of the operation. Table 112 captures the observed efficiency metrics for this scenario. In the 45-minute scenario, one aircraft was delayed and one traffic pattern modification was observed.

Table 112: Scen19 Efficiency Metrics

Go-Arounds	
ATC Initiated Go-Arounds	0
Pilot Initiated Go-Arounds	0
Total	0
Delays	
Manned A/C Departure Delays	1
Manned Aircraft Arrival Delays	0
Unmanned A/C Departure Delays	0
Unmanned A/C Arrival Delays	0
Total	1
Traffic Pattern Modifications	
Extended Down-Winds	1
360° Turns	0
ATC Initiated Runway Changes	0
ATC Requested Short Approaches	0
ATC Requested Early Departure Turns	0
ATC Assigned Straight-Out/Runway Headings	0
Total	1
Miscellaneous Efficiency Measures	
Class D Airspace Denials	0
Re-Sequenced Arrivals	0
Re-Sequenced Departures	0
Altered and/or Cancelled Manned A/C Requests	0
Altered and/or Cancelled Unmanned A/C Requests	0
Total	0

On a 7-point Likert scale, with "1" corresponding to "not at all" and "7" corresponding to "a great deal," the Ground controller's responses on the PRQ indicated that the UAS had virtually no effect on the efficiency of the operations for this scenario. The Local controller also indicated the UAS had no effect on the traffic pattern, sequence, or capacity during the scenario. However, the Local controller did indicate the UAS had some effect on his ability to accommodate manned aircraft and that he provided the UAS some measure of priority handling (both rated as 3).

4.3.10.4 Scen19 Communication

Voice communication is a key element of ATC. Many different communication anomalies can be indicative of traffic saturation and ATC loss of situation awareness. These types of occurrences include transposed call signs, missed transmissions, misidentified aircraft, and repeated ATC instructions. In this scenario, there were no recorded occurrences. (Note: simulation pilot communication errors are not reported since they were not the subject of study.)

However, the SME Observers reported that in some instances, the air traffic controllers used nonstandard phraseology in situations involving the UAS. They added that while this type of phraseology is sometimes necessary, it can lead to confusion, adding risk to the safety of operations. For example, ATC was observed using the phraseology "unmanned aerial vehicle" when issuing traffic advisories to manned aircraft. This demonstrates and suggests the need to examine standards for UAS-specific phraseology.

Another important observation with regard to communications in this scenario was the lack of ATC radio frequency use, or availability, by some UAS PIC. Common throughout the study was the lack of advisories issued to the UAS PIC that operated without direct ATC radio frequency contact (some operators utilized cell phones/landlines to communicate with ATC). It was observed that it is difficult to issue advisories to these aircraft, but it is also assumed that had communications been available via ATC radio frequency, advisories would have been issued.

4.3.10.5 Scen19 Workload and Situation Awareness

In addition to the observations noted in the safety, efficiency, and communications section, other measures of workload and situation awareness were captured via the system recordings, PRQ, and WAK. Table 113 summarizes the traffic counts for this scenario.

Table 113: Scen19 Traffic Count

	Arrivals	Departures	Touch and Go's/ Low Approaches	Overflights
Count:	16	15	11	5

After each run, the participants and SME Observers were asked to provide subjective ratings about their assessment of workload and situation awareness on a Likert scale of 1-7, where "1" corresponds to "Extremely Low" and "7" corresponds to "Extremely High." Both the Local and Ground controllers rated overall workload and complexity as very low (rated as 2). The SME Observers rated these measures as average or below average for this scenario. Table 114 captures the responses.

Table 114: Scen19 Ratings of Overall Workload and Complexity

		Position			
		Local Controller	Local Control SME Observer	Ground Controller	Ground Control SME Observer
Metric:	Overall Complexity	2	4	2	3
	Overall Workload	2	4	2	3

Factors such as mental demand, effort, and the degree to which UAS required attention are some of the contributing factors to overall workload and complexity. Table 115 captures the PRQ responses pertaining to these factors for this scenario.

On a Likert scale, with "1" equal to "Very Poor" and "7" corresponding to "Very Good," the Ground controller self-rated his performance a 7, or very good. The Local controller self-rated his performance a 5, or above average, for this scenario.

On a scale with "1" equal to "Extremely Low" and "7" corresponding to "Extremely High," both controllers rated their mental demand, physical demand, temporal demand, and frustration as very low or extremely low.

On a scale with "1" equal to "not at all" and "7" corresponding to "a great deal," the Ground controller indicated the UAS did not contribute at all to workload, nor did he provide any additional attention to the UAS as compared to manned aircraft (both rated as 1). The Local controller, however, indicated that he did provide notable attention to UAS compared to manned aircraft (rated as 4), and that the UAS contributed some degree to his workload (rated as 3). The REHOST display appeared to provide substantial benefit for maintaining situation awareness; both air traffic controllers rated this item 5 on a scale with "1" equal to "not at all" and "7" corresponding to "a great deal."

Table 115: Scen19 PRQ Workload and Situation Awareness

		Position	
		Local Controller	Ground Controller
Metric:	Mental Demand:	2	2
	Physical Demand:	1	1
	Temporal Demand:	2	2
	Performance:	5	7
	Effort:	2	2
	Frustration:	2	1
	Amount of coordination with GC or LCL:	4	3
	Degree to which staffing GC affected workload (LCL Only):	4	N/A
	Assist with UAS operations other than GC (GC Only):	N/A	No
	If yes to having assisted with any UAS, did the assistance negatively affect your ability to accomplish your primary GC duties (GC Only):	N/A	N/A
	Degree to which UAS contributed workload:	3	1
	Degree to which UAS required additional attention:	4	1
	Degree to which REHOST helped maintain traffic awareness:	5	Not Rated

Participants were also asked to provide instantaneous workload ratings every two minutes during the run via a WAK located at each workstation. Graphed over time, the responses for this scenario are depicted in Figure 23.

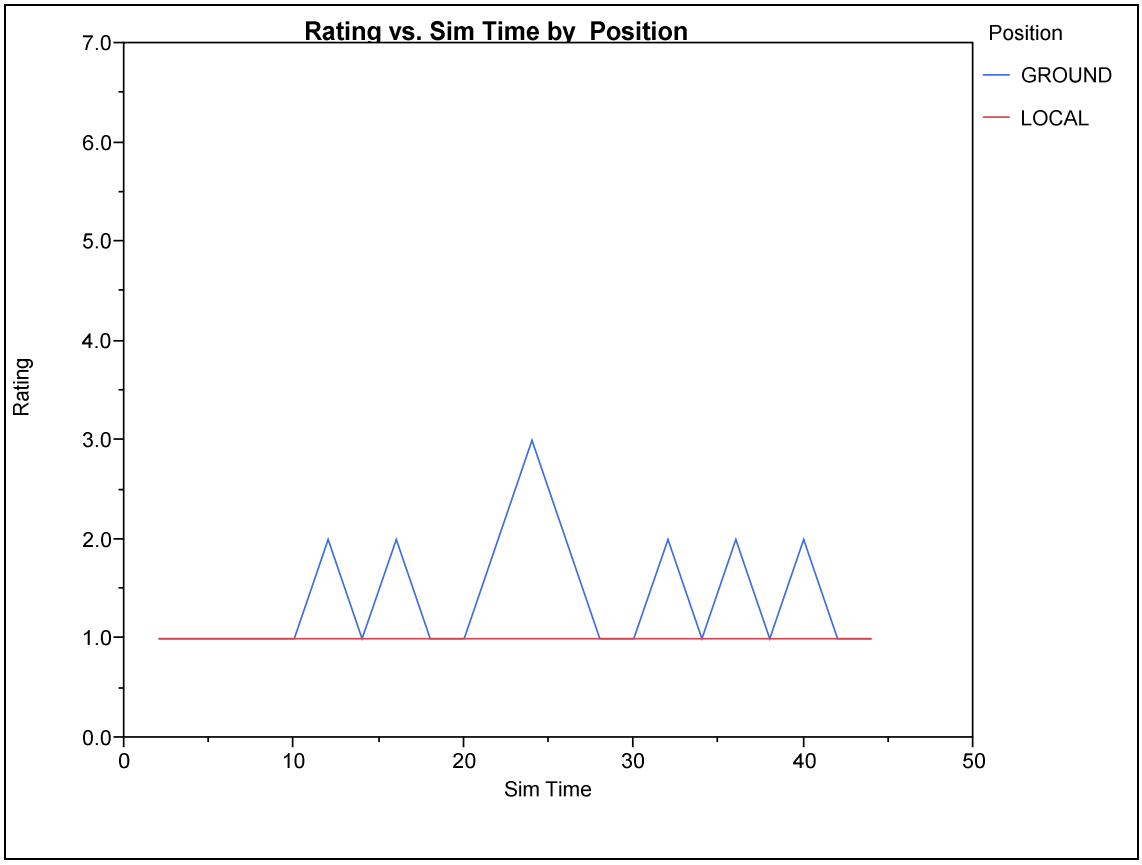

Figure 23: Scen19 WAK Data

In line with the questionnaire data, the air traffic controllers' self-reported instantaneous workload throughout this scenario was lower than average. The minor variability in the Ground controllers' responses is likely attributed to normal fluctuations in workload due to regular variations in traffic operations.

4.3.10.6 Scen19 SME Observations

In addition to collecting the data discussed above, the SME analysis team made supplementary observations during their post-study analysis. These observations captured events, occurrences, and their effects on the scenario which were not recorded elsewhere.

The SME Observers noted the lack of standard ATC phraseology when controlling UAS during this scenario. It was observed that this non-standard phraseology can contribute to an increased risk to safety.

The SME Observers noted that when multiple observers are used, there may be some confusion over the transfer of responsibility for see and avoid from the chase aircraft to the ground

observer. For example, when Grizzly 21 arrived from the Edwards Complex with a chase aircraft, the chase aircraft remained with Grizzly 21 until Grizzly 21 landed. In this example, it is unclear when, or if, the observer duties were transferred from the airborne observer to the ground observer for the remainder of the flight.

Also noted was a lack of clarity regarding the responsibilities of ATC and both the chase and ground observers when ATC issues instructions to extend downwind and the UAS is beyond the observer's line-of-sight. It was recognized by the SME Observers that ATC does not provide, and is not responsible for, the see and avoid requirement.

SME noted that UAS that required the use of the runways were much more reliant on ATC for sequencing and spacing than manned aircraft pilots. This had the potential to increase controller workload and complexity.

4.3.10.7 Scen19 Findings

Upon examination of the complete set of data collected, the ATC operation simulated in this scenario does not appear to be feasible with regard to the safe and efficient flow of air traffic.

4.3.11 Scenario 20

In line with the overall study objectives, the goal of Scenario 20 was to examine the effects of simultaneous multiple UAS platforms with dissimilar flight characteristics on local traffic pattern operations, ATC operations, and Class D airspace.

Scenario 20 specifically examined the effects of the Predator and chase aircraft as they returned from the Edwards Complex (via the COA-approved Class E operating area) and continued operating in Class D airspace with the intention of a full stop landing. The AS800 JPL Blimp and RQ-11 Raven were operating within their respective areas as designated by the applicable COAs. Additionally, the A-160 Hummingbird was operational within the "East-West" pattern northeast of the airport, which by design created a potential conflict with the arrival route of the Predator/chase flight.

4.3.11.1 Scen20 Design

Scenario 20 was developed with the following characteristics:

Airport and Weather Conditions: Simulation start-time was mid-afternoon and VFR prevailed throughout the scenario. Winds were 210° at 9kts. The active runways were 21 and 17.

Manned Aircraft: Seventeen manned aircraft were introduced at random intervals to simulate normal traffic flows at the airport. Operations included both military and civilian departures, arrivals, over-flights, and local pattern work. Four additional VFR (1200 code) targets were injected to simulate over-flight traffic above and/or adjacent to the Class D airspace. These targets did not communicate with ATC.

Special Military Operations: In addition to other manned military flights, an additional C17 Globemaster II (Slam 88) was added to simulate specialized military tactical maneuvers practiced by USAF crews at KVCV and similar airports.

Ground Vehicles: Two ground vehicles were added to the scenario to replicate vehicular traffic at a typical airport. The vehicles simulated routine airfield maintenance and sweeping operations and communicated with ATC on the GC frequency.

Unmanned Aircraft Systems: Four UAS were included in this scenario — the AS800 JPL Blimp, RQ-11 Raven, A-160 Hummingbird, and MQ-1B Predator. Although not a UAS, the Predator chase aircraft, a manned Mooney MO20, was also included in the scenario to simulate the requirements of the current COA.

4.3.11.2 Scen20 Safety

The ATC operations presented in this scenario were evaluated with regard to the safety and efficiency of the flow of traffic. Several notable observations are described in this section.

The Raven operations area is located near the Runway 21 left downwind and in an area commonly used by helicopter traffic transitioning to and from the airport. Additionally, other routine flights traverse this area while the Raven is airborne and it was observed during this scenario that ATC continually allowed operations without restrictions or advisories (to either the UAS or manned aircraft). The small size of the Raven makes it difficult for other pilots to see-and-avoid the Raven, and appeared to be virtually impossible to acquire visually by ATC personnel in the tower. The JPL Blimp operations area is located immediately adjacent to and west of the departure end of Runway 17; departure traffic routinely flew near or through the area without restrictions or advisories.

ATC cleared the A-160 (i.e., Mariner 1) to operate in the east/west pattern, which is located in close proximity to the final approach course to Runway 17. ATC did not issue traffic advisories to Mariner 1 or issue restrictions to other manned aircraft. ATC did, however, issue an advisory to the Predator (i.e., Grizzly 21) flight as it returned from the Edwards Complex.

From an operational perspective, there are several types of incidents that adversely affect the safe, orderly, and expeditious movement of air traffic. These include MAC as well as other ACC, NMAC, OE, OD, RI, and PD. Concerning some of these measures, it is important to note that the focus of this study was to examine the potential effects of UAS operations on Class D airspace. By design, the simulation pilots, both manned and unmanned, were not the direct subject of study in this simulation. Therefore, any occurrences of pilot-induced incidents (e.g., PD, RI, or NMAC caused by pilot error or actions) are considered part of the realistic, complex situations presented to the controller participants and not reported as deficiencies or safety-related findings for the purposes of this evaluation.

Information concerning the study's valid incident safety measures are summarized in Table 116, with reported incident details provided in Table 117. In this 45-minute operation, ATC did not comply with the proper intersecting runway standards as prescribed in the FAO JO7110.65[21], resulting in the one OE depicted in Table 116 and Table 117.

[21] See FAO JO7110.65 paragraph 3-9-8.

Table 116: Scen20 Safety Metrics

Metric:	MAC	Other Accidents	NMAC	OE	OD	RI
Number of Incidents	0	0	0	1	0	0

Table 117: Scen20 Incident Table

Incident Type	Aircraft #1	Aircraft #2	Incident Description
OE	TNKR911	R50095	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4

4.3.11.3 Scen20 Efficiency

Several metrics were captured to evaluate the efficiency of the operation. Table 118 captures the observed occurrences of the efficiency metrics for this scenario. In the 45-minute scenario, one pilot-initiated go-around and two traffic pattern modifications were observed. These occurrences were not related to UAS operations.

Table 118: Scen20 Efficiency Metrics

Go-Arounds	
ATC Initiated Go-Arounds	0
Pilot Initiated Go-Arounds	1
Total	1
Delays	
Manned A/C Departure Delays	0
Manned Aircraft Arrival Delays	0
Unmanned A/C Departure Delays	0
Unmanned A/C Arrival Delays	0
Total	0
Traffic Pattern Modifications	
Extended Down-Winds	1
360° Turns	0
ATC Initiated Runway Changes	0
ATC Requested Short Approaches	0
ATC Requested Early Departure Turns	0
ATC Assigned Straight-Out/Runway Headings	1
Total	2
Miscellaneous Efficiency Measures	
Class D Airspace Denials	0
Re-Sequenced Arrivals	0
Re-Sequenced Departures	0
Altered and/or Cancelled Manned A/C Requests	0
Altered and/or Cancelled Unmanned A/C Requests	0
Total	0

Based on the data and input from the SME Observers, it does not appear that the addition of UAS operations affected the overall efficiency of Class D operations as simulated in this scenario.

4.3.11.4 Scen20 Communication

Voice communication is a key element of ATC. Many different communication anomalies can be indicative of traffic saturation and ATC loss of situation awareness. These types of occurrences include transposed call signs, missed transmissions, misidentified aircraft, and repeat ATC instructions. There were no observed occurrences in this scenario. (Note: simulation pilot communication errors are not reported since they were not the subject of study.)

However, ATC routinely failed to issue traffic advisories (in accordance with FAA JO 7110.65, paragraph 2-1-21) and/or restrictions between the UA operating within their defined areas and the manned aircraft. The ATC participants explained that the only means of communication

available between the ATC tower and the Raven or JPL Blimp operations was via landline. It is presumed that if these UAS PICs had an established method of communication (preferably via ATC radio frequency), the appropriate advisories would have been provided.

4.3.11.5 Scen20 Workload and Situation Awareness

In addition to the observations noted in the safety, efficiency, and communications section, other measures of workload and situation awareness were captured. Indicators of workload and situation awareness were captured during the simulation in several ways, such as PRQ, WAK data, and traffic count. Table 119 summarizes the traffic counts for this scenario.

Table 119: Scen20 Traffic Count

	Arrivals	Departures	Touch and Go's/ Low Approaches	Overflights
Count	11	11	6	7

After each run, participants and SME Observers were asked to provide subjective ratings about their assessment of workload and situation awareness by making ratings on a Likert scale of 1-7, where "1" corresponds to "Extremely Low" and "7" corresponds to "Extremely High." The Local controller and SME observing that position indicated below average ratings for overall workload and complexity. The ratings for the Ground control position were reported as below average by both the participant and the observer. Table 120 captures the responses.

Table 120: Scen20 Ratings of Overall Workload and Complexity

		Position			
		Local Controller	Local SME Observer	Ground Controller	Ground SME Observer
Metric:	Overall Complexity	3	3	1	2
	Overall Workload	3	3	1	2

Factors such as mental demand, effort, and the degree to which UAS required attention are some of the contributing factors to overall workload and complexity. Table 121 captures the PRQ responses pertaining to these factors. For this scenario, both Local and Ground controllers rated all aspects as below average (except for performance, which both rated as above average). These results are consistent with previous observations, indicating that this scenario, as simulated, provided the controllers with minimal challenge.

The REHOST also appeared to provide substantial benefit to the Local controller for maintaining situation awareness (rated 5 on a scale with "1" equal to "not at all" and "7" corresponding to "a great deal"). The Ground controller rated the degree to which REHOST helped a 2, indicating some benefit may have been gained.

Table 121: Scen20 PRQ Workload and Situation Awareness

		Position	
		Local Controller	Ground Controller
Metric:	Mental Demand:	3	1
	Physical Demand:	2	1
	Temporal Demand:	2	1
	Performance:	5	7
	Effort:	3	1
	Frustration:	2	1
	Amount of coordination with GC or LCL:	3	2
	Degree to which staffing GC affected workload (LCL Only):	2	N/A
	Assist with UAS operations other than GC (GC Only):	N/A	Yes, to keep an eye on airborne UAS
	If yes to having assisted with any UAS, did the assistance negatively affect your ability to accomplish your primary GC duties (GC Only):	N/A	No
	Degree to which UAS contributed workload:	3	1
	Degree to which UAS required additional attention:	2	1
	Degree to which REHOST helped maintain traffic awareness:	5	2

Participants were also asked to provide instantaneous workload ratings every two minutes during the run via a WAK located at each workstation. Graphed over time, the responses for this scenario are depicted in Figure 24.

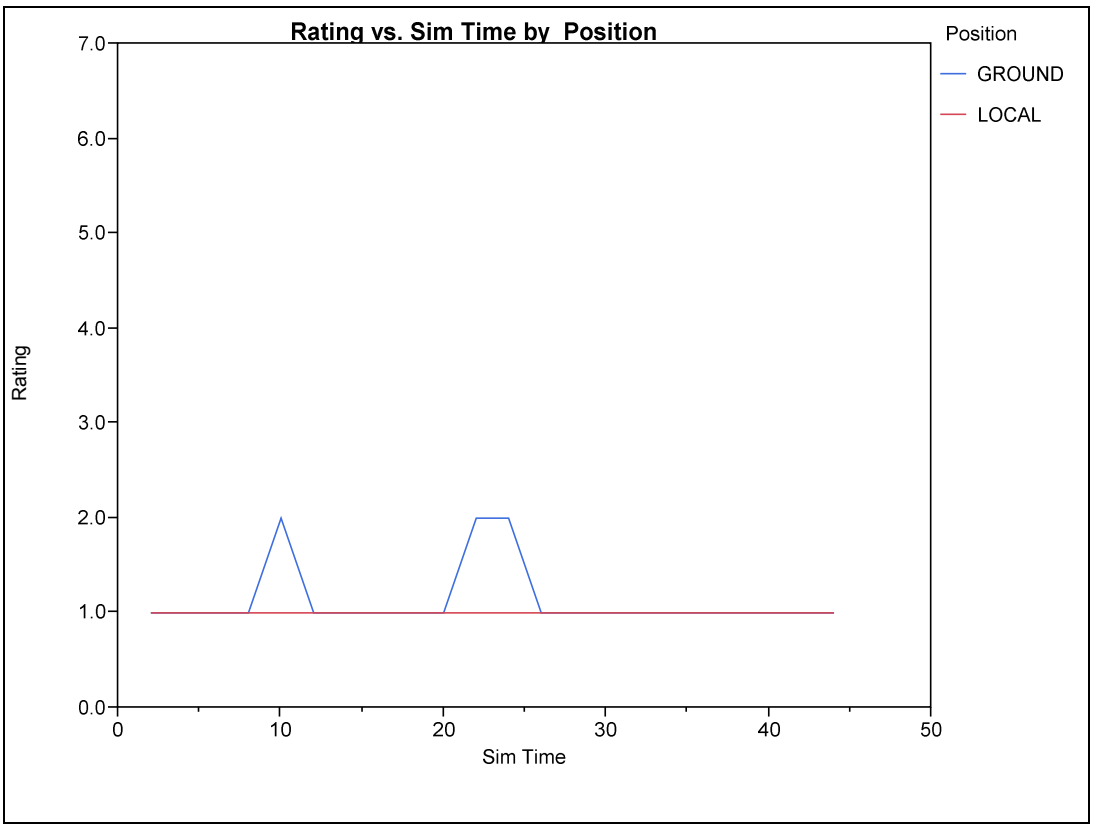

Figure 24: Scen20 WAK Data

In line with the questionnaire data, the controllers' self-reported workload throughout this scenario was rather low. The small variations in the Ground Controller's responses are likely attributed to normal fluctuations in workload due to regular variations in traffic operations.

Based on the data and input from the SME Observers, it does not appear that the addition of UAS operations adversely affected controller workload or situation awareness with respect to Class D operations, as simulated in this scenario.

4.3.11.6 Scen20 SME Observations

In addition to collecting the data discussed above, the SME analysis team made supplementary observations during their post-study analysis. These observations capture events, occurrences, and their effects on the scenario which were not recorded elsewhere.

Grizzly 21 arrived from Edwards Complex with its chase aircraft. The chase aircraft remained with Grizzly 21 until it landed. The chase aircraft then departed the KVCV Class D airspace to the east. It is unclear if, how, or when the observer duties were transferred from the chase aircraft to the visual ground observer for taxiing the UAS to parking.

