

**National Aeronautics and
Space Administration**

UAS-NAS

Integrated Human in the
Loop

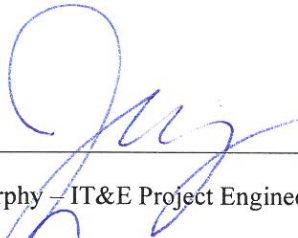
Test Environment Report

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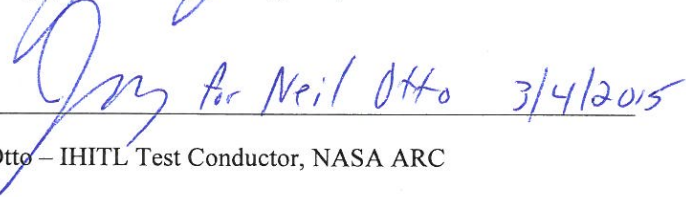
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1 Introduction

The desire and ability to fly Unmanned Aircraft Systems (UAS) in the National Airspace System (NAS) is of increasing urgency. The application of unmanned aircraft to perform national security, defense, scientific, and emergency management are driving the critical need for less restrictive access by UAS to the NAS. UAS represent a new capability that will provide a variety of services in the government (public) and commercial (civil) aviation sectors. The growth of this potential industry has not yet been realized due to the lack of a common understanding of what is required to safely operate UAS in the NAS.

NASA's UAS Integration in the NAS Project is conducting research in the areas of Separation Assurance/Sense and Avoid Interoperability (SSI), Human Systems Integration (HSI), and Communication to support reducing the barriers of UAS access to the NAS. This research was broken into two research themes namely, UAS Integration and Test Infrastructure. UAS Integration focuses on airspace integration procedures and performance standards to enable UAS integration in the air transportation system, covering Sense and Avoid (SAA) performance standards, command and control performance standards, and human systems integration. The focus of the Test Infrastructure theme was to enable development and validation of airspace integration procedures and performance standards, including the execution of integrated test and evaluation. In support of the integrated test and evaluation efforts, the Project developed an adaptable, scalable, and schedulable relevant test environment incorporating live, virtual, and constructive elements capable of validating concepts and technologies for unmanned aircraft systems to safely operate in the NAS.

To accomplish this task, the Project planned to conduct three integrated events: a Human-in-the-Loop simulation and two Flight Test series that integrated key concepts, technologies and/or procedures in a relevant air traffic environment. Each of the integrated events were built on the technical achievements, fidelity and complexity of previous simulations and tests, resulting in research findings that support the development of regulations governing the access of UAS into the NAS.

The purpose of this document is to describe how well the system under test was representative of a "relevant environment", ensuring the research objectives outlined in the Integrated Human-in-the-Loop (IHITL) Simulation Test Plan (IHITL SIM TP-01) were met. Section 1 provides background, high-level objectives and a description of the simulation components. The simulation had six high-level objectives, which required three different test setups. The description of these setups is detailed in Section 2. This section also contains a summary of the data gathered including any anomalies reported during collection. Section 3 discusses lessons learned during the conduct of the simulation. Section 4 provides test environment analysis, including details on system latency as well as feedback from test subjects and subject matter experts.

1.1 General

The integrated IHITL simulation provided data to the UAS researchers to evaluate the state of the simulation environment development by integrating and testing key Sense and Avoid (referred to as Detect and Avoid in the RTCA SC 228 ToR) technologies into a research Ground Control Station (GCS). The technical goals for the IHITL were to: 1) evaluate and measure the effectiveness and acceptability of SAA systems (algorithms and displays) to inform and advise UAS pilots; and 2) evaluate and measure the interoperability and operational acceptability of UAS integration concepts for operating in the NAS. A third Project goal was to characterize the simulation and test environment in order to evaluate the state of the simulation architecture with respect to future UAS research activities. The completion of the IHITL provided valuable data to the SSI and HSI research as well as reduced the risks associated with building a relevant test environment moving towards the Project flight tests.