Manned aircraft were routinely allowed to transgress the designated UAS operational areas without restrictions, and in most cases without any exchange of traffic information. This demonstrates a lack of proper and uniform application of FAA Order JO 7110.65 requirements.

SME noted that UAS that required the use of the runways were much more reliant on ATC for sequencing and spacing than manned aircraft pilots. This had the potential to increase controller workload and complexity.

SME noted that there is a need to establish standardized phraseology and ATC procedures for handling UAS.

4.3.11.7 Scen20 Findings

Upon examination of the complete set of data collected, the ATC operation as simulated in this scenario does not appear to be feasible with regard to the safe and efficient flow of air traffic.

4.3.12 Scenario 21

In line with the overall study objectives, the goal of Scenario 21 was to examine the effects of simultaneous multiple UAS platforms with dissimilar flight characteristics on local traffic pattern operations, ATC operations and Class D airspace. This scenario also included a scripted off nominal event.

4.3.12.1 Scen21 Design

Scenario 21 was developed with the following characteristics:

Airport and Weather Conditions: Simulation start-time was mid-afternoon and VFR prevailed throughout the scenario. Winds were 210° at 9kts. The active Runways were 21 and 17.

Manned Aircraft: Seventeen manned aircraft were introduced at random intervals to simulate normal traffic flows at the airport. Operations included both military and civilian departures, arrivals, over-flights, and local pattern work. Four additional VFR (1200 code) targets were injected to simulate over-flight traffic above and/or adjacent to the Class D airspace. These targets did not communicate with ATC.

*Special Military Operations***:** In addition to other manned military flights, an additional C17 Globemaster II, (Slam 88), was added to simulate specialized military tactical maneuvers practiced by USAF crews at KVCV and similar airports.

Ground Vehicles: Two ground vehicles were added to the scenario to replicate vehicular traffic at a typical airport. The vehicles simulated routine airfield maintenance and sweeping operations and communicated with ATC on the GC frequency.

Unmanned Aircraft Systems: Three UAS were included in this scenario — the AS800 JPL Blimp, A-160 Hummingbird, and MQ-1B Predator.

Off Nominal Event(s): Secondary to the multiple UAS traffic pattern operations, Scenario 21 also examined the effects of a Piper PA-34 Seneca (N744PA) engine failure on climb out from Runway 17. At the time of the emergency, which occurred at approximately 31 ½ minutes into the scenario, the AS800 JPL Blimp and A-160 Hummingbird were each in their respective operations areas, while the MQ-1B Predator was operating in the Runway 21 left closed traffic pattern (mid-field, left downwind).

4.3.12.2 Scen21 Safety

The ATC operations presented in this scenario were evaluated with regard to the safety and efficiency of the flow of traffic. Several notable observations are described in this section.

As rated on a 7-point scale in the PRQ, with "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High," both the Local and Ground controllers appeared to be highly confident in the safety of operations for this scenario, proving ratings of 6 and 7, respectively. The ground control SME Observer also seemed confident in the overall safety of the pattern sequence, rating this aspect of safety a 6 on the same scale. However, despite these results for this scenario, data and post-analysis observations suggest some safety concerns.

The location of the UAS operational areas in this scenario are in close proximity to departure paths of both Runways 17 and 21. Several aircraft flew through or in close proximity to these areas without any warnings or restrictions from ATC. In accordance with FAO JO7110.65[22], ATC shall issue traffic advisories to all aircraft involved when in their judgment proximity warrants it. In this particular operation, it appears that traffic advisories should have been issued to the JPL Blimp because traffic was flying near or through their operational area. The JPL Blimp does not have the capability to monitor ATC frequencies, so a telephone call would be required to advise their operators of potential traffic. The SME observing the Local controller also noted another possible advisory-related safety concern. During the emergency event, DOJ703, who was previously assigned and cleared to land on Runway 17, was re-assigned and cleared to land on Runway 21. DOJ703 was not advised that Mariner 1 was in the ATC-approved operational area.

From an operational perspective, there are several types of incidents that adversely affect the safe, orderly, and expeditious movement of air traffic. These include MAC as well as other ACC, NMAC, OE, OD, RI, and PD. Concerning some of these measures, it is important to note that the focus of this study was to examine the potential effects of UAS operations on Class D airspace. By design, the simulation pilots, both manned and unmanned, were not the direct subject of study in this simulation. Therefore, any occurrences of pilot-induced incidents (e.g., PD, RI, or NMAC caused by pilot error or actions) are considered part of the realistic, complex situations presented to the controller participants and not reported as deficiencies or safety-related findings for the purposes of this evaluation.

Information concerning the study's valid incident safety measures are summarized in Table 122, with reported incident details provided in Table 123. During this 45-minute simulation, there were three OE attributed to ATC, of which two involved UAS.

[22] FAO JO7110.65 2-1-21 states "Unless an aircraft is operating within Class A airspace or omission is requested by the pilot, issue traffic advisories to all aircraft (IFR or VFR) on your frequency when, in your judgment, their proximity may diminish to less than the applicable separation minima. Where no separation minima applies, such as for VFR aircraft outside of Class B/Class C airspace, or a TRSA, issue traffic advisories to those aircraft on your frequency when in your judgment their proximity warrants it."

Table 122: Scen21 Safety Metrics

Metric:	MAC	Other Accidents	NMAC	OE	OD	RI
Number of Incidents	0	0	0	3	0	0

Table 123: Scen21 Incident Table

Incident Type	Aircraft #1	Aircraft #2	Incident Description
OE	N744PA	Grizzly 21 *(UAS)*	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8/3-10-4
OE	N739HZ	TNKR911	Wake turbulence separation for intersection departures was not provided * Reference FAA JO 7110.65 Section 3-9-7
OE	Grizzly 21 *(UAS)*	OMEGA70	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8/3-10-4

4.3.12.3 Scen21 Efficiency

Several metrics were captured to evaluate the efficiency of the operation. Table 124 captures the observed efficiency metrics for this scenario. In the 45-minute simulation, one pilot initiated a go-around, four aircraft were delayed, and five traffic pattern modifications were observed. In addition, three Class D airspace denials and one re-sequenced arrival occurred.

Table 124: Scen21 Efficiency Metrics

Go-Arounds	
ATC Initiated Go-Arounds	0
Pilot Initiated Go-Arounds	1
Total	1
Delays	
Manned A/C Departure Delays	3
Manned Aircraft Arrival Delays	0
Unmanned A/C Departure Delays	0
Unmanned A/C Arrival Delays	1
Total	4
Traffic Pattern Modifications	
Extended Down-Winds	1
360° Turns	2
ATC Initiated Runway Changes	1
ATC Requested Short Approaches	0
ATC Requested Early Departure Turns	0
ATC Assigned Straight-Out/Runway Headings	1
Total	5
Miscellaneous Efficiency Measures	
Class D Airspace Denials	3
Re-Sequenced Arrivals	1
Re-Sequenced Departures	0
Altered and/or Cancelled Manned A/C Requests	0
Altered and/or Cancelled Unmanned A/C Requests	0
Total	4

On a 7 point scale, with "1" corresponding to "not at all" and "7" corresponding to "a great deal," the Local controller indicated the UAS had some effect on the efficiency of manned aircraft (rated as 4). The Local controller also suggested the UAS affected the traffic pattern, sequence, and capacity to a notable degree (rated as 3, 4, and 4, respectively). The Ground controller, however, reported that the UAS had no effect at all on manned aircraft ground operations (rated as 1).

As stated earlier in the scenario description, there was an emergency that involved a manned aircraft, N744PA. N744PA experienced an engine failure after performing a touch and go maneuver on Runway17. Ground control called Joshua Approach Control to inform them to keep all aircraft clear of the Class D airspace during the emergency. The Local controller reported that as a result of the emergency on Runway 17, all other traffic had to be rerouted to Runway 21 and some patterns had to be extended, thus delaying multiple aircraft. The Ground controller stated, "Local had to extend pattern on Runway 21 because all traffic went to Runway 21 because of the

emergency." An example of this was Grizzly 21 flying an extended downwind leg, causing an airborne delay to the UAS.

In addition to the effect on efficiency, the manned aircraft engine failure also appeared to have an effect on the overall manageability of operations for this scenario. On a Likert scale of 1-7, where "1" corresponds to "not at all" and "7" corresponds to "a great deal," both the Local and Ground controllers indicated the engine failure had a notable effect on manageability (rated 3 and 4, respectively). Both controllers also indicated the emergency had little or no effect on the JPL Blimp specifically (rated as 2 by Local, 1 by Ground), but both indicated it had some effect on other UAS operations in the scenario (rated as 3 for both).

4.3.12.4 Scen21 Communication

Voice communication is a key element of ATC. Many different communication anomalies can be indicative of traffic saturation and ATC loss of situation awareness. These types of occurrences include transposed call signs, missed transmissions, misidentified aircraft, and repeat ATC instructions. In this scenario, there was one missed transmission. (Note: simulation pilot communication errors are not reported since they were not the subject of study.)

The SME Observers reported that in some instances, the controllers used nonstandard phraseology in situations involving the UAS. They added that while this type of phraseology is sometimes necessary, it can lead to confusion, thus adding risk to the safety of operations. This demonstrates and suggests the need to examine standards for UAS-specific phraseology.

4.3.12.5 Scen21 Workload and Situation Awareness

In addition to the observations noted in the safety, efficiency, and communications section, other measures of workload and situation awareness were captured via the system recordings, PRQ, and WAK. Table 125 summarizes the traffic counts for this scenario.

Table 125: Scen21 Traffic Count

	Arrivals	Departures	Touch and Go's/ Low Approaches	Overflights
Count	17	17	11	5

After each run, participants and SME Observers were asked to provide subjective ratings about their assessment of workload and situation awareness by making ratings on a Likert scale of 1-7, where the "1" corresponding to "Extremely Low" and the "7" corresponding to "Extremely High."

The Local controller indicated that he experienced average workload and complexity (both rated as 4) for this scenario. The Ground controller also felt that he experienced average workload and complexity (both rated as 4); however, the Ground SME thought that it appeared as though the Ground controller experienced above average workload and complexity (rated as 5 and 6, respectively). Table 126 captures the responses.

Table 126: Scen21 Ratings of Overall Workload and Complexity

		Position			
		Local Controller	Local Observer (SME)	Ground Controller	Ground Observer (SME)
Metric:	Overall Complexity:	4	Not Answered	4	6
	Overall Workload	4	Not Answered	4	5

Factors such as mental demand, effort, and the degree to which the UAS required attention are some of the contributing factors to overall workload and complexity. Table 127 captures the PRQ responses pertaining to these factors for this scenario utilizing the Likert scales of 1-7, where "1" corresponds to "Extremely Low/Very Poor/Decreased a Great Deal/Not At All" and the "7" corresponds to "Extremely High/Very Good/ Increased a Great Deal/A Great Deal."

For this scenario, the Local controller rated his mental demand, physical demand, temporal demand, effort, and frustration as average or below average. However, he did indicate that the UAS contributed to workload to a notable degree (rated as 4) and that the UAS required a considerable amount of attention as compared to manned aircraft (rated as 6).

The Ground controller noted that he assisted the Local controller in keeping an eye on UAS operations, particularly the A-160 and JPL Blimp. The Ground controller rated his mental demand, physical demand, temporal demand, effort, and frustration as below average or well below average. He also indicated that the UAS did not contribute to his workload at all, nor did he provide any additional attention to the UAS as compared to manned aircraft (both rated as 1).

The REHOST also appeared to provide a notable benefit to both controllers for maintaining situation awareness (both rated it a 4 on a scale, with "1" equal to "not at all" and "7" corresponding to "a great deal").

Table 127: Scen21 PRQ Workload and Situation Awareness

		Position	
		Local Controller	Ground Controller
Metric:	Mental Demand:	4	3
	Physical Demand:	2	1
	Temporal Demand:	3	2
	Performance:	5	6
	Effort:	4	2
	Frustration:	4	1
	Amount of coordination with GC or LCL:	4	5
	Degree to which staffing GC affected workload (LCL Only):	2	N/A
	Assist with UAS operations other than GC (GC Only):	N/A	Yes, helped keep an eye on A160 & JPL
	If yes to having assisted with any UAS, did the assistance negatively affect your ability to accomplish your primary GC duties (GC Only):	N/A	No
	Degree to which UAS contributed workload:	4	1
	Degree to which UAS required additional attention:	6	1
	Degree to which REHOST helped maintain traffic awareness:	4	4

Furthermore, participants were asked to provide instantaneous workload ratings every two minutes during the run via a WAK located at each workstation. Graphed over time, the responses for this scenario are depicted in Figure 25.

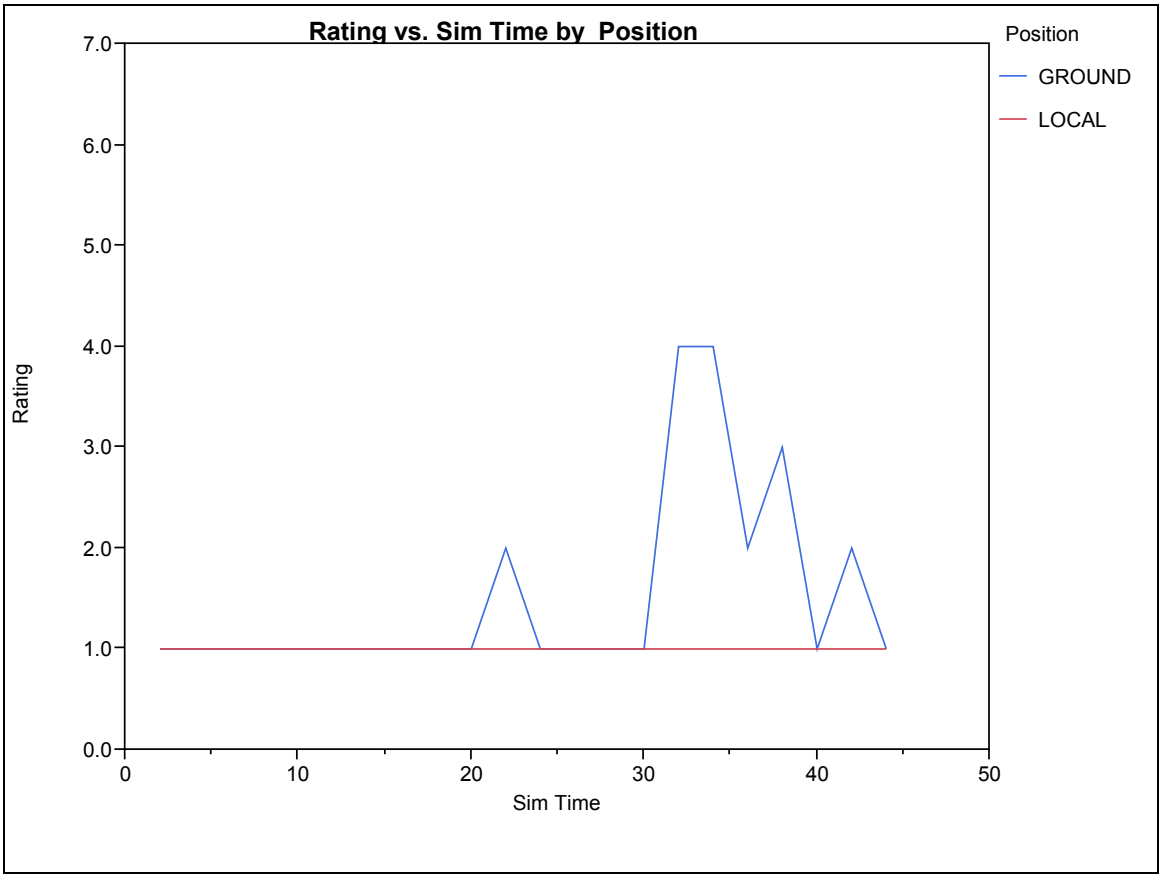

Figure 25: Scen21 WAK Data

In contrast to PRQ responses, the Local controllers' self-reported workload was consistently minimal. The Ground controller's workload was also rather low, but had some variation. The spike in ratings coincides in time with the occurrence of the manned aircraft engine failure that occurred during this scenario. Questionnaire data shows that the ground controller assisted the Local controller during the engine failure emergency (which began about 30 ½ minutes into the scenario) by coordinating with the adjacent sector. His WAK rating logically suggests that these added duties may have resulted in increased workload during this time.

4.3.12.6 Scen21 SME Observations

In addition to collecting data discussed above, the SME analysis team made supplementary observations during their post-study analysis. These observations capture events, occurrences, and their effects on the scenario which were not recorded elsewhere.

In this scenario, during the manned aircraft emergency, ATC instructed Grizzly 21 to extend its downwind traffic pattern leg in order to delay its arrival to the runway. This moved the aircraft approximately three to four miles northeast of the airport. No chase plane was present; therefore, ground observers would have been used to comply with the COA and the requirement to see and avoid. The SME Observers believe it is reasonable to conclude that this extended downwind leg, three to four miles northeast of Runway 21, is beyond the visual range of the ground observer(s). This raises the issue of where the responsibility for see and avoid lies for the UAS when ATC

issues an instruction to "extend downwind," potentially placing the UA beyond the sight of the Ground Observer.

SME noted that UAS that required the use of the runways were much more reliant on ATC for sequencing and spacing than manned aircraft pilots. This had the potential to increase controller workload and complexity.

SME noted that there is a need to establish standardized phraseology and ATC procedures for handling UAS.

4.3.12.7 Scen21 Findings

Upon examination of the complete set of data collected, the ATC operation simulated in this scenario does not appear to be feasible with regard to the safe and efficient flow of air traffic.

4.3.13 Scenario 22

In line with the overall study objectives, the goal of Scenario 22 was to examine the effects of simultaneous multiple UAS platforms with dissimilar flight characteristics on local traffic pattern operations, ATC operations, and Class D airspace. This scenario also included off nominal events.

4.3.13.1 Scen22 Design

Scenario 22 was developed with the following characteristics:

Airport and Weather Conditions: Simulation start-time was mid-afternoon and VFR prevailed throughout the scenario. Winds were 210° at 9kts. The active runways were 21 and 17.

Manned Aircraft: Seventeen manned aircraft were introduced at random intervals to simulate normal traffic flows at the airport. Operations included both military and civilian departures, arrivals, over-flights, and local pattern work. Four additional VFR (1200 code) targets were injected to simulate over-flight traffic above and/or adjacent to the Class D airspace. These targets did not communicate with ATC.

Special Military Operations: In addition to other manned military flights, an additional C17 Globemaster II (Slam 88) was added to simulate specialized military tactical maneuvers practiced by USAF crews at KVCV and similar airports.

Ground Vehicles: Two ground vehicles were added to the scenario to replicate vehicular traffic at a typical airport. The vehicles simulated routine airfield maintenance and sweeping operations and communicated with ATC on the GC frequency.

Unmanned Aircraft Systems: Two UAS were included in this scenario — the A-160 Hummingbird and MQ-1B Predator.

Off Nominal Event(s): Secondary to the multiple UAS traffic pattern operations, Scenario 22 also examined the effects of two events, one scripted the other unscripted. The scripted event featured both the Predator and Hummingbird requesting multiple closed traffic patterns to Runway 21,

creating interactions with the manned aircraft operating within the Class D airspace throughout the scenario. This scenario also examined the effects of an unscripted lost link incident involving the Predator. Though not planned, the event was considered plausible and therefore realistic, so the scenario was not re-run.

4.3.13.2 Scen22 Safety

The ATC operations presented in this scenario were evaluated with regard to the safety and efficiency of the flow of traffic. Several notable observations are described in this section.

As rated on a 7-point scale in the PRQ, with "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High," both participants appeared to be confident in the safety of operations for this scenario. The Local and Ground controllers rated their confidence levels as 5 and 6, respectively. Although the participants believed the operation to be safe, data and post-analysis observations indicated several safety concerns.

Although not self-reported by the participant on the PRQ, it was determined through post-study analysis by the SME analysis team that the Local controller appeared to lose situation awareness during this scenario. A major contributing factor was the simultaneous operations of the A-160 (Mariner 1) and the Predator (Grizzly 21) in the Runway 21 traffic pattern. Complicating the matter further, it appeared that flight characteristics of Mariner 1 made it too slow to mix efficiently with the manned aircraft. During a post-run debrief discussion about the transition of Mariner 1 to Runway 21, one participant remarked, "It's not feasible for ATC [to] operate them [the A-160s] on Runway 21. When we moved them [the A-160s] to Runway 21, it was operating at 40 kts and we had to mix with several aircraft operating at 140 kts [e.g., twin Cessna, Seneca]. Had to issue 360s [360 degree turns] on downwind, base, and final."

From an operational perspective, there are several types of incidents that adversely affect the safe, orderly, and expeditious movement of air traffic. These include MAC as well as other ACC, NMAC, OE, OD, RI, and PD. Concerning some of these measures, it is important to note that the focus of this study was to examine the potential effects of UAS operations on Class D airspace. By design, the simulation pilots, both manned and unmanned, were not the direct subject of study in this simulation. Therefore, any occurrences of pilot-induced incidents (e.g., PD, RI, or NMAC caused by pilot error or actions) are considered part of the realistic, complex situations presented to the controller participants and not reported as deficiencies or safety-related findings for the purposes of this evaluation.

Information concerning the study's valid incident safety measures are summarized in Table 128, with reported incident details provided in Table 129. In this 45-minute scenario, there were five incidents attributed to ATC. Specifically, there was one incident where ATC failed to properly coordinate the use of adjacent airspace as prescribed in FAO JO7110.65, Section 2-1-14, resulting in an OD. There were also four incidents where ATC did not comply with the proper intersecting runway standards as prescribed in the FAO JO7110.65, Sections 3-9-6/3-9-8/3-10-4, resulting in the OE depicted in Table 128 and Table 129.

Table 128: Scen22 Safety Metrics

Metric:	MAC	Other Accidents	NMAC	OE	OD	RI
Number of Incidents	0	0	0	4	1	0

Table 129: Scen22 Incident Table

Incident Type	Aircraft #1	Aircraft #2	Incident Description
OE	N744PA	N44EL	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
OE	Slam 88	N44EL	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
OE	Grizzly 21 *(UAS)*	DOJ703	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
OE	N44EL	Grizzly 21 *(UAS)*	Required same runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-6
OD	Slam 88	N/A	ATC Failed to coordinate use of adjacent airspace *Reference FAA JO 7110.65 Section 2-1-14

4.3.13.3 Scen22 Efficiency

Several metrics were captured to evaluate the efficiency of the operation as simulated. Table 130 captures the observed occurrences of the efficiency metrics for this scenario. In the 45-minute scenario, there were seven aircraft delays and 15 traffic pattern modifications observed. In addition, there was one occurrence of a manned aircraft having its request altered and/or cancelled due to the UAS in the operation.

Table 130: Scen22 Efficiency Metrics

Go-Arounds	
ATC Initiated Go-Arounds	0
Pilot Initiated Go-Arounds	0
Total	0
Delays	
Manned A/C Departure Delays	2
Manned Aircraft Arrival Delays	4
Unmanned A/C Departure Delays	0
Unmanned A/C Arrival Delays	1
Total	7
Traffic Pattern Modifications	
Extended Down-Winds	8
360° Turns	3
ATC Initiated Runway Changes	0
ATC Requested Short Approaches	0
ATC Requested Early Departure Turns	2
ATC Assigned Straight-Out/Runway Headings	2
Total	15
Miscellaneous Efficiency Measures	
Class D Airspace Denials	0
Re-Sequenced Arrivals	0
Re-Sequenced Departures	0
Altered and/or Cancelled Manned A/C Requests	1
Altered and/or Cancelled Unmanned A/C Requests	0
Total	1

The efficiency of the operation for this scenario appeared to be directly affected by the presence of the two UAS in the traffic pattern, which ultimately resulted in multiple delays to manned aircraft and UA. Evidence includes numerous occurrences of ATC issuing instructions for extended down winds, 360 degree turns, and other pattern modifications issued to manned aircraft and UA to maintain sequencing. Based on the data collected and SME Observations, these effects appear to be partially attributed to the dissimilar flight characteristics of the UAS (i.e., the low airspeed of Mariner 1). Another contributing factor was that UAS PIC currently do not have an alternate approved method to visually acquire and follow other aircraft, so additional effort was imposed on ATC to sequence them in the traffic pattern. For example, ATC had to call turns to the UAS and estimate proper safe operating distances near or behind other aircraft the UAS were following.

These observations are further supported by the Local controller's PRQ ratings on related measures. On a 7-point Likert scale, with "1" indicating "not at all" and "7" corresponding to "a great deal," the Local controller indicated airborne UAS operations affected his ability to accommodate manned aircraft a great deal (rated as 7). He indicated UAS operations also affected the efficiency of manned aircraft operations, the traffic pattern, sequence, and capacity a

great deal (all rated as 7). He rated the degree to which he provided priority handling to UAS over manned aircraft (excluding emergency situations) very high (rated as 6).

The Ground controller had very limited direct interaction with the UAS in this scenario. On the same 7-point Likert scale, with "1" indicating "not at all" and "7" corresponding to "a great deal," he indicated that UAS operations had no effect on his ability to accommodate manned aircraft, and that UAS operations had minimal effect on ground operations (rated as 2).

4.3.13.4 Scen22 Communication

Voice communication is a key element of ATC. Many different communication anomalies can be indicative of traffic saturation and ATC loss of situation awareness. These types of occurrences include transposed call signs, missed transmissions, misidentified aircraft, and repeat ATC instructions. In this scenario, there were two instances of transposed instructions, one instance of excessive/repeated ATC instruction, one misidentified aircraft, six missed transmissions, and one repeat transmission. (Note: simulation pilot communication errors are not reported since they were not the subject of study.)

4.3.13.5 Scen22 Workload and Situation Awareness

In addition to the observations noted in the safety, efficiency, and communications section, other measures of workload and situation awareness were captured via the system recordings, PRQ, and WAK. Table 131 summarizes the traffic counts for this scenario.

Table 131: Scen22 Traffic Count

	Arrivals	Departures	Touch and Go's/ Low Approaches	Overflights
Count:	27	25	21	3

After each run, the participants and SME Observers were asked to provide subjective ratings about their assessment of workload and situation awareness by making ratings on a Likert scale of 1-7, where "1" corresponds to "Extremely Low" and "7" corresponds to "Extremely High."

The Local controller rated the overall complexity and workload of this scenario as relatively high (both rated as 6). The SME Observer of this position also indicated above average ratings (both rated as 5). In contrast, the Ground controller and SME Observer rated the overall complexity and work as below average (both rated as 3 by both). Table 132 captures the responses.

Table 132: Scen22 Ratings of Overall Workload and Complexity

		Position			
		Local Controller	Local SME Observer	Ground Controller	Ground SME Observer
Metric:	Overall Complexity	6	5	3	3
	Overall Workload	6	5	3	3

Factors such as mental demand, effort, and the degree to which UAS required attention are some of the contributing factors to overall workload and complexity. Table 133 captures the PRQ responses pertaining to these factors.

On the scale with "1" equal to "Very Poor" and "7" corresponding to "Very Good," both controllers rated their performance a 5, or above average, for this scenario.

On the scale with "1" equal to "Extremely Low" and "7" corresponding to "Extremely High," the Local controller rated his frustration as average, and his mental demand, physical demand, and temporal demand as above average to extremely high. He also indicated the UAS contributed a great deal to workload, and that the UAS required a great deal of attention as compared to manned aircraft (both rated as 7, on a scale with "1" equal to "not at all" and "7" corresponding to "a great deal").

The Ground controller also rated his frustration as average, but rated his mental demand, physical demand, temporal demand, and effort as well below average. He also indicated that the UAS did not contribute to his workload at all, nor did he provide any additional attention to the UAS as compared to manned aircraft.

By design, the Ground control position was always staffed for this study. Although on the PRQ the Ground controller reported he did not assist with UAS operations other than for ground control operations, the SME observed him consistently assisting the Local controller with the position of aircraft and situation awareness when UAS were present.

The REHOST also appeared to provide considerable benefit to the Local controller for maintaining situation awareness (rated 6 on a scale, with "1" equal to "not at all" and "7" corresponding to "a great deal").

Table 133: Scen22 PRQ Workload and Situation Awareness

		Position	
		Local Controller	Ground Controller
Metric:	Mental Demand:	7	1
	Physical Demand:	5	1
	Temporal Demand:	6	1
	Performance:	5	5
	Effort:	6	2
	Frustration:	4	4
	Amount of coordination with GC or LCL:	4	5
	Degree to which staffing GC affected workload (LCL Only):	1	N/A
	Assist with UAS operations other than GC (GC Only):	N/A	No
	If yes to having assisted with any UAS, did the assistance negatively affect your ability to accomplish your primary GC duties (GC Only):	N/A	N/A
	Degree to which UAS contributed workload:	7	3
	Degree to which UAS required additional attention:	7	2
	Degree to which REHOST helped maintain traffic awareness:	6	Not Rated

Additional information that aligns with the generally high ratings for the Local controller's position includes the controller's own comment that he had reached a point of workload saturation. Specifically, he remarked, "I was at max capacity." Through observations made during the run and in post-simulation analysis, the SME Observers determined that the Local controller had not only reached a point of workload saturation, but in their opinion he had also lost situation awareness.

Participants were also asked to provide instantaneous workload ratings every two minutes during the run via a WAK located at each workstation. Graphed over time, the responses for this scenario are depicted in Figure 26.

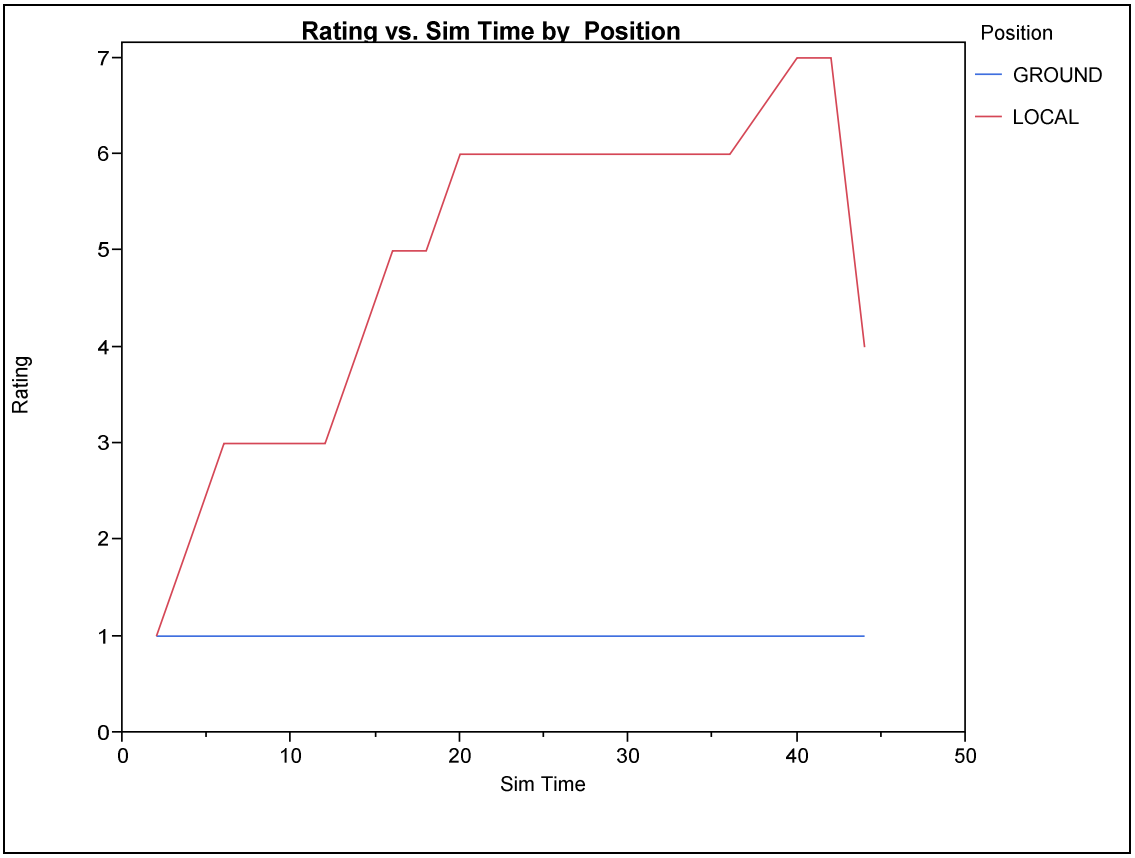

Figure 26: Scen22 WAK Data

In line with PRQ results concerning workload, the Local controller's self-reported instantaneous workload throughout this scenario was rather high. In contrast, but also consistent with PRQ results, the Ground controller rated his workload very low throughout this scenario. Although it is clear from Figure 26 that the Local controller's workload steadily increased throughout the scenario, the final spike in the graph coincides with the occurrence of the unscripted Predator lost link event that occurred at approximately 39 minutes into the scenario.

Based on SME observations and many contributing factors previously identified, approximately 30 minutes into the run the operation presented in this scenario appeared to become unmanageable with regard to the safe and efficient flow of traffic.

4.3.13.6 Scen22 SME Observations

In addition to collecting the data discussed above, the SME analysis team made supplementary observations during their post-study analysis. These observations capture events, occurrences, and their effects on the scenario which were not recorded elsewhere.

The defined purpose of the ground observer is to provide the see-and-avoid responsibility per FAR 91.113. In this scenario, ATC extends the downwind traffic pattern out to 3-4 miles from the approach end of the runway to accommodate the two UAS simultaneously operating in the Runway 21 pattern. This necessitated extending the UAS flights well beyond the visual range of the UAS ground observers. This also raises the question of who is responsible for collision avoidance when a UAS receives instructions to extend downwind beyond the visual range of the ground observer. As observed in this scenario, this issue is not clearly defined in today's environment.

Since UAS PIC are not on board the aircraft, and they currently do not have an alternate approved method to visually acquire and follow other aircraft[23], additional workload is imposed on ATC to sequence them in a traffic pattern. For example, in this scenario, ATC was required to call turns to the UAS when operating in the traffic pattern with other aircraft. ATC also had to estimate proper safe operating distances near or behind other aircraft the UAS were following. This raises several concerns. These include questions about: ATC's responsibility for safe distances; whether ATC's attention is being distracted from higher priority duties; how to safely mitigate an increase to ATC workload; how are the effects of wake turbulence considered; and what are the ground observer's roles regarding visual separation, visual sequencing, and wake turbulence considerations relating to other aircraft in the airspace?

SME noted that UAS which required the use of the runways were much more reliant on ATC for sequencing and spacing than manned aircraft pilots. This had the potential to increase controller workload and complexity.

SME noted that there is a need to establish standardized phraseology and ATC procedures for handling UAS.

Finally, though KVCV recently acquired the REHOST radar display, it was evident to the SME Observers during this run that the lack of full aircraft data blocks associated with targets appeared to cause an increase to the workload of the Local control position.

4.3.13.7 Scen22 Findings

Upon examination of the complete set of data collected, the ATC operation simulated in this scenario does not appear to be feasible with regard to the safe and efficient flow of air traffic.

4.3.14 Scenario 23

In line with the overall study objectives, the goal of Scenario 23 was to examine the effects of simultaneous multiple UAS platforms with dissimilar flight characteristics on local traffic pattern operations, ATC operations, and Class D airspace.

The scenario also included off-nominal events.

[23] Reference JO 7110.65, paragraph 3-8-1, SEQUENCE/SPACINGAPPLICATION Establish the sequence of arriving and departing aircraft by requiring them to adjust flight or ground operation, as necessary, to achieve proper spacing.

4.3.14.1 Scen23 Design

Scenario 23 was developed with the following characteristics:

Airport and Weather Conditions: Simulation start-time was mid-afternoon, and Visual Flight Rules (VFR) prevailed throughout the scenario. Winds were 210° at 9kts. The active runways were 21 and 17.

Manned Aircraft: Seventeen manned aircraft were included to simulate normal traffic flows at the airport. Operations included both military and civilian departures, arrivals, over-flights, and local pattern work. Four additional VFR (1200 code) targets were introduced to simulate over-flight traffic above and/or adjacent to the Class D airspace, and did not communicate with ATC.

Special Military Operations: In addition to other manned military flights, an additional C17 Globemaster II (Slam 88), was added to simulate specialized military tactical maneuvers practiced by USAF crews at KVCV and similar airports.

Ground Vehicles: Two ground vehicles were added to the scenario to replicate vehicular traffic at a typical airport. The vehicles simulated routine airfield maintenance and runway sweeping operations, and communicated with ATC on the GC frequency.

Unmanned Aircraft Systems: Three UAS were included in this scenario; the AS800 JPL Blimp, and two A-160 Hummingbirds. The A-160s were introduced at different times during the scenario. . The approved operating area of the JPL Blimp was north of Runway 21 and west of Runway 17, at or below 700' AGL. The approved operating area for the A-160s was 2-3 miles north of Runway 21 and east of the extended centerline of Runway 17, surface to 5,000' MSL, and Class D airspace including traffic patterns for both runways and the Warrior Ramp.

Off Nominal Event(s): Secondary to the simultaneous multiple UAS operations, Scenario 23 also examined one A-160 which was airborne at the start of the scenario, within the confines of its normal operations area, northeast of the airport. Five minutes into the scenario, the second A-160 departed and requested closed traffic operations at the Warrior Ramp. Approximately 10 minutes later, the first A-160 requested to terminate operations and return for landing at the Warrior Ramp, with the second A-160 still in the closed traffic pattern.

4.3.14.2 Scen23 Safety

The ATC operations presented in this scenario were evaluated with regards to the safety and efficiency of the flow of traffic. Several notable observations are described in this section.

As delineated in the COA, there are segregated areas of airspace in which individual UAS operations are conducted. In this scenario, there were two separate segregated areas of airspace in use. ATC treated these areas as sterile restricted airspaces, but did not restrict manned aircraft from these areas. UAS segregation from manned aircraft was exhibited when the Warrior Ramp was used only for UAS ops.

Manned traffic was operating on Runway 21 and Runway 17, making it impossible for either of the A-160s to move to either runway.

Segregation of UAS from manned aircraft can create a false sense of security for ATC especially if an unpredictable event occurs. In this scenario, one A-160 remained within its ops area; however, its operation required multiple advisories to arriving aircraft as noted by an SME Observer.

This scenario was deemed unmanageable, as stated in the daily debrief, and became so when an A-160 was inbound on the Warrior Ramp at the same time as another A-160 was operating in the Warrior Ramp's closed traffic pattern. Although the Local controller authorized two simultaneous A-160 operations on the same runway, from the SME Observer's perspective, it appeared that this required too much of the Local controller's attention. In respect to workload and situation awareness, the situation seemed to get a bit confusing for the controllers, since there were no clearly defined landing areas with a minimum of 200 feet between them[24].

The Local controller noted post scenario that he did not feel there was a conflict when the two A-160 helicopters returned to base and was fairly confident in the safety of operations. Rated on a 7-point scale in the PRQ, with "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High", both local and ground controllers had just above average to extremely high confidence levels for safe operations (ratings of 5 and 7 respectively). SME observers had average to just above average confidence ratings in the overall safety of pattern sequence (local SME rating: 4, ground SME rating: 5), and both SME observers had just above average confidence levels in overall safety and efficiency of traffic flow (both ratings: 5).

Although the confidence levels were noted as being above average and the Local controller did not report any conflicts, post-run analysis showed that the scenario reached a point of unmanageability when both A-160 UAS tried to operate simultaneously at and near the Warrior Ramp. ATC's failure to issue safety advisories with respect to wake turbulence contributed to this dynamic. SME observed that no advisories were issued pertaining to Slam 88's flight with respect to other departures from Runway 17[25].

Another safety concern observed was when the UAS flew in close proximity to other manned aircraft. ATC generally did not issue traffic or safety advisories. This demonstrated a lack of proper and uniform application of 7110.65 rules[26] and also contributed to the unmanageability of this scenario.

From an operational perspective, there are several types of incidents that adversely affect the safe, orderly and expeditious movement of air traffic. These include MAC, other ACC, NMAC, OE, OD, RI, and PD. Concerning some of these measures, it is important to note that focus of this study was to examine the potential effects of UAS operations on Class D airspace. By design, the simulation pilots, both manned and unmanned, were confederates in this simulation (i.e., not the direct subjects of study). Therefore, any occurrences of pilot-induced incidents (e.g., PD, RI or NMAC caused by pilot error or actions) are considered part of the realistic, complex situations presented to the controller participants and not reported as deficiencies or safety related findings for the purposes of this evaluation.

[24] See FAA0 7110.65 section 3-11-5.
[25] See FAAO 7110.65 section 2-1-20.
[26] See FAAO 7110.65 section 2-1-21.

Information concerning the study's incident safety measures are summarized in Table 134, with reported incident details provided in Table 135. In this 45-minute operation, ATC did not comply with the proper intersecting runway standards as prescribed in the FAO JO7110.65T[27], resulting in the three OE depicted in Table 134 and Table 135.

Table 134: Scen23 Safety Metrics

Metric:	MAC	Other Accidents	NMAC	OE	OD	RI
Number of Incidents	0	0	0	3	0	0

Table 135: Scen23 Incident Table

Incident Type	Aircraft #1	Aircraft #2	Incident Description
OE	Slam 88	Tanker 911	Required intersecting runway separation was not provided[1]
OE	Slam 88	N44EL	Required intersecting runway separation was not provided[2]
OE	R50095	N739HZ	Required intersecting runway separation was not provided[3]

4.3.14.3 Scen23 Efficiency

Several metrics were captured to evaluate the efficiency of the operation simulated. Table 136 captures the observed occurrences of the efficiency metrics for this scenario. In the 45-minute operation, one ATC initiated go-around, three aircraft delays, and five traffic pattern modifications were observed. In addition, there were two instances where manned aircraft requests were altered and/or cancelled.

[27] See FAO JO7110.65 paragraph 3-9-8.

Table 136: Scen23 Efficiency Metrics

Go-Arounds	
ATC Initiated Go-Arounds	1
Pilot Initiated Go-Arounds	0
Total	1
Delays	
Manned A/C Departure Delays	0
Manned Aircraft Arrival Delays	2
Unmanned A/C Departure Delays	0
Unmanned A/C Arrival Delays	1
Total	3
Traffic Pattern Modifications	
Extended Down-Winds	2
360° Turns	2
ATC Initiated Runway Changes	1
ATC Requested Short Approaches	0
ATC Requested Early Departure Turns	0
ATC Assigned Straight-Out/Runway Headings	0
Total	5
Miscellaneous Efficiency Measures	
Class D Airspace Denials	0
Re-Sequenced Arrivals	0
Re-Sequenced Departures	0
Altered and/or Cancelled Manned A/C Requests by ATC	2
Altered and/or Cancelled Unmanned A/C Requests by ATC	0
Total	2

The efficiency of the operation for this scenario appears to be affected by the A-160 flight operations that were inbound to the Warrior Ramp. This resulted in delays to manned aircraft (e.g. N44EL experienced a delay in order to accommodate the two A-160 flights that were inbound and turning base to the Warrior ramp).

On a 7-point scale where, “1” corresponds to “Not at All” and “7” corresponds to “A Great Deal”, the Local controller reported that UAS operations had a considerable effect on his ability to accommodate manned aircraft and on the efficiency of manned aircraft ops (both rated 5). In contrast, both Local and Ground controllers reported that the UAS did not at all affect the traffic pattern, the sequence of traffic or the capacity of traffic (all rated 1).

4.3.14.4 Scen23 Communication

Voice communication is a key element of air traffic control. Many different communication anomalies can be indicative of traffic saturation and ATC loss of situation awareness. These types of occurrences include transposed call signs, missed transmissions, misidentified aircraft, and repeat ATC instructions.

In this scenario, the SME analysis team observed one instance where the Ground controller missed a transmission. (Note: simulation pilot communication errors are not reported since they were not the subjects of study.)

4.3.14.5 Scen23 Workload and Situation Awareness

In addition to the observations noted in the safety, efficiency, and communications section, other measures of workload and situation awareness were captured via the system recordings, PRQ, and WAK.

Table 137 summarizes the traffic counts for this scenario.

Table 137: Scen23 Traffic Count

	Arrivals	Departures	Touch and Go's/Low Approaches	Overflights
Count	26	26	21	5

After each run, participants and SME Observers were asked to provide subjective ratings about their assessment of workload and situation awareness by marking ratings on a Likert scale of 1-7, where "1" corresponds to "Extremely Low" and the "7" responds to "Extremely High".

The Local controller indicated he experienced an average overall complexity and workload. The Local SME Observer also reported that the overall complexity and workload of the Local controller were both average.

By design, the Ground control position was staffed; however, the controller did not assist with any UAS operations other than ground control operations and therefore had no interaction with the UAS. Therefore the workload of the Ground controller was rated as very low by the Ground controller and the SME Observer who was observing him. Table 138 captures the responses.

Table 138: Scen23 Ratings of Overall Workload and Complexity

		Position			
		Local Controller	Local SME Observer	Ground Controller	Ground SME Observer
Metric:	Overall Complexity	4	4	2	2
	Overall Workload	4	4	2	2

Factors such as mental demand, effort, and the degree in which UAS required attention are some of the contributing factors to overall workload and complexity. Table 139 captures the PRQ responses pertaining to these factors for this scenario utilizing the same Likert scale of 1-7, where "1" corresponds to "Extremely Low" and the "7" responds to "Extremely High."

On the scale with "1" equal to "Very Poor" and "7" corresponding to "Very Good", the Local controller self-rated his performance as just above average. The Ground controller rated his performance level as very good.

On the scale with "1" equal to "Extremely Low" and "7" corresponding to "Extremely High", the Local controller rated his physical demand as very low, his mental demand and temporal demand as just below average and his effort and frustration level as average. In contrast, on the scale in which "1" corresponds to "Not at All" and "7" corresponds to "A Great Deal", the Local controller reported that the UAS had a notable effect on his workload (rated 4), and that the degree in which the UAS required additional attention was considerable. The SME observers noted that it appeared that the Local controller had difficulty maintaining situation awareness when both A-160s were inbound and approaching the Warrior Ramp at the same time. This appeared to be due to the amount of attention required to handle the two UAS simultaneously.

The Ground controller rated his mental demand, physical demand, and temporal demand as extremely low, and his effort and frustration as very low. He reported that the UAS did not require any additional attention as compared to manned aircraft.