NASA Ames, NASA Armstrong, and NASA Langley Research Centers shared responsibility for

conducting the tests, each providing a test lab and critical functionality. The experiment was divided into three distinct test setups each focusing on different aspects of the primary technical goals. The first was a three-week study looking at the controller acceptability of pilot initiated maneuvers based on SAA alerts, resolutions, and the GCS displays. The second was a two-week study focusing on the acceptability of the same SAA alerts, resolutions, and GCS displays to the UAS pilot. The third was divided into two test conditions, the first investigated the threshold between the existing Traffic Alert and Collision Avoidance (TCAS) II alerting logic present on commercial aircraft and potential self-separation alerting for UAS; the second investigated aspects of UAS communication delay and wind uncertainty with respect to Air Traffic Control (ATC) and UAS pilot maneuver negotiation.

The three test setups were conducted in parallel and divided by the Center participants. The first and second setups, which had similar hardware and software requirements, were conducted out of NASA Ames and NASA Armstrong over a seven-week period beginning 9 June 2014. The third test setup test condition involving the TCAS II alerting logic, run jointly between NASA Ames and NASA Langley's UAS Lab, started data collection on 9 June 2014 over a three-week period. The third set setup test condition involving communication and wind uncertainty was run standalone out of the NASA Langley's UAS Lab from 9 June 2014 to 9 July 2014. Over the course of the IHITL, data was collected from a total of 10 pilot and 21 controller subjects from the combined three test setups.

Test facilities fell into two categories:

Development Facilities:

- Distributed System Research Laboratory (DSRL) at NASA Ames
- Flight Deck Display Research Laboratory (FDDRL) at NASA Ames
- LVC Distributed Environment Lab at NASA Armstrong
- Research Ground Control Station (RGCS)/UAV Simulation Development Lab at NASA Armstrong
- UAS Sense and Avoid Research (USAR) Lab at NASA Langley (Stinger Gaffarian Technologies (SGT))

Test Facilities:

- Crew Vehicle Simulation Research Facility (CVSRF) at NASA Ames
- Distributed System Research Laboratory (DSRL) at NASA Ames
- LVC Distributed Environment Lab at NASA Armstrong
- RGCS/UAV Simulation Development Lab at NASA Armstrong
- UAS Sense and Avoid Research Lab at NASA Langley

1.2 Background

The UAS Integration in the NAS Project has ongoing research efforts focusing on the investigation of Sense and Avoid, defined by the collision avoidance (CA) and self separation (SS) concepts, and its interoperability with separation assurance (SA). As shown in Figure 1, these concepts have distinct thresholds (which are a focus of the research) that may overlap in both temporal and spatial domains.

The self-separation algorithm research was coupled with the investigation of the UAS GCS pilot environment, display of the SAA advisories to the pilot, and interaction between pilots using these advisories and air traffic controllers. As such, the Project conducted a series of integrated human-in-the-loop simulations in order to evaluate pilot and controller acceptance of the usability, display, and timeliness of different types of SAA advisories. The IHITL utilized the Distributed Test Environment (DTE)

developed by the Project to provide the core infrastructure and supporting simulation Live, Virtual, Constructive (LVC) software components in order to simulate a virtual UAS flying under nominal (non-contingency) operations, interacting with ATC and virtual manned aircraft. An instance of the DTE was configured to meet the requirements for each of the IHITL test setups, providing the appropriate level of functionality, fidelity, and security. The DTE test components included a research prototype GCS, an engineering GCS display, a flight simulator with an integrated TCAS system, and constructive aircraft target generators and virtual ATC workstations.