Participants were also asked to provide subjective ratings about the degree to which the REHOST display helped them maintain traffic awareness on the scale where "1" corresponds to "Not at all" and the "7" corresponds to "A Great Deal." The Local controller reported that it had a significant effect on his ability to maintain situation awareness; the Ground controller reported that it had a notable effect on his ability. Therefore, it can be inferred that the situation awareness of both of the controllers benefited from the system.

The REHOST also seemed to have helped maintain situation awareness a great deal as it was rated on the high end of the scale by the Local controller and average by the Ground controller. Finally, performance by both controllers was self-rated as above average.

Table 139: Scen23 PRQ Workload and Situation Awareness

		Position	
		Local Controller	Ground Controller
Metric:	Mental Demand:	3	1
	Physical Demand:	2	1
	Temporal Demand:	3	1
	Performance:	5	7
	Effort:	4	2
	Frustration:	4	2
	Amount of coordination with GC or LCL:	3	4
	Degree to which staffing GC affected workload (LCL Only):	2	N/A
	Assist with UAS operations other than GC (GC Only):	N/A	Not Rated
	If yes to having assisted with any UAS, did the assistance negatively affect your ability to accomplish your primary GC duties (GC Only):	N/A	N/A
	Degree to which UAS contributed workload:	5	N/A
	Degree to which UAS required additional attention:	6	1
	Degree to which REHOST helped maintain traffic awareness:	6	4

Participants were asked to provide instantaneous workload ratings every two minutes during the run, via a WAK located at each workstation. Graphed over time, the responses for this scenario are depicted in Figure 27.

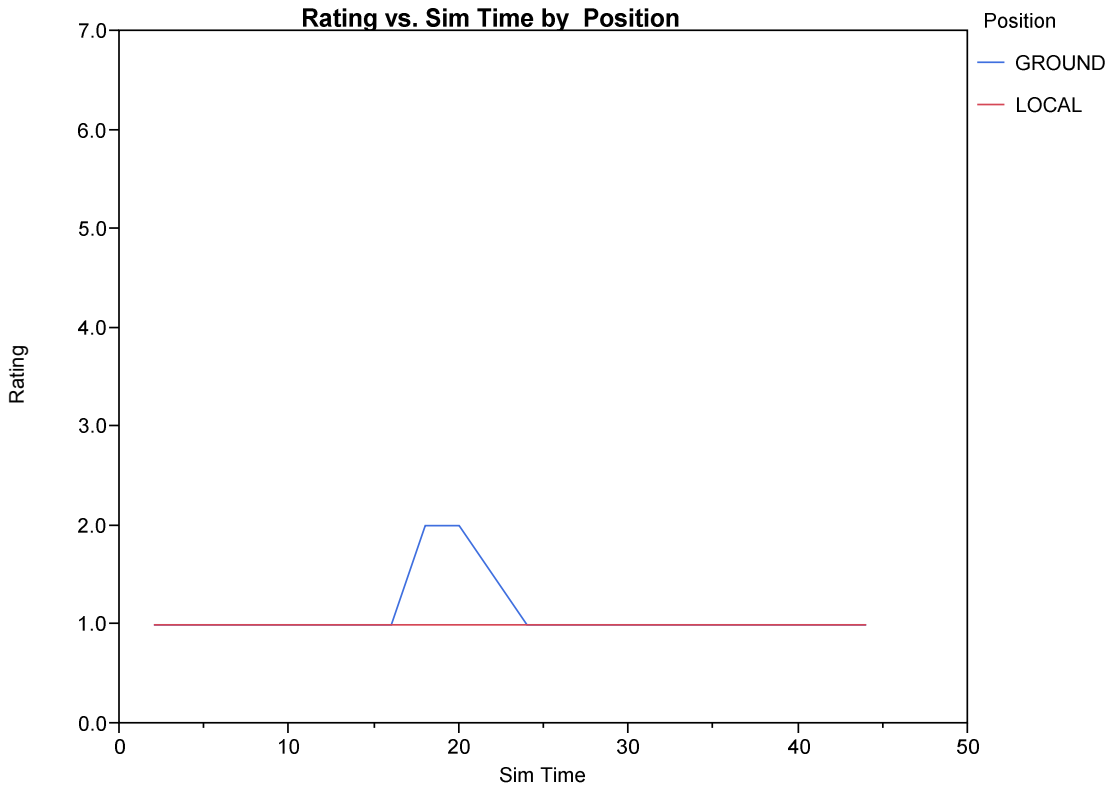

Figure 27: Scen23 WAK Data

In line with the questionnaire data, the controllers' self-reported workload throughout this scenario was rather low. The small peak in the graph coincides in time with the simultaneous operations of two A-160s in this scenario. This supports SME observations suggesting that these simultaneous operations presented an issue to the controllers, and in turn, slightly increased workload.

4.3.14.6 Scen23 SME Observations

In addition to collecting data discussed above, the SME analysis team made supplementary observations during their post study analysis. These observations capture events, occurrences, and their effects on the scenario which were not recorded elsewhere.

In this scenario SME Observers noted an issue of landing two UAS helicopters on the same ramp without having a clearly defined separate landing area with minimum separation[28]. Without verbal acknowledgement that the first aircraft had landed and was clear of the landing area, the second aircraft could not be permitted to land. At the current time, it is not clearly defined who is responsible to call the area clear (i.e., pilot, ground observer, or the ground crew); in this scenario, ATC took on this responsibility.

[28] See FAA0 7110.65 section 3-11-5.

SME noted that UAS which required the use of the runways were much more reliant on ATC for sequencing and spacing than manned aircraft pilots. This had the potential to increase controller workload and complexity.

SME noted that there is a need to establish standardized phraseology and ATC procedures for handling UAS.

SME suggested that discussions need to take place to clearly define the roles and responsibilities of multiple visual observers.

4.3.14.7 Scen23 Findings

Upon examination of the complete set of data collected, the ATC operation simulated in this scenario does not appear to be feasible with regard to the safe and efficient flow of air traffic.

4.3.15 Scenario 24

In line with the overall study objectives, the goal of Scenario 24 was to examine the effects of simultaneous multiple UAS platforms with dissimilar flight characteristics on local traffic pattern operations, ATC operations, and Class D airspace. The scenario also included off-nominal events.

4.3.15.1 Scen24 Design

Scenario 24 was developed with the following characteristics:

Airport and Weather Conditions: Simulation start-time was mid-afternoon, and Visual Flight Rules (VFR) prevailed throughout the scenario. Winds were 210° at 9kts. The active runways were 21 and 17.

Manned Aircraft: Seventeen manned aircraft were included to simulate normal traffic flows at the airport. Operations included both military and civilian departures, arrivals, over-flights, and local pattern work. Four additional VFR (1200 code) targets were introduced to simulate over-flight traffic above and/or adjacent to the Class D airspace, and did not communicate with ATC.

Special Military Operations: In addition to other manned military flights, an additional C17 Globemaster II (Slam 88), was added to simulate specialized military tactical maneuvers practiced by USAF crews at KVCV and similar airports.

Ground Vehicles: Two ground vehicles were added to the scenario to replicate vehicular traffic at a typical airport. The vehicles simulated routine airfield maintenance and runway sweeping operations, and communicated with ATC on the GC frequency.

Unmanned Aircraft Systems: Four UAS were included in this scenario; the AS800 JPL Blimp, RQ-11 Raven, A-160 Hummingbird, and the MQ-1B Predator. Although not a UAS, the Predator Chase aircraft, a manned Mooney MO20, was included in the scenario to simulate the requirements of the current COA. The approved operating area for the A-160 was 2-3 miles north of Runway 21 and east of the extended centerline of Runway 17, surface to 5,000' MSL. The approved operating area for the MQ-1B Predator was Class D airspace including traffic

patterns to both runways. The approved operating area of the JPL Blimp was north of Runway 21 and west of Runway 17, at or below 700' AGL. The approved operating area for the Raven was southeast of Runway 21 over the old housing area, at or below 400' AGL.

Off Nominal Event(s): Secondary to the simultaneous multiple UAS operation, Scenario 24 also examined the effects of an indefinite REHOST failure. The REHOST failure began 20 minutes into the scenario and was inoperable for the remainder of the scenario. During the scenario, the AS800 was within the defined operations area, southwest of runway 17; the A-160 Hummingbird was within the "East-West" operations pattern northeast of the airport; and the RQ-11 Raven was within the operational area over the former base housing located at the airport. Additionally, the Predator and Predator chase aircraft returned from the Edwards Complex, where the Predator completed a full-stop arrival at KVCV and the chase aircraft departed the Class D airspace to the east.

4.3.15.2 Scen24 Safety

The ATC operations presented in this scenario were evaluated in regard to the safety and efficiency of the flow of traffic. Several notable observations are described in this section.

On a 7-point scale in the PRQ, with a "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High," both Ground and Local controllers rated their confidence level for safe operations in the scenario as 7. This indicates that they appeared to be extremely confident in the safety of operations.

Although the Local and Ground controllers appeared to be confident in the safety of operations, the data and post-analysis observations appear to show some safety concerns.

The Local SME Observer rated the overall safety of pattern sequence as just below average (rated as 3); the Ground SME Observer rated it as very high. Overall, the SME ratings for the overall safety and efficiency of traffic flow did not coincide — the Local SME Observer viewed the safety of the operations as just below average and the efficiency of operation as just above average while the Ground SME Observer viewed the safety of operations as very high and the efficiency as just below average.

Post analysis, the SME observers noted that ATC did not consistently issue safety and traffic advisories to manned and unmanned aircraft. Specifically, it was observed that N744PA in right traffic Runway and the A-160 in the Mariner operation area received no advisories (of each other). Additionally, when Slam 88 was on the "abeam approach maneuver" and flew through the Raven ops area with the Raven airborne at the same altitude, it received no traffic or safety advisory.

From an operational perspective, there are several types of incidents that adversely affect the safe, orderly and expeditious movement of air traffic. These include MAC, other ACC, NMAC, OE, OD, RI, and PD. Concerning some of these measures, it is important to note that focus of this study was to examine the potential effects of UAS operations on Class D airspace. By design, the simulation pilots, both manned and unmanned, were confederates in this simulation (i.e., not the direct subjects of study). Therefore, any occurrences of pilot-induced incidents (e.g., PD, RI or NMAC caused by pilot error or actions) are considered part of the realistic, complex

situations presented to the controller participants and not reported as deficiencies or safety related findings for the purposes of this evaluation.

Information concerning the study's incident safety measures are summarized in Table 140, with reported incident details provided in Table 141. In this 45-minute operation, ATC did not comply with the proper intersecting runway standards as prescribed in the FAO JO7110.65T[29], resulting in the six OE depicted in Table 140 and Table 141.

Table 140: Scen24 Safety Metrics

Metric:	MAC	Other Accidents	NMAC	OE	OD	RI
Number of Incidents	0	0	0	6	0	0

Table 141: Scen24 Incident Table

Incident Type	Aircraft #1	Aircraft #2	Incident Description
OE	Slam 88	TNKR911	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section 3-9-8
OE	Slam 88	N744PA	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section 3-9-8
OE	Grizzly 21 *(UAS)*	R50095	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section 3-9-8
OE	SWA3471	N739HZ	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section 3-9-8
OE	OMEGA70	N44EL	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section 3-9-8
OE	OMEGA70	Slam 88	Required same runway separation was not provided * Reference FAA JO 7110.65 Section 3-9-6

[29] See FAO JO7110.65 paragraph 3-9-8.

4.3.15.3 Scen24 Efficiency

Several metrics were captured to evaluate the efficiency of the operation simulated. In the 45-minute operation, one ATC initiated go-around, one aircraft delay and three traffic pattern modifications were observed. In addition, there was one instance where a manned aircraft had its request cancelled/altered due to the UAS in the operation. Table 142 captures the observed efficiency metrics for this scenario.

Table 142: Scen24 Efficiency Metrics

Go-Arounds	
ATC Initiated Go-Arounds	1
Pilot Initiated Go-Arounds	0
Total	1
Delays	
Manned A/C Departure Delays	1
Manned Aircraft Arrival Delays	0
Unmanned A/C Departure Delays	0
Unmanned A/C Arrival Delays	0
Total	1
Traffic Pattern Modifications	
Extended Down-Winds	0
360° Turns	0
ATC Initiated Runway Changes	3
ATC Requested Short Approaches	0
ATC Requested Early Departure Turns	0
ATC Assigned Straight-Out/Runway Headings	0
Total	3
Miscellaneous Efficiency Measures	
Class D Airspace Denials	0
Re-Sequenced Arrivals	0
Re-Sequenced Departures	0
Altered and/or Cancelled Manned A/C Requests	1
Altered and/or Cancelled Unmanned A/C Requests	0
Total	1

On a 7-point scale, with "1" corresponding to "Not at All" and "7" corresponding to "A Great Deal," both the Local and Ground controllers reported that the UAS did not affect the scenario's traffic pattern, sequence, or capacity (all rated 1).

Furthermore, on a 7-point scale with "1" corresponding to "Not At All" and "7" indicating "A Great Deal", the Local and Ground controllers reported that the degree to which priority handling was provided to the UAS was rated respectively as very little (rated 2) to not at all (rated 1). The UAS did not divert from control instructions and was reported to have performed

as expected. As a result fewer delays, traffic pattern modifications and other efficiency measures occurred. Based on these measures and on the responses given by ATC controllers and SME Observers on the PRQ, it would appear as though the UAS had very little effect on the efficiency of operations in this scenario.

4.3.15.4 Scen24 Communication

Voice communication is a key element of air traffic control. Many different communication anomalies can be indicative of traffic saturation and ATC loss of situation awareness. These types of occurrences include transposed call signs, missed transmissions, misidentified aircraft, and repeat ATC instructions.

In this scenario, there were no instances of any of these metrics. Note: simulation pilot communication errors are not reported since they were not the subjects of study.)

It was also observed that the controllers frequently used common, everyday language to UAS as no standard UAS prescribed phraseology exists.

4.3.15.5 Scen24 Workload and Situation Awareness

In addition to the observations noted in the safety, efficiency, and communications section, other measures of workload and situation awareness were captured via the system recordings, PRQ, WAK. Table 143 summarizes traffic count data for this scenario.

Table 143: Scen24 Traffic Count

	Arrivals	Departures	Touch and Go's/ Low Approaches	Overflights
Count:	18	18	13	7

After each run, participants and SME Observers were asked to provide subjective ratings about their assessment of workload and situation awareness by marking ratings on a Likert scale of 1-7, where the “1” corresponds to “Extremely Low” and the “7” corresponds to “Extremely High.”

The Local Controller indicated an average overall workload and a just above average overall complexity. The SME observing the Local controller reported average ratings for overall workload and complexity. The Ground controller felt that the overall complexity of the scenario was average and the overall workload that he experienced was just below average, and the Ground SME Observer reported very low ratings for both overall workload and complexity.

Table 144: Scen24 Ratings of Overall Workload and Complexity

		Position			
		Local Controller	Local Observer (SME)	Ground Controller	Ground Observer (SME)
Metric:	Overall Complexity:	5	4	4	2
	Overall Workload	4	4	3	2

Factors such as mental demand, effort, and the degree in which UAS required attention are some of the contributing factors to overall workload and complexity. Table 145 captures the PRQ responses pertaining to these factors.

On a scale with "1" equal to "Very Poor and "7" corresponding to "Very Good", both controllers rated their performance as good (both rated 6).

On a scale with "1" equal to "Extremely Low" and "7" corresponding to "Extremely High", the Local controller rated his frustration as extremely low and his physical and temporal demand as very low. He rated his mental demand and effort as average. He also indicated that the UAS had an average effect on his workload, his ability to accommodate manned aircraft and the degree in which the UAS required additional attention.

By design, the Ground control position was always staffed for this study. Although on the PRQ the Ground controller reported he did not assist with UAS operations other than for ground control operations, the SMEs observed him consistently assisting the Local controller with the position of aircraft and situation awareness when UAS were present.

The Ground controller indicated the UAS had no effect on his physical demand, temporal demand, effort, and frustration (all rated 1) and a very small effect on his mental demand.

Participants were also asked to provide subjective ratings about the degree to which the REHOST display helped them maintain traffic awareness on the scale where "1" corresponds to "Not at all" and the "7" corresponds to "A great Deal". A REHOST failure began 20 minutes into the scenario and continued for the remainder of the scenario. The Local and Ground controllers reported that the failure had no affect at all on UAS operations or on manned aircraft operations. They did not modify any UAS operations due to the failure. The Ground controller also felt the REHOST failure had no effect on the manageability of overall operations whereas the Local controller felt that the affect was just below average. According to controller responses and comments made in the daily debrief it appears as though the REHOST failure had little effect on operations and on controller workload**.** Specifically, when asked if they would have continued to work traffic with an indefinite REHOST failure, one controller replied, "Yes, because we worked them before we had REHOST, but REHOST does make things easier/better and is necessary for multiple UAS." Controllers were, however, quick to note that the level of traffic in the airspace does make a difference on their level of comfort regarding working without REHOST.

Table 145: Scen24 PRQ Workload and Situation Awareness

		Position	
		Local Controller	Ground Controller
Metric:	Mental Demand:	4	2
	Physical Demand:	2	1
	Temporal Demand:	2	1
	Performance:	6	6
	Effort:	4	1
	Frustration:	1	1
	Amount of coordination with GC or LCL:	4	4
	Degree to which staffing GC affected workload (LCL Only):	2	N/A
	Assist with UAS operations other than GC (GC Only):	N/A	No
	If yes to having assisted with any UAS, did the assistance negatively affect your ability to accomplish your primary GC duties (GC Only):	N/A	N/A
	Degree to which UAS contributed workload:	4	1
	Degree to which UAS required additional attention:	4	1
	Degree to which REHOST helped maintain traffic awareness:	Not Rated	Not Rated

Participants were asked to provide instantaneous workload ratings every two minutes during the run, via a WAK located at each workstation. Graphed over time, the responses for this scenario are depicted in Figure 28.

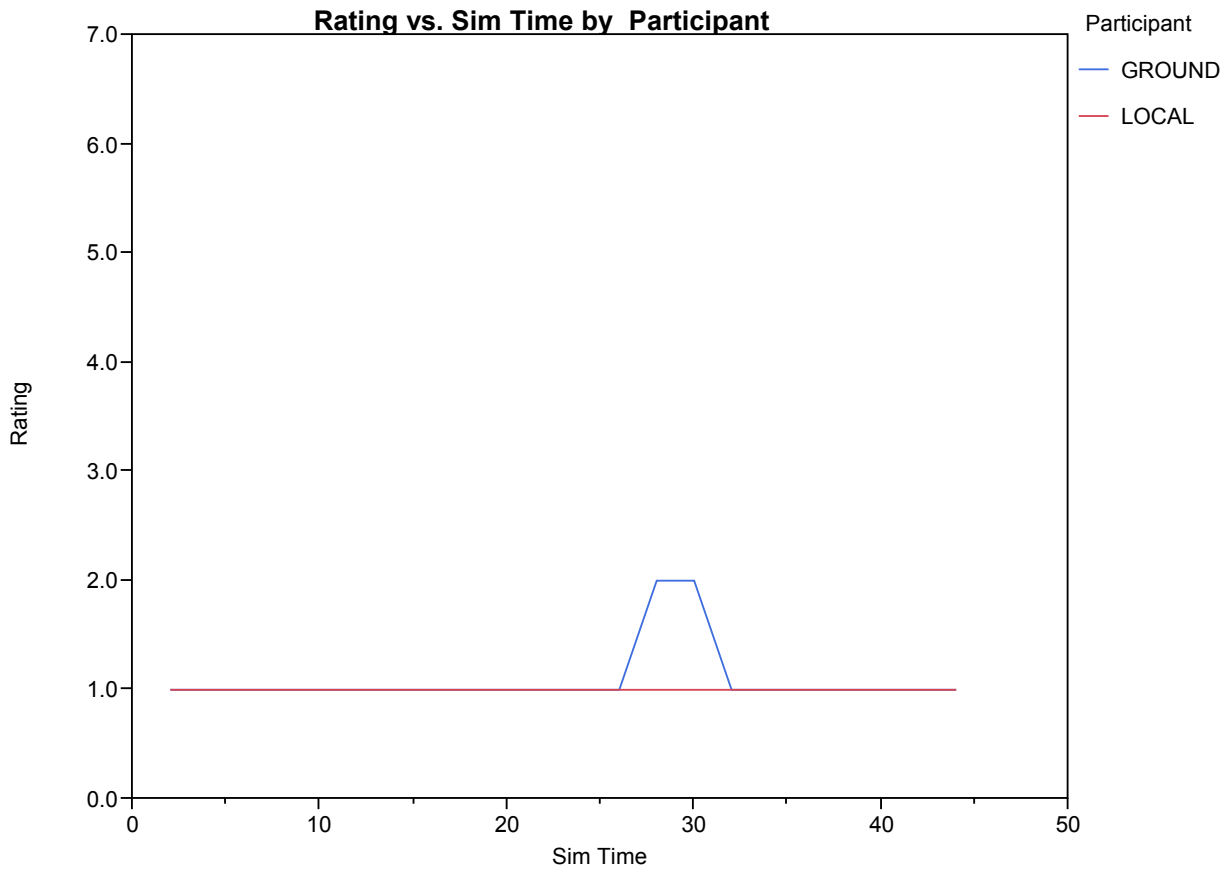

Figure 28: Scen24 WAK Data

In line with the questionnaire data, the controllers' self-reported workload throughout this scenario was rather low. The REHOST failure in this scenario occurred at approximately 20 minutes into the scenario and lasted the remainder of the scenario. The mostly flat ratings surrounding this failure support SME observations and controller reports that no additional workload was created due to the REHOST failure itself, but rather there were typical, manageable changes in workload due to regular traffic level variations.

4.3.15.6 Scen24 SME Observations

In addition to collecting data discussed above, the SME analysis team made supplementary observations during their post study analysis. These observations capture events, occurrences, and their effects on the scenario which were not recorded elsewhere.

SME noted that UAS that required the use of the runways were much more reliant on ATC for sequencing and spacing than manned aircraft pilots. This had the potential to increase controller workload and complexity.

SME noted that there is a need to establish standardized phraseology and ATC procedures for handling UAS.

SME suggested that the use of a landline as the sole communication tool between ATC and both the JPL and the Raven pilot may have contributed to untimely traffic advisories and safety alerts.

SME also suggested that discussions take place regarding the need for any special handling for UAS that are too small to be seen from a distance.

SME additionally suggested that discussions need to take place to clearly define the roles and responsibilities of multiple visual observers.

The answers to all these questions must be clearly defined and resolved before permitting multiple simultaneous UAS operations in Class D airspace.

4.3.15.7 Scen24 Findings

Upon examination of the complete set of data collected, the ATC operation simulated in this scenario does not appear to be feasible with regard to the safe and efficient flow of air traffic.

4.3.16 Scenario 25

In line with the overall study objectives, the goal of Scenario 25 was to examine the effects of simultaneous multiple UAS platforms with dissimilar flight characteristics on local traffic pattern operations, ATC operations, and Class D airspace. This scenario also included (scripted) off nominal events.

4.3.16.1 Scen25 Design

Scenario 25 was developed with the following characteristics:

Airport and Weather Conditions: Simulation start-time was mid-afternoon and VFR prevailed throughout the scenario. Winds were 210° at 9kts. The active runways were 21 and 17.

Manned Aircraft: Seventeen manned aircraft were introduced at random intervals to simulate normal traffic flows at the airport. Operations included both military and civilian departures, arrivals, over-flights, and local pattern work. Four additional VFR (1200 code) targets were injected to simulate over-flight traffic above and/or adjacent to the Class D airspace. These targets did not communicate with ATC.

Special Military Operations: In addition to other manned military flights, a C17 Globemaster II (Slam 88) was added to simulate specialized military tactical maneuvers practiced by USAF crews at KVCV and similar airports.

Ground Vehicles: Two ground vehicles were added to the scenario to replicate vehicular traffic at a typical airport. The vehicles simulated routine airfield maintenance and sweeping operations and communicated with ATC on the GC frequency.

Unmanned Aircraft Systems: Four UAS were included in this scenario — the AS800 JPL Blimp, RQ-11 Raven, A-160 Hummingbird, and MQ-1B Predator. Although not a UAS, the Predator chase aircraft, a manned Mooney MO20, was included in the scenario to simulate the airborne observer requirements of the current COA.

Off Nominal Event(s): Secondary to the simultaneous multiple UAS operations, Scenario 25 also examined the effects of a temporary REHOST failure. The temporary REHOST failure began approximately 20 minutes into the scenario and lasted eight minutes before service was restored. The MQ-1B Predator was in a Runway 21 closed traffic pattern. After completing the requested number of touch and go maneuvers, the Predator and the Predator's chase plane departed the Class D airspace and proceeded en route to the Edwards Complex.

4.3.16.2 Scen25 Safety

The ATC operations presented in this scenario were evaluated with regard to the safety and efficiency of the flow of traffic. Several notable observations are described in this section.

As rated on a 7-point scale in the PRQ, with "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High," both participants appeared to be confident in the safety of operations for this scenario. The Local and Ground controllers rated their confidence levels as 6 and 7, respectively. Although the participants believed the operation to be safe, data and post-analysis observations indicated some safety concerns.

By design, the UAS operation areas in this Class D airspace were not "sterilized" for UAS operations only (i.e., the airspace was not restricted or otherwise segregated). As such, ATC allowed manned aircraft to fly through the UAS operation areas. For example, Slam 88 and other manned aircraft routinely flew through, or in close proximity to, the JPL Blimp and Raven operation areas in this scenario without restriction, which in the opinion of the SME Observers created potential safety risks.

FAO JO7110.65 requires ATC to issue traffic advisories to all aircraft involved when in their judgment proximity warrants it[30]. On multiple occasions during this scenario, manned aircraft were often provided with traffic advisories while the involved UAS were not.

From an operational perspective, there are several types of incidents that adversely affect the safe, orderly and expeditious movement of air traffic. These include MAC as well as other ACC, NMAC, OE, OD, RI, and PD. Concerning some of these measures, it is important to note that the focus of this study was to examine the potential effects of UAS operations on Class D airspace. By design, the simulation pilots, both manned and unmanned, were not the direct subject of study in this simulation. Therefore, any occurrences of pilot-induced incidents (e.g., PD, RI, or NMAC caused by pilot error or actions) are considered part of the realistic, complex situations presented to the controller participants and not reported as deficiencies or safety-related findings for the purposes of this evaluation.

Information concerning the study's incident safety measures are summarized in Table 146, with reported incident details provided in Table 147. In this 45-minute scenario, there were five incidents attributed to ATC. Specifically, there were five OE where ATC did not comply with

[30] FAO JO7110.65 Section 2-1-21 states "Unless an aircraft is operating within Class A airspace or omission is requested by the pilot, issue traffic advisories to all aircraft (IFR or VFR) on your frequency when, in your judgment, their proximity may diminish to less than the applicable separation minima. Where no separation minima applies, such as for VFR aircraft outside of Class B/Class C airspace, or a TRSA, issue traffic advisories to those aircraft on your frequency when in your judgment their proximity warrants it."

the proper intersecting runway standards as prescribed in FAO JO7110.65, Sections 3-9-8 and 3-10-4, Intersecting Runway Separation, resulting in the OE depicted in Table 146 and Table 147.

Table 146: Scen25 Safety Metrics

Metric:	MAC	Other Accidents	NMAC	OE	OD	RI
Number of Incidents	0	0	0	5	0	0

Table 147: Scen25 Incident Table

Incident Type	Aircraft #1	Aircraft #2	Incident Description
OE	Slam 88	N744PA	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
OE	Grizzly 21 *(UAS)*	R50095	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
OE	N744PA	N739HZ	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
OE	NASA901	Slam 88	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4
OE	OMEGA70	N44EL	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section(s) 3-9-8 / 3-10-4

4.3.16.3 Scen25 Efficiency

Several metrics were captured to evaluate the efficiency of the operation simulated. Table 148 captures the observed occurrences of the efficiency metrics for this scenario. In the 45-minute scenario, two aircraft delays and nine traffic pattern modifications were observed. In addition, one manned aircraft request was altered and one arrival was re-sequenced. Although these measures were observed and recorded throughout the scenario, they were not directly attributed to any of the UAS operations.

Table 148: Scen25 Efficiency Metrics

Go-Arounds	
ATC Initiated Go-Arounds	0
Pilot Initiated Go-Arounds	0
Total	0
Delays	
Manned A/C Departure Delays	1
Manned Aircraft Arrival Delays	1
Unmanned A/C Departure Delays	0
Unmanned A/C Arrival Delays	0
Total	2
Traffic Pattern Modifications	
Extended Down-Winds	2
360° Turns	2
ATC Initiated Runway Changes	2
ATC Requested Short Approaches	0
ATC Requested Early Departure Turns	1
ATC Assigned Straight-Out/Runway Headings	2
Total	9
Miscellaneous Efficiency Measures	
Class D Airspace Denials	0
Re-Sequenced Arrivals	1
Re-Sequenced Departures	0
Altered and/or Cancelled Manned A/C Requests by ATC	1
Altered and/or Cancelled Unmanned A/C Requests by ATC	0
Total	2

On a 7-point scale, with "1" corresponding to "not at all" and "7" corresponding to "a great deal," both the Local and Ground controllers reported that the UAS did not affect the scenario's traffic pattern, sequence, or capacity (all rated 1).

The Ground controller similarly reported that the UAS operations had no effect on the efficiency of manned aircraft operations nor his ability to accommodate manned aircraft operations (both rated as 1). In addition, the Ground controller reported that he did not provide priority handling to the UAS (excluding emergency situations). In contrast, the Local controller reported that he did provide substantial priority handing to UAS (rated as 5).

In his role, the Local controller also reported a notable effect of airborne UAS operations on the efficiency of manned aircraft operations and his ability to accommodate manned aircraft operations (both rated as 4). In addition, the Local controller reported having employed the use of extended patterns, though it was not specifically attributed to UAS operations.

4.3.16.4 Scen25 Communication

Voice communication is a key element of ATC. Many different communication anomalies can be indicative of traffic saturation and ATC loss of situation awareness. These types of occurrences include transposed call signs, missed transmissions, misidentified aircraft, and repeat ATC instructions. In this scenario, there were no recorded occurrences. (Note: simulation pilot communication errors are not reported since they were not the subject of study.)

As previously mentioned, consistent with current KVCV operations, the Raven and JPL Blimp do not communicate with ATC using ATC frequencies. The operators for these UAS utilize landline and cell phones for all coordination. Common throughout the study and specific to this scenario, traffic advisories were not issued to the UAS using landlines and cell phones. In fact, SME Observers stated that ATC did not provide the Raven and JPL flight crews with traffic or wake turbulence advisories, though it appeared such advisories may have been warranted[31].

4.3.16.5 Scen25 Workload and Situation Awareness

In addition to the observations noted in the safety, efficiency, and communications sections, other measures of workload and situation awareness were captured via the system recordings, PRQ, and WAK. Table 149 summarizes traffic count data for this scenario.

Table 149: Scen25 Traffic Count

	Arrivals	Departures	Touch and Go's/ Low Approaches	Overflights
Count	17	17	12	7

This scenario included four UAS, a chase plane for the Predator, and a temporary REHOST failure. On the PRQ for this scenario, the air traffic controllers reported they did not treat the Predator any differently with a chase plane present.

Additionally, the participants and SME Observers were asked to provide subjective ratings about their assessment of overall workload and situation awareness by making ratings on a Likert scale of 1-7, where "1" corresponds to "Extremely Low" and the "7" responds to "Extremely High." Table 150 captures the responses.

The participant and the SME Observer both indicated that the Local controller experienced above average overall workload and complexity. The Ground controller also rated overall

[31] FAO JO7110.65 Section 2-1-21 states "Unless an aircraft is operating within Class A airspace or omission is requested by the pilot, issue traffic advisories to all aircraft (IFR or VFR) on your frequency when, in your judgment, their proximity may diminish to less than the applicable separation minima. Where no separation minima applies, such as for VFR aircraft outside of Class B/Class C airspace, or a TRSA, issue traffic advisories to those aircraft on your frequency when in your judgment their proximity warrants it."

complexity as above average but overall workload as just below average (the SME observer rated both as average for the Ground controller).

Table 150: Scen25 Ratings of Overall Workload and Complexity

		Position			
		Local Controller	Local Control SME Observer	Ground Controller	Ground Control SME Observer
Metric:	Overall Complexity	5	6	5	4
	Overall Workload	5	5	3	4

Factors such as mental demand, effort, and the degree to which UAS required attention are some of the contributing factors to overall workload and complexity. Table 151 captures the PRQ responses pertaining to these factors.

On a scale with "1" equal to "Very Poor" and "7" corresponding to "Very Good," the Local and Ground controllers self-rated their performance on the high end for this scenario (rated 6 and 7, respectively).

On a scale with "1" equal to "Extremely Low" and "7" corresponding to "Extremely High," both air traffic controllers rated their mental demand, physical demand, temporal demand, effort, and frustration as below average to extremely low.

However, on a scale with "1" equal to "not at all" and "7" corresponding to "a great deal," the Local controller indicated the UAS notably contributed to workload (rated as 4) and the UAS required substantial attention as compared to manned aircraft (rated as 6). In contrast, the Ground controller indicated the UAS did not contribute to his workload at all, and that the UAS required minimal additional attention as compared to manned aircraft.

Participants were also asked to provide subjective ratings about the degree to which the REHOST display helped them maintain traffic awareness on the scale where "1" corresponds to "not at all" and "7" corresponds to "a great deal". Both the Local and Ground controllers indicated situation awareness benefit from the system (they rated 4 and 3, respectively). Also on the PRQ, the Local controller indicated that from his perspective, the REHOST failure had no effect on either manned or UAS operations, he did not modify any UAS operations as a result, and the overall manageability of operations was not affected at all. However, the Ground controller indicated that the REHOST failure did have some effect on both manned and UAS operations from his perspective (rated as 3 for both), but that there was minimal impact on overall manageability (rated as 2). Similar to the Local controller, the Ground controller reported he did not specifically modify any UAS operations due to the failure.

Of special interest were the SME observations that when the REHOST temporarily failed, workload appeared to increase, and thus commented "they were working harder." The SME Observers also stated that the overall complexity of this scenario seemed to negatively affect the situation awareness of the air traffic controllers.

Table 151: Scen25 PRQ Workload and Situation Awareness

		Position	
		Local Controller	Ground Controller
Metric:	Mental Demand:	3	2
	Physical Demand:	2	1
	Temporal Demand:	2	1
	Performance:	6	7
	Effort:	3	2
	Frustration:	3	1
	Amount of coordination with GC or LCL:	4	4
	Degree to which staffing GC affected workload (LCL Only):	3	N/A
	Assist with UAS operations other than GC (GC Only):	N/A	No
	If yes to having assisted with any UAS, did the assistance negatively affect your ability to accomplish your primary GC duties (GC Only):	N/A	N/A
	Degree to which UAS contributed workload:	4	2
	Degree to which UAS required additional attention:	6	1
	Degree to which REHOST helped maintain traffic awareness:	4	3

Particpants were also asked to provide instantaneous workload ratings every two minutes during the run via a WAK located at each workstation. Graphed over time, the responses for this scenario are depicted in Figure 29.

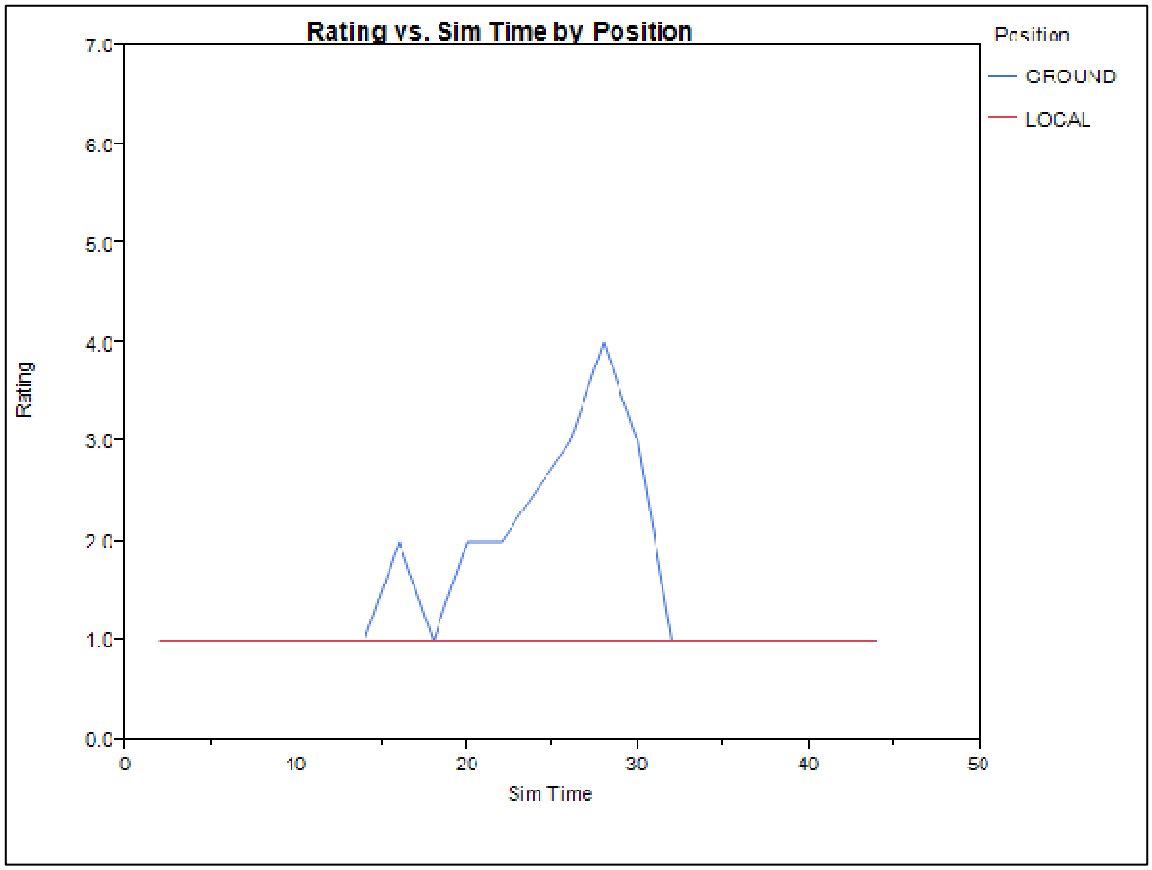

Figure 29: Scen25 WAK Data

Contrary to questionnaire responses, the local controller's self-reported workload throughout the scenario appeared to be rather low, while the Ground controller's self-reported workload appeared to spike at various points. While the first small spike on the Ground controller side may be attributed to normal traffic operations, the second spike, of much greater magnitude than the first, coincides with the occurrence of the temporary REHOST failure which lasted from approximately 20 minutes to 28 minutes. This confirms previous observations and comments suggesting that controller workload increased during the REHOST failure.

4.3.16.6 Scen25 SME Observations

In addition to collecting data discussed above, the SME analysis team made supplementary observations during their post-study analysis. These observations capture events, occurrences, and their effects on the scenario which were not recorded elsewhere.

SME noted that UAS that required the use of the runways were much more reliant on ATC for sequencing and spacing than manned aircraft pilots. This had the potential to increase controller workload and complexity.

SME noted that there is a need to establish standardized phraseology and ATC procedures for handling UAS.

SME suggested that the use of a landline as the sole communication tool between ATC and both the JPL and the Raven pilot may have contributed to untimely traffic advisories and safety alerts.

SME also suggested that discussions take place regarding the need for any special handling for UAS that are too small to be seen from a distance.

SMEs additionally suggested that discussions need to take place to clearly define the roles and responsibilities of multiple visual observers.

The answers to all these questions must be clearly defined and resolved before permitting multiple simultaneous UAS operations in Class D airspace.

4.3.16.7 Scen25 Findings

Upon examination of the complete set of data collected, the ATC operation simulated in this scenario does not appear to be feasible with regard to the safe and efficient flow of air traffic.

4.3.17 Scenario 26

In line with the overall study objectives, the goal of Scenario 26 was to examine the effects of simultaneous multiple UAS platforms with dissimilar flight characteristics on local traffic pattern operations, ATC operations, and Class D airspace. The scenario also included off-nominal events.

4.3.17.1 Scen26 Design

Scenario 26 was developed with the following characteristics:

Airport and Weather Conditions: Simulation start-time was mid-afternoon, and Visual Flight Rules (VFR) prevailed throughout the scenario. Winds were 210° at 9kts. The active runways were 21 and 17.

Manned Aircraft: Seventeen manned aircraft were included to simulate normal traffic flows at the airport. Operations included both military and civilian departures, arrivals, over-flights, and local pattern work. Four additional VFR (1200 code) targets were introduced to simulate over-flight traffic above and/or adjacent to the Class D airspace, and did not communicate with ATC.

Special Military Operations: In addition to other manned military flights, an additional C17 Globemaster II (Slam 88), was added to simulate specialized military tactical maneuvers practiced by USAF crews at KVCV and similar airports.

Ground Vehicles: Two ground vehicles were added to the scenario to replicate vehicular traffic at a typical airport. The vehicles simulated routine airfield maintenance and runway sweeping operations, and communicated with ATC on the GC frequency.

Unmanned Aircraft Systems: Four UAS were included in this scenario; the AS800 JPL Blimp, the RQ-11 Raven, the A-160 Hummingbird, and the MQ-1B Predator. Although not a UAS, the

Predator Chase aircraft, (a manned Mooney MO-20), was included in the scenario to simulate the requirements of the current COA.

Off Nominal Event(s): Secondary to the simultaneous multiple UAS traffic pattern operations, Scenario 26 also examined the effects of the VCV ATCT REHOST system, inoperable for the entire scenario. During the scenario, the AS800 was within the defined operations area, southwest of runway 17, and the A-160 Hummingbird was within the "East-West" operations pattern northeast of the airport. At approximately 18 minutes into the scenario, the A-160 experienced a "Spill-Out" from their normal operations area. By design, the pilot of the A-160 was instructed not to notify ATC of the Spill-Out, unless specifically question by the Local Controller. The RQ-11 Raven was within the operational area over the former base housing located at the airport. Additionally, the Predator and Predator chase aircraft (a manned MO20), returned from the Edwards Complex, whereupon the Predator completed a full-stop arrival at KVCV, and the chase aircraft departed the Class D airspace to the east.

4.3.17.2 Scen26 Safety

The ATC operations presented in this scenario were evaluated with regards to the safety and efficiency of the flow of traffic. Several notable observations are described in this section.

As rated on a 7-point scale in the PRQ, with "1" corresponding to "Extremely Low" and "7" corresponding to "Extremely High," both the Ground and Local controllers appeared to be highly confident in the safety of operations (rated 7 and 6 respectively). Also neither of the two controllers reported losing their situation awareness or of reaching their saturation points throughout the operation portrayed in this scenario.

Although the participants reported high confidence levels in the overall safety of this operation, the data and post analysis observations appear to suggest some safety concerns. SME observers noted that throughout the study, ATC disregarded issuing of advisories to UAS. In accordance with FAAO 7110.65[32], ATC shall issue traffic advisories to all aircraft involved when in their judgment proximity warrants it. It is imperative for UAS to receive safety advisories (i.e. wake turbulence, traffic, terrain, etc.) even though the pilot is not onboard the aircraft. UAS PICs need these advisories in order to maintain situation awareness in flight. Non issuance of advisories can create the potential for errors and can greatly impact the safety of UAS.

Another safety concern observed was when the UAS were within their own operational areas, as the location of UAS ops areas are in close proximity to departure paths of both runways 17 and 21. As observed in this scenario, manned aircraft were permitted to fly through these active areas without restriction or advisories as required by FAAO 7110.65.[33] This gives ATC a false sense of safety which is not provided for by segregation unless manned aircraft are restricted from or advised of the these areas.

The close proximity of Raven operations to Runway 21 contributed to these two NMAC, both of which involved the Raven. The Raven's small size is also a factor since it is not visible from the tower even with binoculars. Another contributory factor is that Raven operations do not monitor

[32] See FAAO 7110.65 section 2.1.21.
[33] See FAAO 7110.65 section 2-1-21.

ATC frequencies, making it cumbersome to communicate with them since a telephone call needs to be made for each advisory. It was also noted that ATC may not have been properly trained on the Raven's operational flight characteristics or operations. All of these factors add additional risk to the safety of the operations.

It should be mentioned that the A-160 spill-out was noticed almost immediately by the Local controller and that he issued several traffic advisories to other manned aircraft operating to Runway 17.

From an operational perspective, there are several types of incidents that adversely affect the safe, orderly and expeditious movement of air traffic. These include MAC, other ACC, NMAC, OE, OD, RI, and PD. Concerning some of these measures, it is important to note that focus of this study was to examine the potential effects of UAS operations on Class D airspace. By design, the simulation pilots, both manned and unmanned, were confederates in this simulation (i.e., not the direct subjects of study). Therefore, any occurrences of pilot-induced incidents (e.g., PD, RI or NMAC caused by pilot error or actions) are considered part of the realistic, complex situations presented to the controller participants and not reported as deficiencies or safety related findings for the purposes of this evaluation.

Information concerning the study's valid incident safety measures are summarized in Table 152, with reported incident details provided in Table 153. In the 45-minute operation, there were six ATC OE and two NMAC.

Table 152: Scen26 Safety Metrics

Metric:	MAC	Other Accidents	NMAC	OE	OD	RI
Number of Incidents	0	0	2	6	0	0

Table 153: Scen26 Incident Table

Incident Type	Aircraft #1	Aircraft #2	Incident Description
NMAC	Grizzly 21 (UAS)	RQ11 Raven (UAS)	ATC permitted Grizzly 21 to operate within the confines of the Raven Operations Area. Less than 500' separation (359')
NMAC	Slam 88	RQ11 Raven (UAS)	ATC permitted Slam 88 to operate within the confines of the Raven Operations Area. Less than 500' separation (225')
OE	Slam 88	N90PH	Required intersecting runway separation was not provided * Reference FAA JO 7110.65 Section 3-9-8
OE	R50095	N739HZ	Required intersecting runway separation was not provided[3] * Reference FAA JO 7110.65 Section 3
OE	Slam 88	N44EL	Required intersecting runway separation was not provided[4] * Reference FAA JO 7110.65 Section 3
OE	Slam 88	Grizzly 21 (UAS)	Required intersecting runway separation was not provided[5] * Reference FAA JO 7110.65 Section 3
OE	RYN5	N44EL	Required intersecting runway separation was not provided[6] * Reference FAA JO 7110.65 Section 3
OE	Slam 88	N744PA	Required intersecting runway separation was not provided[7] * Reference FAA JO 7110.65 Section 3

4.3.17.3 Scen26 Efficiency

Several metrics were captured to evaluate the efficiency of the operation simulated. Table 154 captures the observed occurrences of the efficiency metrics for this scenario.

In the 45-minute scenario, there were five aircraft delays and eight traffic pattern modifications observed. In addition, there were three instances where manned aircraft were denied requests to perform tactical training maneuvers and two re-sequenced arrivals.

Table 154: Scen26 Efficiency Metrics

Go-Arounds	
ATC Initiated Go-Arounds	0
Pilot Initiated Go-Arounds	0
Total	0
Delays	
Manned A/C Departure Delays	1
Manned Aircraft Arrival Delays	1
Unmanned A/C Departure Delays	2
Unmanned A/C Arrival Delays	1
Total	5
Traffic Pattern Modifications	
Extended Down-Winds	4
360° Turns	2
ATC Initiated Runway Changes	2
ATC Requested Short Approaches	0
ATC Requested Early Departure Turns	0
ATC Assigned Straight-Out/Runway Headings	0
Total	8
Miscellaneous Efficiency Measures	
Class D Airspace Denials	0
Re-Sequenced Arrivals	2
Re-Sequenced Departures	0
Altered and/or Cancelled Manned A/C Requests	3
Altered and/or Cancelled Unmanned A/C Requests	0
Total	5

The efficiency of the operation for this scenario appears to be affected by the presence of the four UAS in the traffic pattern. Their presence appeared to result in delays to both manned and unmanned aircraft. For example, Grizzly 21 had their downwind extended 4 nm for sequencing of other aircraft, which resulted in a delay. Delays and traffic pattern modifications may be attributed to the inability of ATC to determine UAS position due to the REHOST outage and the lack of issuance of safety advisories to UAS as required by FAAO 7110.65[34].

Further evidence of the effects of simultaneous multiple UAS operations include numerous occurrences of ATC issuing instructions for extended down winds, 360 degree turns and ATC initiated runway changes, all of which were considered as delaying and/or sequencing tactics. In contrast to the evidence presented in Table 3, the Local controller's ratings on the PRQ indicate that the UAS in general had no effect on the efficiency of the operations in this scenario. On a 7-point scale, with a “1” corresponding to “Not at All” and “7” corresponding to “A Great Deal”,

[34] See FAAO 7110.65 section 2-1-21.

the Local controller reported that the UAS did not affect the traffic pattern, sequence or the capacity (all rated 1).

The A-160 spill-out appeared to have some effect on the operations. On a 7-point scale, with a "1" corresponding to "Not at All" and "7" corresponding to "A Great Deal", the controller indicated a notable effect of the spill-out on the overall manageability of the operation (rated 4). On the same scale, when asked specifically to rate the degree to which the spill-out affected operations on Runway 17, the Local controller indicated a still notable, but slightly lower effect (rated 3), and commented that he then had to call traffic to aircraft arriving on Runway 17.

Since the Ground controller had very limited interaction with the UAS in this scenario, his efficiency ratings on the same topic were consistently rated low overall.

4.3.17.4 Scen26 Communication

Voice communication is a key element of air traffic control. Many different communication anomalies can be indicative of traffic saturation and ATC loss of situation awareness. These types of occurrences include transposed call signs, missed transmissions, misidentified aircraft, and repeat ATC instructions

In this scenario, there was one instance in which the Ground controller transposed instructions. (Note: simulation pilot communication errors are not reported since they were not the subjects of study.)

During this scenario, the SME Observers reported that in some instances, the controllers used nonstandard phraseology in situations involving the UAS. They also noted that it was necessary for ATC to do so, demonstrating and suggesting the need to examine standards for UAS-specific phraseology.

4.3.17.5 Scen26 Workload and Situation Awareness

In addition to the observations noted in the safety, efficiency, and communication section, other measures of workload and situation awareness were captured via the system recordings, PRQ, and WAK. Table 155 summarizes traffic count data for this scenario.

Table 155: Scen26 Traffic Count

	Arrivals	Departures	Touch and Go's/ Low Approaches	Overflights
Count	20	22	16	7

After each run, participants and SME Observers were asked to provide subjective ratings about their assessment of workload and situation awareness by marking ratings on a Likert scale of 1-7, where "1" corresponds to "Extremely Low" and the "7" corresponds to "Extremely High".

The Local controller and the Local SME observer indicated just above average ratings for overall workload and above average to high ratings for complexity. The Local SME Observer reported that workload appeared to be high due to ATC's omission of providing safety advisories[35] to Mercy 2 and the Predator in several instances when they flew through the Raven's ops area. The same ratings for the Ground control position were reported as below average to average by both the participant and the Ground SME observer. Table 156 captures the responses.

Table 156: Scen26 Ratings of Overall Workload and Complexity

		Position			
		Local Controller	Local SME Observer	Ground Controller	Ground SME Observer
Metric:	Overall Complexity	5	6	4	2
	Overall Workload	5	5	2	2

Factors such as mental demand, effort, and the degree in which UAS required attention are some of the contributing factors to overall workload and complexity. Table 157 captures the PRQ responses pertaining to these factors for this scenario utilizing the same Likert scale of 1-7, where "1" corresponds to "Extremely Low" and the "7" responds to "Extremely High."

On the scale with "1" equal to "Very Poor" and "7" corresponding to "Very Good", the Local controller rated his performance as good and the Ground controller rated his as very good.

On the scale with "1" equal to "Extremely Low" and "7" corresponding to "Extremely High," the Local controller rated his physical demand and temporal demand as very low and his mental demand, effort and frustration as average. He indicated that the UAS required a notable amount of additional attention and priority handling (rated 4 on a scale with "1" equal to "Not at All" and "7" corresponding to "A Great Deal") and also contributed to his workload a considerable amount (rated 5 on the same scale).

The Ground controller rated his physical demand as extremely low, his temporal demand, effort and frustration as very low and his mental demand as just below average. He indicated that the UAS did not require additional attention as compared to manned aircraft and had a very low impact on his overall workload.

[35] See FAAO 7110.65 section 2-1-21.

Participants were also asked to provide subjective ratings about the degree to which the REHOST display helped them maintain traffic awareness on the scale where "1" corresponds to "Not at all" and the "7" corresponds to "A Great Deal." However, REHOST was not available during this scenario to help the controllers maintain situation awareness. Participants did not feel that the lack of REHOST had an adverse effect on the manageability of operations and were able to work all four UAS into the traffic pattern. When asked if it was possible to work UAS without REHOST in reality, one controller stated: "Yes, because we worked them before we had REHOST, but REHOST does make things easier/better and is necessary for multiple UAS." SME Observers agree that the REHOST outage did not appear to increase workload; however, there were times during the outage that the local controller appeared to work harder in trying to identify aircraft.

Table 157: Scen26 PRQ Workload and Situation Awareness

		Position	
		Local Controller	Ground Controller
Metric:	Mental Demand:	4	3
	Physical Demand:	2	1
	Temporal Demand:	2	2
	Performance:	6	7
	Effort:	4	2
	Frustration:	4	2
	Amount of coordination with GC or LCL:	4	4
	Degree to which staffing GC affected workload (LCL Only):	2	N/A
	Assist with UAS operations other than GC (GC Only):	N/A	Yes, helped keep track of UAS
	If yes to having assisted with any UAS, did the assistance negatively affect your ability to accomplish your primary GC duties (GC Only):	N/A	No, I was more alert due to REHOST OTS.
	Degree to which UAS contributed workload:	5	1
	Degree to which UAS required additional attention:	4	1
	Degree to which REHOST helped maintain traffic awareness:	Not Rated	Not Rated

Participants were asked to provide instantaneous workload ratings every two minutes during the run, via a WAK located at each workstation. Graphed over time, the responses for this scenario are depicted in Figure 30.

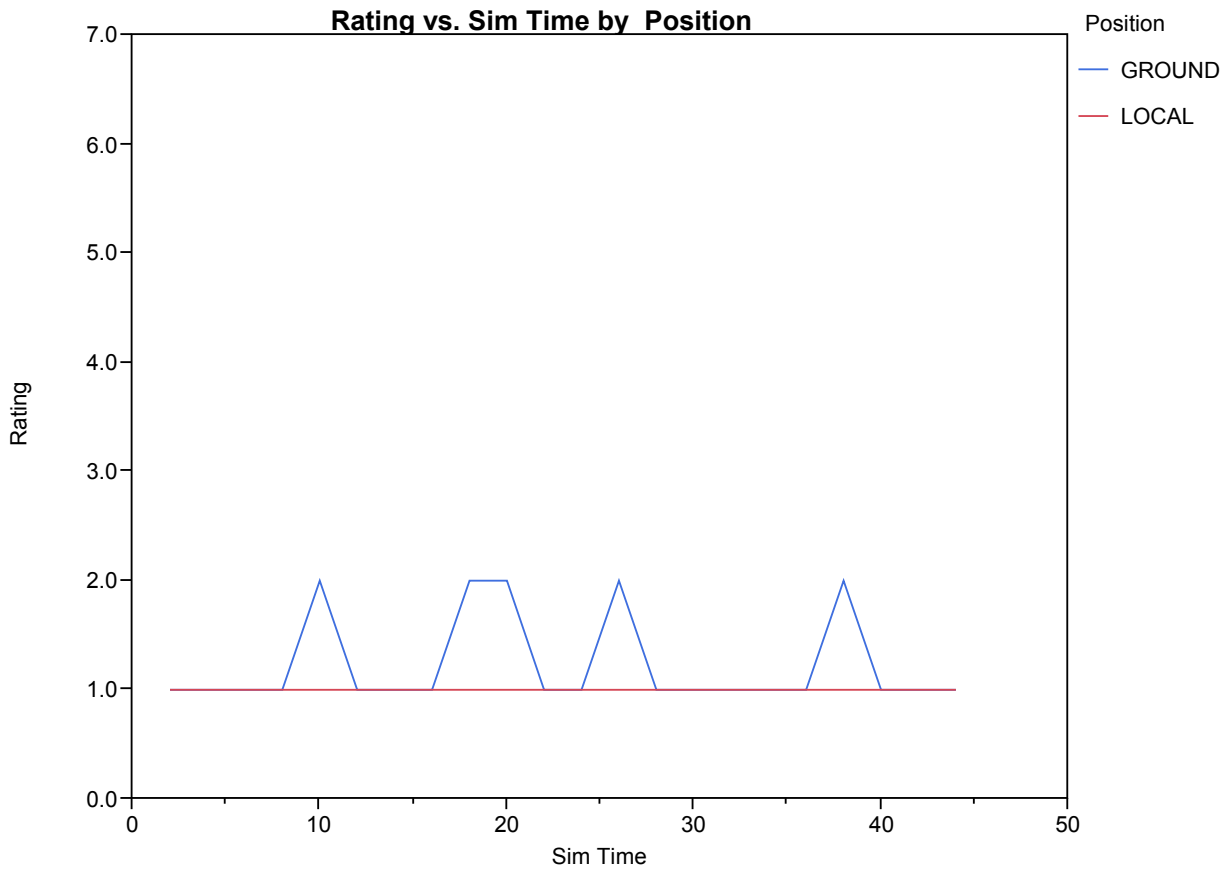

Figure 30: Scen26 WAK Data

Contrary to questionnaire responses, the local controller's self-reported workload throughout the scenario appeared to be rather low. However, the ground controller's rather low self-reported workload throughout the scenario was in line with questionnaire responses. The relatively low workload ratings support the comments and observations by the controllers and SME Observers that the REHOST failure, which lasted the duration of the scenario, did not seem to adversely affect controllers' workload. While the Ground controller's instantaneous workload ratings spiked multiple times, these spikes were small enough in magnitude and duration that they may be attributed to normal fluctuations in workload due to varying traffic levels. The second of these elevations, and the one that was the longest in duration, coincided with the occurrence of the A-160 spill out, which occurred at approximately 18 minutes and 30 seconds into the run and lasted until approximately 20 minutes and 30 seconds.

4.3.17.6 Scen26 SME Observations

In addition to the collecting of data, discussed above, the SME analysis team made supplementary observations during their post study analysis. These observations capture events, occurrences, and their effects on the scenario which were not recorded elsewhere.

As exhibited in this scenario and throughout the entire study, the SME observers noted that there is some confusion over transfer of control and responsibilities between ATC and UAS ground

visual observers. How do ground observers and airborne observers transfer responsibilities? It is unclear when the observer duties are transferred from chase aircraft to ground observer. Furthermore, when UAS aircraft are moved beyond the visual range of their ground observer, who then holds the responsibility for see and avoid?

SME noted that there is a need to establish standardized phraseology and ATC procedures for handling UAS.

SME noted that UAS which required the use of the runways were much more reliant on ATC for sequencing and spacing than manned aircraft pilots. This had the potential to increase controller workload and complexity.

SME also suggested that discussions take place regarding the need for any special handling for UAS that are too small in size to be seen from a distance.

SMEs suggested that discussions need to take place to clearly define the roles and responsibilities of multiple visual observers.

The answers to all these questions must be clearly defined and resolved before permitting multiple simultaneous UAS operations in Class D airspace.

4.3.17.7 Scen26 Findings

Upon examination of the complete set of data collected, the ATC operation simulated in this scenario does not appear to be feasible with regard to the safe and efficient flow of air traffic.

5. Results Summary

The findings of this study were based on data collected during the simulation study and the knowledge and experience of ATC SME proficient in FAA policy and procedures regarding operating UAS in the NAS. The scenarios developed and tested were based on actual flight operations conducted at KVCV. Although the events evaluated occurred in a simulated environment, the realism and authenticity of the operation experienced by the Class D field controllers were similar to actual events and considered high fidelity. It is recognized that it is impractical to simulate all possible combinations of events that could occur in Class D airspace when mixing manned and multiple simultaneous unmanned aircraft. That said, the scope of the HITL simulation included 26 distinct operational scenarios; as such, the findings and observations are not exhaustive or statistically validated, but they do represent an accurate depiction of what was observed in the high fidelity simulated environment. A summary of findings follows.

1. Safety Issues
    a. ATC could not always maintain positive control of operations.
    b. The lack of positive control of aircraft compromised safety when UAS were present.
    c. ATC provided an extra margin of spacing when UAS were in the pattern.
    d. The Raven fly away event resulted in ATC sterilizing Class D airspace, which had an effect on all manned and unmanned aircraft.

e. ATC routinely did not provide traffic or safety alerts to UAS when in the ATC-approved UAS operating areas.
f. ATC routinely did not provide traffic or safety alerts to manned aircraft that flew through or near established UAS operating areas (e.g., Raven and JPL Blimp operations areas).
g. ATC did not appear to understand the consequences (e.g., potential traffic conflicts) during lost link events that involved the Predator and Raven.
h. ATC control instructions to UAS occasionally caused the downwind legs to be extended 3 to 5 miles from the runways, which placed the UAS beyond the presumed visual range of a ground observer.
i. ATC occasionally placed the Predator in a holding pattern when necessary to accommodate aircraft for sequencing, which placed the Predator beyond the presumed visual range of the ground observer.
j. The responsibility for see and avoid was in question when UAS complied with ATC instructions to extend upwind/downwind. This placed the UAS in a position that was beyond the presumed visual range of the ground observers. The ground observer's view of the Predator on downwind to Runway 21 appeared to be obstructed by buildings.
k. It is presumed that the ground observer for the Predator, located at the approach end of Runway 21, could not see the Raven while it operated under the downwind due to the Raven's small size. Therefore, compliance with see and avoid was in question.
l. It appeared that ATC did not see the Raven due to its small size, which made it difficult to issue traffic advisories.
m. When active, UAS-approved operating areas conflicted with normal traffic flow and traffic patterns.
n. The JPL Blimp operations area is located near the departure path for Runway 17. Manned aircraft routinely flew through or near this area without knowledge of the JPL operations or traffic advisories.
o. Dissimilar flight characteristics and the inability of the UAS PIC to visually acquire and follow other aircraft in the traffic pattern were observed as a main causal factor for delays, loss of situation awareness, extended patterns, and general reduction in overall safety.
p. ATC did not have knowledge of the weight class and/or wake turbulence separation criteria for UAS. This lack of guidance appeared to present a safety risk to operations and demonstrated a need for such criteria.
q. Several NMAC were observed with manned aircraft flying through the UAS operating area.
r. A mid-air collision occurred when a manned aircraft flew through the Raven's operating area.
s. The A-160 operating area was too close to the final approach course to runway 17, causing heightened concern by ATC.
t. ATC did not provide intersecting or same runway separation, or intersection departure separation, in accordance with FAA JO 7110.65.

2. Efficiency Issues
    a. The presence of UAS in the traffic patterns caused ATC to issue go arounds and other traffic pattern modifications to accommodate UAS operations.
    b. Delays to manned and unmanned aircraft were observed and documented.
    c. ATC altered or denied manned aircraft requests, and/or denied entry into Class D airspace, during UAS fly away and lost link events.
    d. ATC occasionally delayed departures and denied touch and go patterns due to the presence of UAS.
    e. Manned aircraft were re-sequenced due to the presence of UAS.
    f. The traffic patterns were routinely widened and extended due to UAS' inability to visually follow other aircraft on their own.
    g. Significant impact to Class D operations was observed when UAS required use of the runways.
    h. Predator lost link events caused cessation of A-160 operations because of their conflicting lost link procedures.
    i. The A-160's slow flight characteristics caused concern and sequencing problems while using Runway 21 with other aircraft present.
    j. ATC noted that it was not feasible to operate the A-160 and the Predator simultaneously on the same runway.
    k. When the A-160 and the Predator were operating on the runways, the SME Observers noted reduced ATC situation awareness for several minutes.
    l. Slam 88 (a heavy C-17 Globemaster) was occasionally denied tactical training maneuvers due to the presence of manned aircraft and UAS.
    m. SME noted that UAS which required the use of the runways were much more reliant on ATC for sequencing and spacing than manned aircraft pilots. This had the potential to increase controller workload and complexity.
    n. SME observed ATC routinely utilizing REHOST tower radar system. ATC indicated the REHOST display aided in the sequencing of aircraft.

3. Communications Issues
    a. Non-standard phraseology was routinely used between ATC and UAS PIC, highlighting the need for UAS-specific phraseology.
    b. ATC could not communicate with the JPL Blimp and the Raven PIC via ATC frequency, causing delays and/or omissions of critical traffic information.
    c. ATC occasionally missed radio transmissions and transposed call signs.

4. ATC Workload and Situation Awareness
    a. The presence of UAS contributed to ATC workload, especially with more than one UAS present and/or under off-nominal operating conditions such as a lost link or fly away.
    b. Increased workload coincided with the presence of UAS utilizing the runway or a request from a UAS PIC.
    c. Lost link events, and in particular fly away events, notably increased workload, affected the manageability of the traffic in Class D, and appeared to reduce ATC situation awareness.
    d. ATC knowledge of the existing lost link procedures for the A-160 and the Predator helped prepare ATC when an actual lost link occurred.

e. The REHOST display appeared to be highly beneficial for ATC in maintaining situation awareness of Class D operations, especially during scenarios that included UAS.

5. Other
    a. UAS operating areas are not published. Therefore, awareness of these areas by other pilots is limited or non-existent, creating a safety risk.
    b. SME suggested that discussions take place regarding the need for any special handling for small UAS that are too small in size to be continuously seen.
    c. Though not directly observed or simulated, when multiple visual observers are used, there may be some confusion over transfer of responsibility for see and avoid from the chase aircraft to the ground observer. A clear delineation of where duties and responsibilities begin and end, as well as standard operating and communication procedures, must be defined and successfully tested before permitting multiple simultaneous UAS operations in Class D airspace.
    d. Multiple COA in the same Class D airspace should be vetted to de-conflict operations under normal and off-nominal conditions, including the lost link procedures of other UAS and the traffic patterns for all runways.
    e. Although not directly observed or simulated, loss of link for both aircraft could simultaneously occur during simultaneous UAS operations. In this arguably rare case, to mitigate the risk of collision of two (or more) UAS in lost link status, segregation or de-confliction of lost link procedures would need to be addressed.
    f. Standard Class D airspace sequencing techniques by ATC, such as, "extend downwind," may place the UAS beyond the visual range of the visual observer.
    g. SME involved in the study noted that until visual observer (ground and airborne) duties, ATC roles and responsibilities for handling UAS, standardized lost link procedures, adequate mitigation for pilot in command compliance with FAR 91.113[36], and safe options to address the UAS inability to comply with visual ATC instructions are properly addressed and appropriate training is conducted, integrated Class D operations with manned and multiple simultaneous unmanned aircraft should not be permitted.
    h. The SME Observers noted that when the Predator was operating on Runway 17, ATC routinely instructed Grizzly 21 to extend downwind to follow a manned aircraft. This placed the Predator 3-4 miles northwest of the airport. An airborne visual observer/chase aircraft was providing see and avoid services. ATCS indicated that in an effort to avoid interference with aircraft in the traffic pattern for Runway 17, they instructed the chase aircraft to hold at High Key located 3-4 miles east of Runway 21 until such time as the Predator was ready to depart Class D airspace. Runway 17 is nearly 2 miles long, adding the 3-4 mile extended downwind and the fact that the airborne chase is holding 3-4 miles east of Runway 21, the Predator would end up approximately 8-10 miles from the airborne observer/chase aircraft's position. It is reasonable to assume that this action placed the Predator beyond the visual range of the airborne observer/chase aircraft. This raises the question of where the responsibility for see and avoid lies

[36] FAR 91.113: (b) *General.* When weather conditions permit, regardless of whether an operation is conducted under instrument flight rules or visual flight rules, vigilance shall be maintained by each person operating an aircraft so as to see and avoid other aircraft. When a rule of this section gives another aircraft the right-of-way, the pilot shall give way to that aircraft and may not pass over, under, or ahead of it unless well clear.

for the Predator when it is operating beyond the visual range of the visual observer

6. Study Recommendations

In conclusion, this limited-scope operational assessment of multiple simultaneous UAS operations in Class D airspace suggests the proposed operations were, in general, not feasible as simulated.

This operational assessment brought focus to the fact that a UAS appears to be heavily reliant on systems such as voice/data links, onboard sensors, and other entities such as visual observers and air traffic controllers in order to safely conduct operations in Class D airspace.

ATC SME noted that until visual observer (ground and airborne) duties and ATC roles and responsibilities for handling UAS, including standardized lost link procedures, adequate mitigation for pilot in command compliance with FAR 91.113[37], and safe options to address the UAS' inability to comply with visual ATC instructions are properly addressed with appropriate training, Class D operations with manned and multiple simultaneous unmanned aircraft should not be permitted.

Several major safety, efficiency, workload, and situation awareness issues were observed and raised during the course of this study.

- The responsibility for see-and-avoid was in question when UAS complied with ATC instructions to extend upwind/downwind. This placed the UAS in a position that was beyond the presumed visual range of the ground observers.
- Dissimilar flight characteristics and the inability of UAS pilots to visually acquire and follow other aircraft in the traffic pattern were observed as a main causal factor for delays, loss of situation awareness, extended patterns, and a general reduction in overall safety.
- Significant impact to Class D operations was observed when UAS required use of the runways.
- The presence of UAS in the traffic patterns caused ATC to issue go-arounds and other traffic pattern modifications to accommodate UAS operations.
- ATC altered or denied manned aircraft requests and/or denied entry into Class D airspace during UAS fly away and lost link events.
- The presence of UAS contributed to ATC workload, especially at times when more than one UAS was present.
- Lost link events, and in particular, fly away events, notably increased workload, affected the manageability of the traffic in Class D airspace, and appeared to reduce ATC situation awareness.
- There are currently no guidelines in place to address the communication and coordination between multiple visual observers when more than one UAS is operating in a single

[37] FAR 91.113: (b) *General.* When weather conditions permit, regardless of whether an operation is conducted under instrument flight rules or visual flight rules, vigilance shall be maintained by each person operating an aircraft so as to see and avoid other aircraft. When a rule of this section gives another aircraft the right-of-way, the pilot shall give way to that aircraft and may not pass over, under, or ahead of it unless well clear.

airspace. These procedures must be identified and approved before permitting multiple UAS operations in Class D airspace.

It is anticipated that the exploratory nature of this study will help to identify further areas of research in Class D operations as the UAS community progresses toward the goal of UAS integration into the NAS.

It is recommended, prior to implementing any operation observed in this study, that robust validation studies and comprehensive safety evaluations first be conducted.

Acronyms

A/V	Audio Visual
ACC	Aircraft Accident
AFTIL	Airway Facilities Tower Integration Laboratory
ATC	Air Traffic Control
ATCT	Air Traffic Control Tower
ATWIT	Air Traffic Workload Input Technique
CCCS	Combined Control and Communications System
COA	Certificate of Waiver or Authorization
CSS	Cab Simulation Suite
DESIREE	Distributed Environment for Simulation, Rapid Engineering, and Experimentation
DIS	Distributed Interactive Simulation
DIS/IP	Distributed Interactive Simulation over Internet Protocol
DoD	Department of Defense
ETVS	Enhanced Terminal Voice Switch
FAA	Federal Aviation Administration
GC	Ground Control
HITL	Human-in-the-loop
IEEE	Institute of Electrical and Electronics Engineers
IFR	Instrument Flight Rules
IP	Internet Protocol
IVSR	Interim Voice Switch Replacement
JO	Job Order
KVCV	Southern California Logistics Airport, Victorville, California
LCL	Local Control
LVC	Live Virtual Constructive
MAC	Mid-Air Collision
MDARC	Mosaic-tracking Direct Access Radar Channel
MOA	Military Operations Area
MSL	Mean Sea Level
MTOW	Maximum Takeoff Weight
NAS	National Airspace System
NMAC	Near Mid-Air Collision
OD	Operational Deviation
OE	Operational Error
ORF	Observer Rating Form
PD	Pilot Deviation
PEQ	Post-Experiment Questionnaire
PIC	Pilot in Command
POTS	Plain Old Telephone Service
PRQ	Post-Run Questionnaire
PTT	Push-to-Talk
RCE	Radio Communications Equipment
RDVS	Rapid Deployment Voice Switch

RI	Runway Incursion
SA	Situation Awareness
SME	Subject Matter Expert
SOP	Standard Operating Procedure
STVS	Small Tower Voice Switch
SUA	Special Use Airspace
SVA/ JPVD	Simulation Action Viewer/Java Plan View Display
TGF	Target Generation Facility
TRACON	Terminal Radar Approach Control
UA	Unmanned Aircraft
UAS	Unmanned Aircraft Systems
USAF	Unites States Air Force
USB	Universal Serial Bus
VBSV	Virtual Binocular System SV
VFR	Visual Flight Rules
VSCS	Voice Switching and Control System
WAK	Workload Assessment Keypad
WJHTC	William J. Hughes Technical Center

Glossary

Several key terms are used throughout this document. They are defined in this section.

Aircraft Accident (ACC)	An occurrence associated with the operation of an aircraft which takes place between the time any person boards the aircraft with the intention of flight and until such time as all such persons have disembarked, and in which any person suffers death or serious injury, or in which the aircraft receives substantial damage
Near Mid-Air Collision (NMAC)	An incident associated with the operation of an aircraft in which the possibility of collision occurs as a result of proximity of less than 500 feet to another aircraft, or a report is received from a pilot or flight crewmember stating that a collision hazard existed between two or more aircraft.
Operational Error (OE)	An occurrence attributable to an element of the air traffic system in which: **(a)** Less than 90% of the applicable separation minima results between two or more airborne aircraft, or less than the applicable separation minima results between an aircraft and terrain or obstacles (e.g., operations below minimum vectoring altitude (MVA); aircraft/equipment / personnel on runways), as required by FAA Order 110.65 or other national directive; or **(b)** An aircraft lands or departs on a runway closed to aircraft operations after receiving air traffic authorization, or **(c)** An aircraft lands or departs on a runway closed to aircraft operations, at an uncontrolled airport and it was determined that a NOTAM regarding the runway closure was not issued to the pilot as required.
Operational Deviation (OD)	An occurrence attributable to an element of the air traffic system which did not result in an Operational Error (OE) as defined in this Notice, but:

	(a) Less than the applicable separation minima existed between an aircraft and adjacent airspace without prior approval; or **(b)** An aircraft penetrated airspace that was delegated to another position of operation or another facility without prior coordination and approval; or **(c)** An aircraft penetrated airspace that was delegated to another position of operation or another facility at an altitude or route contrary to the altitude or route requested and approved in direct coordination or as specified in a letter of agreement (LOA), pre-coordination, or internal procedure; or **(d)** An aircraft is either positioned and/or routed contrary to that which was coordinated individually or; as specified in a LOA/directive between positions of operation in either the same or a different facility; or ***NOTE:*** *This does not apply to inter/intra-facility traffic management initiatives.* **(e)** An aircraft, vehicle, equipment, or personnel encroached upon a landing area that was delegated to another position of operation without prior coordination and approval.
Pilot Deviation (PD)	The actions of a pilot that result in the violation of a Federal Aviation Regulation or a North American Aerospace Defense (Command Air Defense Identification Zone) tolerance.
Runway Incursion (RI)	Any occurrence at an airport involving an aircraft, vehicle, person, or object on the ground that creates a collision hazard or results in a loss of separation with an aircraft. The occurrence may involve a pilot taking off, intending to take off, landing, or intending to land. ***NOTE:*** *Runway incursions result from one of three types of airport surface incidents: pilot deviations, operational errors, and vehicle or pedestrian deviations.*
Lost Link	For the purposes of this study, a "lost link" was defined as a loss of command and control link by any UAS.
FAR 91.113	FAR 91.113 Right-of-way rules: Except water operations. (b) *General.* When weather conditions permit, regardless of whether an operation is

	conducted under instrument flight rules or visual flight rules, vigilance shall be maintained by each person operating an aircraft so as to **see and avoid** other aircraft. When a rule of this section gives another aircraft the right-of-way, the pilot shall give way to that aircraft and may not pass over, under, or ahead of it unless well clear.
"Cooperative Aircraft"	For the purposes of this study, Cooperative Aircraft are aircraft whereupon ATC has control jurisdiction and/or have established two-way radio communication
"Non-Cooperative Aircraft"	For the purposes of this study, Non-Cooperative aircraft are aircraft that although may be observed by ATC (visually or with REHOST), will not enter ATC's control jurisdiction and will not establish two-way communications.

Appendices

Appendix A - Informed Consent

I, _____, understand that this study, entitled "Multi-UAS Operational Assessment – Class D Airspace" is sponsored by the Federal Aviation Administration and is being directed by Karen Buondonno, FAA.

Nature and Purpose:

I have been recruited to volunteer as a participant in this project. The purpose of the study is to determine the effects of alternative air traffic control procedures in a high-fidelity, controller-in-the-loop simulation. The results of the study will be used to establish the feasibility of implementing these alternative or similar air traffic control procedures in an operational environment, with the ultimate goal of addressing UAS integration in the NAS.

Experimental Procedures:

Two Air Traffic Controllers will arrive at the simulation laboratory and stay for a total of twelve days (eight days of participation, one weekend, plus two days of travel). Each Controller participant will work complex traffic scenarios that involve Unmanned Aircraft Systems (UAS). The first day of the simulation will consist of a project briefing, equipment familiarization, and practice scenarios. Over the following days, participants will work twenty-four 45-minute scenarios. On the final day, participants will work any uncompleted scenarios and will participate in a 2-3 hour debriefing session. The participants will work from 8:30 AM to 4:30 PM each day with a lunch break and at least two rest breaks.

After each scenario, the participants will complete questionnaires relating to the simulation they had just experienced. In addition, subject-matter experts will make over-the-shoulder observations during the simulation. Finally, an automated data collection system will record system operations and generate a set of standard ATC simulation measures, which include safety, efficiency, and communications measures. The simulation will be audio-video recorded in case researchers need to reexamine any important simulation events.

Confidentiality:

My participation is strictly confidential, and I understand that no individual names or identities will be associated with the data or released in any reports.

Benefits:

I understand that the only benefit to me is that I will be able to provide the researchers with valuable feedback and insight into the effects of UAS operations in Class D Airspace. My data will help the FAA to establish the feasibility of these operations within such an environment.

Participant Responsibilities:

I am aware that to participate in this study I must be an Air Traffic Controller who is qualified at my facility and holds a current medical certificate. I will control traffic and answer any questions asked during the study to the best of my abilities. I will not discuss the content of the experiment with anyone outside of the research team until the study is completed.

Participant Assurances:

I understand that my participation in this study is completely voluntary and I have the freedom to withdraw at any time without penalty. I also understand that the researchers in this study may terminate my participation if they believe this to be in my best interest. I understand that if new findings develop during the course of this research that may relate to my decision to continue participation, I will be informed.

I have not given up any of my legal rights or released any individual or institution from liability for negligence.

The research team has adequately answered all the questions I have asked about this study, my participation, and the procedures involved. I understand that Karen Buondonno or another member of the research team will be available to answer any questions concerning procedures throughout this study.

If I have questions about this study or need to report any adverse effects from the research procedures, I will contact Karen Buondonno at (609) 485-4036.

Discomfort and Risks:

I understand that I will not be exposed to any foreseeable risks or intrusive measurement techniques. I agree to immediately report any injury or suspected adverse effect to Karen Buondonno at (609) 485-4036.

Signature Lines:

I have read this informed consent form. I understand its contents, and I freely consent to participate in this study under the conditions described. I understand that, if I want to, I may have a copy of this form.

Research Participant:_____ Date:_____

Investigator:_____ Date:_____

Witness:_____ Date:_____

Appendix B - Biographical Questionnaire

Multi-UAS Operational Assessment: Class D Airspace

ATC Biographical Questionnaire Participant #:

This questionnaire seeks information regarding your experience as an Air Traffic Controller. Researchers will only use this information to characterize responses on average. **Your identity will remain anonymous.**

1. Gender							○ Male	○ Female
2. Age							_____ Years	
3. How long have you been an Air Traffic Controller?							_____ Years _____ Months	
4. How much of this time was spent in an Air Traffic Control Tower?							_____ Years _____ Months	
a. Other Facility?							_____ Years _____ Months	
5. How many of the past **12 months** have you actively controlled traffic in an ATCT?							_____ Months	
6. Rate your **skill** as an Air Traffic Controller.	Not Skilled						Very Skilled	
	1	2	3	4	5	6	7	
7. Rate your current **stress level**.	Not Stressed						Very Stressed	
	1	2	3	4	5	6	7	
8. Rate your level of **motivation** to participate in this study	Not Motivated						Very Motivated	
	1	2	3	4	5	6	7	
9. Do you have previous ATC **experience with UAS** at your facility?							○ Yes	○ No
a. If yes, please list the **types of UAS** that you have worked with. _____								
10. Prior to this study, have you had experience using the **REHOST** system at your facility?							○ Yes	○ No
a. If yes, how long have you been using **REHOST?**							_____ Months	
b. If yes, when was the last time you used **REHOST** at your facility?							_____ Months _____ Days Ago	
11. Rate your experience with **simulators of all types** (e.g., home flight simulators, home ATC simulators, trainers).	No Experience						Very Experienced	
	1	2	3	4	5	6	7	

BASELINE

Multi-UAS Operational Assessment: Class D Airspace

Post-Run Questionnaire

Position: **Ground**	Date:	Scenario:
Participant Number:	Study Day:	Run:

Please answer the following questions based upon your experience in **the run just completed**.

1. **Mental Demand** – How mentally demanding was the task?

Extremely Low — Extremely High

1	2	3	4	5	6	7

2. **Physical Demand** – How physically demanding was the task?

Extremely Low — Extremely High

1	2	3	4	5	6	7

3. **Temporal Demand** – How hurried or rushed was the pace of the task?

Extremely Low — Extremely High

1	2	3	4	5	6	7

4. **Performance** – How successful were you in accomplishing your role?

Very Poor — Very Good

1	2	3	4	5	6	7

5. **Effort** – How hard did you have to work to accomplish your level of performance?

Extremely Low — Extremely High

1	2	3	4	5	6	7

6. **Frustration** – How insecure, discouraged, irritated, stressed, and annoyed were you?

Extremely Low — Extremely High

1	2	3	4	5	6	7

7. Rate your amount of **coordination** with the local controller.

Extremely Low — Extremely High

1	2	3	4	5	6	7

8. Rate the **overall complexity** of the run you just completed.

Extremely Low — Extremely High

1	2	3	4	5	6	7

*****BASELINE*****

Multi-UAS Operational Assessment: Class D Airspace

Post-Run Questionnaire

Position: **Ground**	Date:	Scenario:
Participant Number:	Study Day:	Run:

9. Rate the **overall workload** of the run you just completed.

Extremely Low — Extremely High

1	2	3	4	5	6	7

10. Rate your **confidence level** for safe operations during this run.

Extremely Low — Extremely High

1	2	3	4	5	6	7

11. Were **manned aircraft delayed** in any way?

○ Yes	○ No

If Yes, Explain _____

_____

12. Rate the degree to which **pilot communications** were:

	Extremely Low						Extremely High
a. Clear	1	2	3	4	5	6	7
b. Concise	1	2	3	4	5	6	7
c. Timely	1	2	3	4	5	6	7
d. Correct	1	2	3	4	5	6	7

Explain _____

_____

13. Rate the degree to which the **REHOST** display helped you maintain traffic awareness.

Not at All — A Great Deal

1	2	3	4	5	6	7

14. Did you reach a "**saturation point**" at any time during this run?

○ Yes	○ No

If Yes, Explain _____

_____

_____

Multi-UAS Operational Assessment: Class D Airspace

Post-Run Questionnaire

Position: **Ground**	Date:	Scenario:
Participant Number:	Study Day:	Run:

Please answer the following questions based upon your experience in **the run just completed**.

1. **Mental Demand** – How mentally demanding was the task?

Extremely Low — Extremely High

1	2	3	4	5	6	7

2. **Physical Demand** – How physically demanding was the task?

Extremely Low — Extremely High

1	2	3	4	5	6	7

3. **Temporal Demand** – How hurried or rushed was the pace of the task?

Extremely Low — Extremely High

1	2	3	4	5	6	7

4. **Performance** – How successful were you in accomplishing your role?

Very Poor — Very Good

1	2	3	4	5	6	7

5. **Effort** – How hard did you have to work to accomplish your level of performance?

Extremely Low — Extremely High

1	2	3	4	5	6	7

6. **Frustration** – How insecure, discouraged, irritated, stressed, and annoyed were you?

Extremely Low — Extremely High

1	2	3	4	5	6	7

7. Did you **assist with any UAS operations** other than Ground Control Operations?

○ Yes	○ No	N/A

   a. **If yes to 8,** Explain.

_____

_____

   b. **If yes to 8,** Did this assistance negatively affect your ability to accomplish your primary Ground Control duties?

○ Yes	○ No

Explain _____

_____

Multi-UAS Operational Assessment: Class D Airspace

Post-Run Questionnaire

Position: **Ground**	Date:	Scenario:
Participant Number:	Study Day:	Run:

8. Rate your amount of **coordination** with the local controller.

Extremely Low — Extremely High

1	2	3	4	5	6	7

9. Rate the **overall complexity** of the run you just completed.

Extremely Low — Extremely High

1	2	3	4	5	6	7

10. Rate your **overall workload** for the run you just completed.

Extremely Low — Extremely High

1	2	3	4	5	6	7

11. Rate the degree to which **taxiing** UAS contributed to your workload.

Not at All — A Great Deal

1	2	3	4	5	6	7	N/A

12. Rate the effect UAS operations had on your **ability** to accommodate manned aircraft.

Not at All — A Great Deal

1	2	3	4	5	6	7

13. Rate the effect UAS operations had on the efficiency of manned aircraft ground operations

Not at All — A Great Deal

1	2	3	4	5	6	7

14. Rate the degree to which UAS ground movement required **additional attention** as compared to manned aircraft.

None — A Great Deal

1	2	3	4	5	6	7	N/A

15. Rate the degree to which you **provided priority handling to UAS** ground control over manned aircraft (excluding emergency situations).

Not at All — A Great Deal

1	2	3	4	5	6	7	N/A

16. Rate your **confidence level** for safe operations during this run.

Extremely Low — Extremely High

1	2	3	4	5	6	7

Multi-UAS Operational Assessment: Class D Airspace

Post-Run Questionnaire

Position: **Ground**	Date:	Scenario:
Participant Number:	Study Day:	Run:

17. Were **UAS delayed** in any way?

○ Yes	○ No

If Yes, Explain _____

_____

18. Were **manned aircraft delayed** in any way?

○ Yes	○ No

If Yes, Explain _____

_____

19. Did you provide **additional spacing and/or separation for UAS** operations above what would normally be required for manned aircraft?

○ Yes	○ No	○ N/A

If Yes, Explain _____

_____

20. Did the **UAS perform** as expected?

○ Yes	○ No

If No, Explain _____

_____

21. Did the **UAS divert** from its issued control instructions?

○ Yes	○ No

If Yes, Explain _____

_____

22. Rate the degree to which **pilot communication** were:

	Extremely Low						Extremely High
a. Clear	1	2	3	4	5	6	7
b. Concise	1	2	3	4	5	6	7
c. Timely	1	2	3	4	5	6	7
d. Correct	1	2	3	4	5	6	7

Explain _____

_____

Multi-UAS Operational Assessment: Class D Airspace
Post-Run Questionnaire

Position: **Ground**	Date:	Scenario:
Participant Number:	Study Day:	Run:

23. Rate the degree to which the **REHOST** display helped you maintain traffic awareness.

Not at All — A Great Deal

1	2	3	4	5	6	7

24. Did you **treat the UAS differently** than manned aircraft?

○ Yes	○ No

If Yes, Explain _____

_____

_____

25. Rate the degree to which **UAS affected:**

	Not at All						A Great Deal
a. the traffic pattern	1	2	3	4	5	6	7
b. the sequence	1	2	3	4	5	6	7
c. the capacity	1	2	3	4	5	6	7

Explain _____

_____

_____

26. Did you reach a "**saturation point**" at any time during this run?

○ Yes	○ No

If Yes, Explain _____

_____

_____

27. At any point during the run, did you **lose "situation awareness**" (i.e. did you "lose the flick")?

○ Yes	○ No

If Yes, Explain _____

_____

_____

BASELINE
Multi-UAS Operational Assessment: Class D Airspace
Post-Run Questionnaire

Position: **Local**	Date:	Scenario:
Participant Number:	Study Day:	Run:

Please answer the following questions based upon your experience in **the run just completed**.

1. **Mental Demand** – How mentally demanding was the task?

Extremely Low — Extremely High

1	2	3	4	5	6	7

2. **Physical Demand** – How physically demanding was the task?

Extremely Low — Extremely High

1	2	3	4	5	6	7

3. **Temporal Demand** – How hurried or rushed was the pace of the task?

Extremely Low — Extremely High

1	2	3	4	5	6	7

4. **Performance** – How successful were you in accomplishing your role?

Very Poor — Very Good

1	2	3	4	5	6	7

5. **Effort** – How hard did you have to work to accomplish your level of performance?

Extremely Low — Extremely High

1	2	3	4	5	6	7

6. **Frustration** – How insecure, discouraged, irritated, stressed, and annoyed were you?

Extremely Low — Extremely High

1	2	3	4	5	6	7

7. Rate your amount of **coordination** with the ground controller.

Extremely Low — Extremely High

1	2	3	4	5	6	7

8. Rate the degree to which **having the Ground Control position continuously staffed** affected your workload.

Decreased a Great Deal — Increased a Great Deal

1	2	3	4	5	6	7

9. Rate the **overall complexity** of the run you just completed.

Extremely Low — Extremely High

1	2	3	4	5	6	7

*****BASELINE*****

Multi-UAS Operational Assessment: Class D Airspace

Post-Run Questionnaire

Position: **Local**	Date:	Scenario:
Participant Number:	Study Day:	Run:

10. Rate the **overall workload** of the run you just completed.

Extremely Low — Extremely High

1	2	3	4	5	6	7

11. Rate your **confidence level** for safe operations during this run.

Extremely Low — Extremely High

1	2	3	4	5	6	7

12. Were any of the **following used** because of Manned Aircraft? (Check all that apply)

Extended Patterns		Go Arounds (unplanned)	
Extensive Vectors		Departure Delays	
Denial of Entry into Class D Airspace		Missed Approach (unplanned)	
Denial of Touch and Go		Denial of Any Service	

Explain _____

_____

_____

13. Did any of the **following occur** during this run? (Check all that apply)

Near Mid-Air Collision		Pilot Non-Compliance with ATC	
Mid-Air Collision		Pilot Deviation	
Runway Incursion		Operational Deviation	
Change of Pattern Sequence		Readback Error(s)	
Excessive repeated ATC clearances		Other Incidents/Accidents	

Explain _____

_____

_____

*****BASELINE*****

Multi-UAS Operational Assessment: Class D Airspace

Post-Run Questionnaire

Position: **Local**	Date:	Scenario:
Participant Number:	Study Day:	Run:

14. At any point during the run, did you **lose "situation awareness**" (i.e. did you "lose the flick")?

○ Yes	○ No

If Yes, Explain _____

_____

15. Were **manned aircraft delayed** in any way?

○ Yes	○ No

If Yes, Explain _____

_____

16. Rate the degree to which the **REHOST** display helped you maintain traffic awareness.

Not at All						A Great Deal
1	2	3	4	5	6	7

17. Did you reach a "**saturation point**" at any time during this run?

○ Yes	○ No

If Yes, Explain _____

_____

_____

18. Rate the degree to which **pilot communications** were:

	Extremely Low						Extremely High
a. Clear	1	2	3	4	5	6	7
b. Concise	1	2	3	4	5	6	7
c. Timely	1	2	3	4	5	6	7
d. Correct	1	2	3	4	5	6	7

Explain _____

_____

Multi-UAS Operational Assessment: Class D Airspace

Post-Run Questionnaire

Position: **Local**	Date:	**Scenario:**
Participant Number:	Study Day:	Run:

Please answer the following questions based upon your experience in **the run just completed**.

1. **Mental Demand** – How mentally demanding was the task?

Extremely Low — Extremely High

1	2	3	4	5	6	7

2. **Physical Demand** – How physically demanding was the task?

Extremely Low — Extremely High

1	2	3	4	5	6	7

3. **Temporal Demand** – How hurried or rushed was the pace of the task?

Extremely Low — Extremely High

1	2	3	4	5	6	7

4. **Performance** – How successful were you in accomplishing your role?

Very Poor — Very Good

1	2	3	4	5	6	7

5. **Effort** – How hard did you have to work to accomplish your level of performance?

Extremely Low — Extremely High

1	2	3	4	5	6	7

6. **Frustration** – How insecure, discouraged, irritated, stressed, and annoyed were you?

Extremely Low — Extremely High

1	2	3	4	5	6	7

7. Rate your amount of **coordination** with the ground controller.

Extremely Low — Extremely High

1	2	3	4	5	6	7

8. Rate the degree to which **having the Ground Control position continuously staffed** affected your workload.

Decreased a Great Deal — Increased a Great Deal

1	2	3	4	5	6	7

9. Rate the **overall complexity** of the run you just completed.

Extremely Low — Extremely High

1	2	3	4	5	6	7

Multi-UAS Operational Assessment: Class D Airspace
Post-Run Questionnaire

Position: **Local**	Date:	Scenario:
Participant Number:	Study Day:	Run:

10. Rate your **overall workload** for the run you just completed.

Extremely Low — Extremely High

1	2	3	4	5	6	7

11. Rate the degree to which **UAS** contributed to your workload.

Not at All — A Great Deal

1	2	3	4	5	6	7	N/A

12. Rate the effect airborne UAS operations had on your **ability** to accommodate manned aircraft.

Not at All — A Great Deal

1	2	3	4	5	6	7

13. Rate the effect airborne UAS operations had on the **efficiency** of manned aircraft operations

Not at All — A Great Deal

1	2	3	4	5	6	7

14. Rate the degree to which UAS required **additional attention** as compared to manned aircraft.

None — A Great Deal

1	2	3	4	5	6	7	N/A

15. Rate the degree to which you **provided priority handling to UAS** operations over manned aircraft (excluding emergency situations).

Not at All — A Great Deal

1	2	3	4	5	6	7	N/A

16. Rate your **confidence level** for safe operations during this run.

Extremely Low — Extremely High

1	2	3	4	5	6	7

17. At any point during the run, did you **lose "situation awareness**" (i.e. did you "lose the flick")?

○ Yes	○ No

If Yes, Explain _____

_____

Multi-UAS Operational Assessment: Class D Airspace
Post-Run Questionnaire

Position: **Local**	Date:	Scenario:
Participant Number:	Study Day:	Run:

18. Were any of the **following used** because of UAS or manned Aircraft? (Check all that apply)

Extended Patterns		Go Arounds (unplanned)	
Extensive Vectors		Departure Delays	
Denial of Entry into Class D Airspace		Missed Approach (unplanned)	
Denial of Touch and Go		Denial of Any Service	

Explain _____

_____

19. Did any of the **following occur** during this run? (Check all that apply)

Near Mid-Air Collision		Pilot Non-Compliance with ATC	
Mid-Air Collision		Pilot Deviation	
Runway Incursion		Operational Deviation	
Change of Pattern Sequence		Readback Error(s)	
Excessive repeated ATC clearances		Other incidents/accidents	

Explain _____

_____

20. Were **UAS delayed** in any way?

○ Yes	○ No

If Yes, Explain _____

_____

21. Were **manned aircraft delayed** in any way?

○ Yes	○ No

If Yes, Explain _____

_____

22. Did you provide an extra margin of **spacing and/or separation for UAS** operations above what would normally be required for manned aircraft?

○ Yes	○ No	○ N/A

If Yes, Explain _____

_____

Multi-UAS Operational Assessment: Class D Airspace

Post-Run Questionnaire

Position: **Local**	Date:	Scenario:
Participant Number:	Study Day:	Run:

23. Did the **UAS perform** as expected?

○ Yes	○ No

If No, Explain _____

_____

24. Did the **UAS divert** from its issued control instructions?

○ Yes	○ No

If Yes, Explain _____

_____

25. Did any **manned aircraft alter or cancel their requests** because of ongoing UAS operations within Class D airspace?

○ Yes	○ No

If Yes, Explain _____

_____

26. Did any **unmanned aircraft alter or cancel their requests** because of ongoing UAS operations within Class D airspace?

○ Yes	○ No

If Yes, Explain _____

_____

27. Rate the degree to which **pilot communications** were:

	Extremely Low						Extremely High
a. Clear	1	2	3	4	5	6	7
b. Concise	1	2	3	4	5	6	7
c. Timely	1	2	3	4	5	6	7
d. Correct	1	2	3	4	5	6	7

Explain _____

_____

28. Rate the degree to which the **REHOST** display helped you maintain traffic awareness.

Not at All						A Great Deal
1	2	3	4	5	6	7

Multi-UAS Operational Assessment: Class D Airspace
Post-Run Questionnaire

Position: **Local**	Date:	Scenario:
Participant Number:	Study Day:	Run:

29. Did you **treat the UAS differently** than manned aircraft?

○ Yes	○ No

If Yes, Explain _____

_____

_____

30. Rate the degree to which **UAS affected:**

	Not at All						A Great Deal
a. the traffic pattern	1	2	3	4	5	6	7
b. the sequence	1	2	3	4	5	6	7
c. the capacity	1	2	3	4	5	6	7

Explain _____

_____

_____

31. Did you reach a "**saturation point**" at any time during this run?

○ Yes	○ No

If Yes, Explain _____

_____

_____

Multi-UAS Operational Assessment: Class D Airspace

S10

Post-Run Questionnaire

Position: **Local**	Date:	**Scenario: 10**:
Participant Number:	Study Day:	Run:

Please answer the following questions based upon your experience in **the scenario just completed**.

1. Rate the degree to which the **Raven "flyaway"** affected the **manageability** of the overall operations.

Not at All						A Great Deal
1	2	3	4	5	6	7

2. Did you ever **see the Raven**?

○ Yes	○ No

3. Once you were aware of the Raven "flyaway," what did you do to ensure **safe operations** (e.g. blocking airspace)?

_____

_____

4. Based on the **information you were given** from the GCS did you feel you had a good idea of where the Raven was throughout the rest of the scenario?

○ Yes	○ No

Explain _____

_____

5. Have you ever experienced a **Raven lost link** in real life?

○ Yes	○ No

Explain _____

_____

6. Did the "flyaway" cause you to **shut off all traffic on Runway 21**?

○ Yes	○ No

Explain _____

_____

Multi-UAS Operational Assessment: Class D Airspace

S11

Post-Run Questionnaire

Position: **Local**	Date:	**Scenario: 11**
Participant Number:	Study Day:	Run:

Please answer the following questions based upon your experience in **the scenario just completed**.

1. Rate the degree to which the **A-160 lost link** affected the **manageability** of the overall operations.

Not at All						A Great Deal
1	2	3	4	5	6	7

2. Once you were aware of the A-160 lost link, what did you do to ensure **safe operations** (e.g. blocking airspace)?

_____

_____

3. Have you ever experienced an **A-160 lost link** in real life?

○ Yes	○ No

Explain _____

_____

4. Rate the degree to which the A-160 lost link **affected other manned aircraft Class D operations.**

Not at All						A Great Deal
1	2	3	4	5	6	7

Explain _____

_____

Multi-UAS Operational Assessment: Class D Airspace

S12

Post-Run Questionnaire

Position: **Local**	Date:	**Scenario: 12**
Participant Number:	Study Day:	Run:

Please answer the following questions based upon your experience in **the scenario just completed**.

1. Did you treat the Predator any **differently** when there was a chase plane?

○ Yes	○ No

If yes, explain _____

_____

2. Did you approve the **Predator runway change**?

○ Yes	○ No

If no, explain why not _____

_____

******If No to Question 2 stop here******

3. Rate the degree to which the **Predator runway change** affected the **manageability** of the overall operations.

Not at All — A Great Deal

1	2	3	4	5	6	7

4. Were any **manned aircraft touch-and-go operations** affected by Predator operations on the same runway?

○ Yes	○ No

If yes, explain _____

_____

Multi-UAS Operational Assessment: Class D Airspace

S13

Post-Run Questionnaire

Position: **Local**	Date:	**Scenario: 13**
Participant Number:	Study Day:	Run:

Please answer the following questions based upon your experience in **the scenario just completed**.

1. Did you authorize two **simultaneous Predator operations** on the same runway?

○ Yes	○ No

If no, explain why not _____

_____

******If No to Question 1 stop here******

2. Rate the degree to which the **simultaneous Predator operations** affected the **manageability** of the overall operations.

Not at All — A Great Deal

1	2	3	4	5	6	7

3. Were any **manned aircraft touch-and-go operations** affected by Predator operations on the same runway?

○ Yes	○ No

If yes, explain _____

_____

Multi-UAS Operational Assessment: Class D Airspace

S14

Post-Run Questionnaire

Position: **Local**	Date:	**Scenario: 14**
Participant Number:	Study Day:	Run:

Please answer the following questions based upon your experience in **the scenario just completed**.

1. Rate the degree to which the **Blimp "spill-out"** affected the **manageability** of the overall operations.

Not at All						A Great Deal
1	2	3	4	5	6	7

2. How were you first **made aware of the "spill-out"** (e.g. noticed it personally, informed by ATC, etc.)?

_____

_____

Multi-UAS Operational Assessment: Class D Airspace

S15

Post-Run Questionnaire

Position: **Local**	Date:	**Scenario: 15**
Participant Number:	Study Day:	Run:

Please answer the following questions based upon your experience in **the scenario just completed**.

1. Rate the degree to which the **Predator lost link** affected the **manageability** of the operations.

Not at All — A Great Deal

1	2	3	4	5	6	7

2. Rate the degree to which the Predator lost link **affected A-160 operations**.

Not at All — A Great Deal

1	2	3	4	5	6	7

Explain _____

_____

3. Rate the degree to which the Predator lost link **affected other manned aircraft Class D operations.**

Not at All — A Great Deal

1	2	3	4	5	6	7

Explain _____

_____

4. Rate the degree to which **knowing the lost link procedure** (i.e. the predictability) **affected your ability to handle the situation.**

Not at All — A Great Deal

1	2	3	4	5	6	7

Explain _____

_____

Multi-UAS Operational Assessment: Class D Airspace

S16

Post-Run Questionnaire

Position: **Local**	Date:	**Scenario: 16**
Participant Number:	Study Day:	Run:

Please answer the following questions based upon your experience in **the scenario just completed**.

1. Rate the degree to which the **A-160 lost link** affected the **manageability** of the overall operations.

Not at All — A Great Deal

1	2	3	4	5	6	7

2. Rate the degree to which A-160 lost link affected **manned aircraft operations on Runway 17.**

Not at All — A Great Deal

1	2	3	4	5	6	7

Explain _____

_____

3. Rate the degree to which A-160 lost link affected **manned aircraft operations on Runway 21.**

Not at All — A Great Deal

1	2	3	4	5	6	7

Explain _____

_____

4. Rate the degree to which the A-160 lost link **affected Predator operations**.

Not at All — A Great Deal

1	2	3	4	5	6	7

Explain _____

_____

5. Rate the degree to which the A-160 lost link **affected other manned aircraft Class D operations.**

Not at All — A Great Deal

1	2	3	4	5	6	7

Explain _____

_____

Position: **Local** Date: **Scenario: 16**
Participant Number: Study Day: Run:

6. Rate the degree to which **knowing the lost link procedure** (i.e. the predictability) **affected your ability to handle the situation.**

Not at All A Great Deal

1	2	3	4	5	6	7

Explain _____

_____

Multi-UAS Operational Assessment: Class D Airspace

S17

Post-Run Questionnaire

Position: **Local**	Date:	**Scenario: 17**
Participant Number:	Study Day:	Run:

Please answer the following questions based upon your experience in **the scenario just completed**.

1. Did you treat the Predator any **differently** when there was a chase plane?

○ Yes	○ No

If yes, explain _____

_____

2. Did you approve the **Predator runway change**?

○ Yes	○ No

If no, explain why not _____

_____

******If No to Question 2 stop here******

3. Rate the degree to which the **Predator runway change** affected the **manageability** of the overall operations.

Not at All						A Great Deal
1	2	3	4	5	6	7

4. Were any **manned aircraft touch and go operations** affected by Predator operations on the same runway?

○ Yes	○ No

If yes, explain _____

_____

Multi-UAS Operational Assessment: Class D Airspace

S18

Post-Run Questionnaire

Position: **Local**	Date:	**Scenario: 18**
Participant Number:	Study Day:	Run:

Please answer the following questions based upon your experience in **the scenario just completed**.

1. Did you treat the Predator any **differently** when there was a chase plane?

○ Yes	○ No

If yes, explain _____

_____

2. Rate the degree to which the **A-160 "spill-out"** affected the **manageability** of the overall operations.

Not at All — A Great Deal

1	2	3	4	5	6	7

3. Rate the degree to which the A-160 "spill-out" affected **operations on Runway 17.**

Not at All — A Great Deal

1	2	3	4	5	6	7

Explain _____

_____

4. How were you first **made aware of the "spill-out"** (e.g. noticed it personally, informed by ATC.)?

_____

_____

5. Describe your workload with all four UAS operating simultaneously.

_____

_____

Multi-UAS Operational Assessment: Class D Airspace

S19

Post-Run Questionnaire

Position: **Local**	Date:	**Scenario: 19**
Participant Number:	Study Day:	Run:

Please answer the following questions based upon your experience in **the scenario just completed**.

1. Did you treat the Predator any **differently** when there was a chase plane?

○ Yes	○ No

If yes, explain _____

_____

2. Rate the degree to which the **Predator returning to the airport** affected the **manageability** of the overall operations.

Not at All — A Great Deal

1	2	3	4	5	6	7

Multi-UAS Operational Assessment: Class D Airspace

S20

Post-Run Questionnaire

Position: **Local**	Date:	**Scenario: 20**
Participant Number:	Study Day:	Run:

Please answer the following questions based upon your experience in **the scenario just completed**.

1. Did you treat the Predator any **differently** when there was a chase plane?

○ Yes	○ No

If yes, explain _____

_____

2. Rate the degree to which the **Predator return to base via runway 21** affected the **manageability** of the overall operations.

Not at All — A Great Deal

1	2	3	4	5	6	7

3. Rate the degree to which the **A-160 in the East/West Ops** area affected the Predator's return to base.

Not at All — A Great Deal

1	2	3	4	5	6	7

Explain _____

_____

Multi-UAS Operational Assessment: Class D Airspace

S21

Post-Run Questionnaire

Position: **Local**	Date:	**Scenario: 21**
Participant Number:	Study Day:	Run:

Please answer the following questions based upon your experience in **the scenario just completed**.

1. Rate the degree to which the **N744PA engine failure** affected the **manageability** of the overall operations.

Not at All — A Great Deal

1	2	3	4	5	6	7

2. Rate the degree to which the emergency affected **JPL operations**.

Not at All — A Great Deal

1	2	3	4	5	6	7

Explain _____

_____

3. Rate the degree to which the emergency affected any **other UAS operations**.

Not at All — A Great Deal

1	2	3	4	5	6	7

Explain _____

_____

Multi-UAS Operational Assessment: Class D Airspace

S22

Post-Run Questionnaire

Position: **Local**	Date:	**Scenario: 22**
Participant Number:	Study Day:	Run:

Please answer the following questions based upon your experience in **the scenario just completed**.

1. Did you approve **simultaneous UAS touch and go operations** on the same runway?

○ Yes	○ No

If no, explain why not _____

_____

******If No to Question 1 stop here******

2. Rate the degree to which the **simultaneous UAS touch and go operations** on the same runway affected the **manageability** of the overall operations.

Not at All						A Great Deal
1	2	3	4	5	6	7

Explain _____

_____

Multi-UAS Operational Assessment: Class D Airspace

S23

Post-Run Questionnaire

Position: **Local**	Date:	**Scenario: 23**
Participant Number:	Study Day:	Run:

Please answer the following questions based upon your experience in **the scenario just completed**.

1. Did you authorize two **simultaneous A-160 operations** on the same runway?

○ Yes	○ No

If no, explain why not _____

_____

******If No to Question 1 stop here******

2. Rate the degree to which the **Warrior Ramp operations** affected the **manageability** of the overall operations.

Not at All — A Great Deal

1	2	3	4	5	6	7

Explain _____

_____

3. How did you resolve the conflict when the A-160 requested to return to base?

Explain _____

_____

c. Would you handle it differently next time?

○ Yes	○ No

Explain _____

_____

Multi-UAS Operational Assessment: Class D Airspace

S24

Post-Run Questionnaire

Position: **Local**	Date:	**Scenario: 24**
Participant Number:	Study Day:	Run:

Please answer the following questions based upon your experience in **the scenario just completed**.

1. Did you treat the Predator any **differently** when there was a chase plane?

○ Yes	○ No

If yes, explain _____

_____

2. Rate the degree to which the **REHOST failure** affected the **UAS operations**.

Not at All — A Great Deal

1	2	3	4	5	6	7

Explain _____

_____

3. Did you **modify any UAS operations** due to the REHOST failure?

○ Yes	○ No

If yes, explain _____

_____

4. Rate the degree to which the **REHOST failure** affected the **manned aircraft operations**.

Not at All — A Great Deal

1	2	3	4	5	6	7

Explain _____

_____

5. Rate the degree to which the **REHOST failure** affected the **manageability** of the overall operations.

Not at All — A Great Deal

1	2	3	4	5	6	7

Multi-UAS Operational Assessment: Class D Airspace

Post-Experiment Questionnaire

Participant Number: Date:

Please base your answers to the questions below on your experiences in the different training and simulation exercises in which you participated.

1. Please rate the **OVERALL realism** of the following conditions.

	Extremely Unrealistic						Extremely Realistic
a. Visual Environment	1	2	3	4	5	6	7
b. Equipment (i.e. keyboards, hardware)	1	2	3	4	5	6	7
c. Traffic Volume	1	2	3	4	5	6	7
d. Traffic Mix/Diversity	1	2	3	4	5	6	7
e. Performance of Aircraft	1	2	3	4	5	6	7
f. Communication with Pilots	1	2	3	4	5	6	7
g. Overall Simulation Environment	1	2	3	4	5	6	7

2. Did the presence of multiple, simultaneous UAS operations in your airspace affect your **workload**?

○ Yes	○ No

Explain _____

_____

3. Did the presence of multiple, simultaneous UAS operations in your airspace affect your **situation awareness** concerning your overall traffic?

○ Yes	○ No

Explain _____

_____

4. Describe the **overall impact** of multiple, simultaneous UAS operations on Class D airspace.

Explain _____

_____

_____

Multi-UAS Operational Assessment: Class D Airspace
Post-Experiment Questionnaire

Participant Number: Date:

_____

5. From your point of view, what do you believe to be the **major challenges** in the effort to integrate multiple, simultaneous UAS operations in Class D airspace and how might these challenges be mitigated?

Explain _____

_____

_____

_____

6. Are there **any additional tools, requirements or procedures** you feel are necessary to implement the proposed concept in an operational setting?

Explain _____

_____

_____

_____

7. Describe anything that could be changed to **improve the realism** of the simulation.

Explain _____

_____

_____

_____

8. Were there any **distractions (i.e. being videotaped, background noise etc.)** in the simulation that detracted from the reality of the environment?

○ Yes	○ No

a. **If yes to 8**, did these distractions affect your ability to do your job?

○ Yes	○ No

Explain _____

_____

_____

_____

Multi-UAS Operational Assessment: Class D Airspace
Post-Experiment Questionnaire

Participant Number: Date:

9. Please **critique the operational in-briefing** you were given on the first day of this study.

Explain _____

_____

_____

_____

Appendix E - Observer Rating Forms

Multi-UAS Operational Assessment: Observer Rating Forms

Name: **Position:**	**Date:** **Study Day**	**Scenario:** **Run:**

	Extremely Low						Extremely High
Overall Workload:	1	2	3	4	5	6	7
Overall Complexity:	1	2	3	4	5	6	7

SAFETY

1. Were the following observed?

	Yes	**No**	**Notes**
Operational Error(s)			
Operational Deviation(s)			
Mid Air Collision(s)			
Near Mid Air Collision(s)			
Runway Incursion/Accident(s)			
Positive Control			
Loss of Runway Separation			

TRAFFIC MANAGEMENT/EFFICIENCY

2. Which of the following best describes the controllers' actions with regards to the UAS? (Check all that apply)

Segregation from Manned Aircraft			Integration with Manned Aircraft	
Segregation from other UAS			Integration with other UAS	

Notes _____

_____

Name:	**Date:**	**Scenario:**
Position:	**Study Day**	**Run:**

3. Were the following observed?

	Yes	**No**	**Notes**
Manned Aircraft Departure Delays			
Manned Aircraft Arrival Delays			
UAS Departure Delays			
UAS Arrival Delays			
Class D Airspace Clearance Denial			
	Yes	**No**	**Notes**
Re-sequenced Arrivals			
Re-sequenced Departures			
Modified Traffic Patterns			
Missed Approaches[38]			
Unplanned Go-Arounds			

[38] If 'yes' please explain thoroughly

Name:	**Date:**	**Scenario:**
Position:	**Study Day**	**Run:**

4. Rate the following on the scale below by circling **one** number:

	Extremely Low	**Extremely High**	**Notes**
Overall Safety of Pattern Sequence	1 2 3 4 5 6 7		
Overall Efficiency of Pattern Sequence	1 2 3 4 5 6 7		
Overall Efficiency of Taxiway and Runway Assignments	1 2 3 4 5 6 7		
Overall Safety and Efficiency of Traffic Flow	1 2 3 4 5 6 7		

WORKLOAD/SITUATION AWARENESS

5. Were the following observed?

	Yes	**No**	**Notes**
Excessive Controller Responses (e.g. say again, standby)			
Excessive Repeated Clearances/Instructions			

6. **Comments** on observed Workload and Situation Awareness of the controller (e.g. losing the flick, correct speech cadence, volume and delivery, etc.):

_____

_____

_____

7. Rate the following on the scale below by circling **one** number:

	Not Effective						**Very Effective**		**Notes**
Controller's Effective Recovery from Equipment Malfunctions	1	2	3	4	5	6	7	**N/A**	

Name: **Position:**	**Date:** **Study Day**	**Scenario:** **Run:**

	Very Poor						**Very Good**	**Notes**
Controller's Function as a Tower Team Member	1	2	3	4	5	6	7	

PRIORITY OF DUTY

8. Were the following observed?

	Yes	**No**	**Notes**
Priority of Duty Maintained			
Issued Traffic/Safety Alerts			
Issued Accurate/Effective Control Instructions			

COMMUNICATION

9. Were the following observed?

	Yes	**No**	**Notes**
Used Prescribed Phraseology			
Communication is Clear and Concise			
Coordination is Effective and Timely			
Transposed Call Signs, Headings, Airspeeds, Altitudes, Etc.			
Misidentified A/C by Call Sign			
Readback Errors Handled Appropriately			

Name:	**Date:**	**Scenario:**
Position:	**Study Day**	**Run:**

CONTROL INFORMATION/TECHNICAL KNOWLEDGE

10. Were the following observed?

	Yes	No	Notes
Adherence to LOA's and Directives			
Adherence to COA's (with the exception of allowing multiple simultaneous UAS operations)			

	Yes	No	N/A	Notes
Blimp remained within its Ops Area				
Hummingbird remained within its Ops Area				
Raven remained within its Ops Area				

11. Rate the following on the scale below by circling **one** number:

	Never						Always	Notes
How Often the Controller Used REHOST	1	2	3	4	5	6	7	

	Very Poor						Very Good	Notes
Controller's Knowledge of Aircraft/UAS Capabilities/Limitations	1	2	3	4	5	6	7	