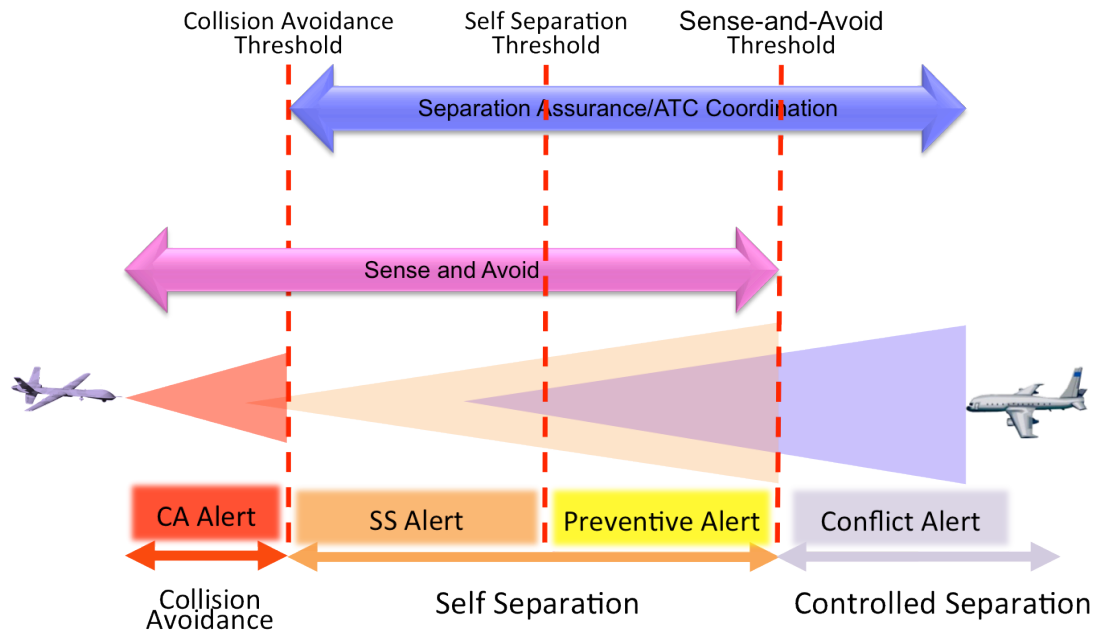


Figure 1. Sense and Avoid and Separation Assurance Interoperability. The Sense and Avoid concept encompasses the collision avoidance, self-separation, and boundary with separation assurance.

1.3 Overall Test Goals and Objectives

The integrated Human in the Loop simulation served as the mechanism to test two primary technical goals:

- 1.) Integrate and evaluate the state of UAS concepts and supporting technologies defined within the scope of the UAS Integration in the NAS Project. Identify areas of future research and development emphasis and reduce risk for the flight tests
- 2.) Evaluate and measure the effectiveness and acceptability of the SAA algorithms and displays to inform and advise pilots of UAS aircraft, as well as the acceptability of resulting maneuvers and workload to the air traffic controller.

These high-level test goals were further broken down into six general test objectives:

- Integrate and evaluate the state of UAS concepts and supporting technologies defined within the scope of the UAS Integration in the NAS Project as a function of traffic scenarios
- Evaluate the pilot and controller acceptability of UAS maneuvers in response to SAA advisories
- Assess the impact of variable winds on the execution of SAA advisories as well as interoperability with TCAS equipped aircraft

- Assess the impact of communication delay and wind uncertainty on the air traffic controller workload and acceptability of SAA self-separation maneuvers
- Evaluate the acceptability and performance of the LVC (i.e. software components of the DTE) to provide a relevant environment
- Collect data to improve batch simulation models.

1.4 Simulation Configurations

The IHITL has two distinct system configurations shown in Figure 2 and Figure 3. These figures describe the system level requirements for IHITL in the abstract, the specific hardware and software components that comprise the implemented test setups are described later in this document.

Figure 2 provides a high-level diagram of IHITL System Configuration 1. System Configuration 1 was designed to connect virtual air traffic control (ATC) and constructive aircraft processes running at NASA Ames with a prototype research UAS GCS at NASA Armstrong. The framework for the simulation DTE was supplied by LVC components connected via the High Level Architecture (HLA) messaging infrastructure. A virtual UAS simulator was integrated into a prototype research GCS along with a traffic display (GCS-TD) used to present SAA (SS and CA) advisories to the pilot. The LVC components sent and received data through a gateway connected to the HLA network. The constructive manned aircraft and ATC workstations communicated directly via a local gateway and communicated to the other components via that gateway and the HLA. The constructive manned aircraft generators provided the required background traffic supporting a more realistic environment.

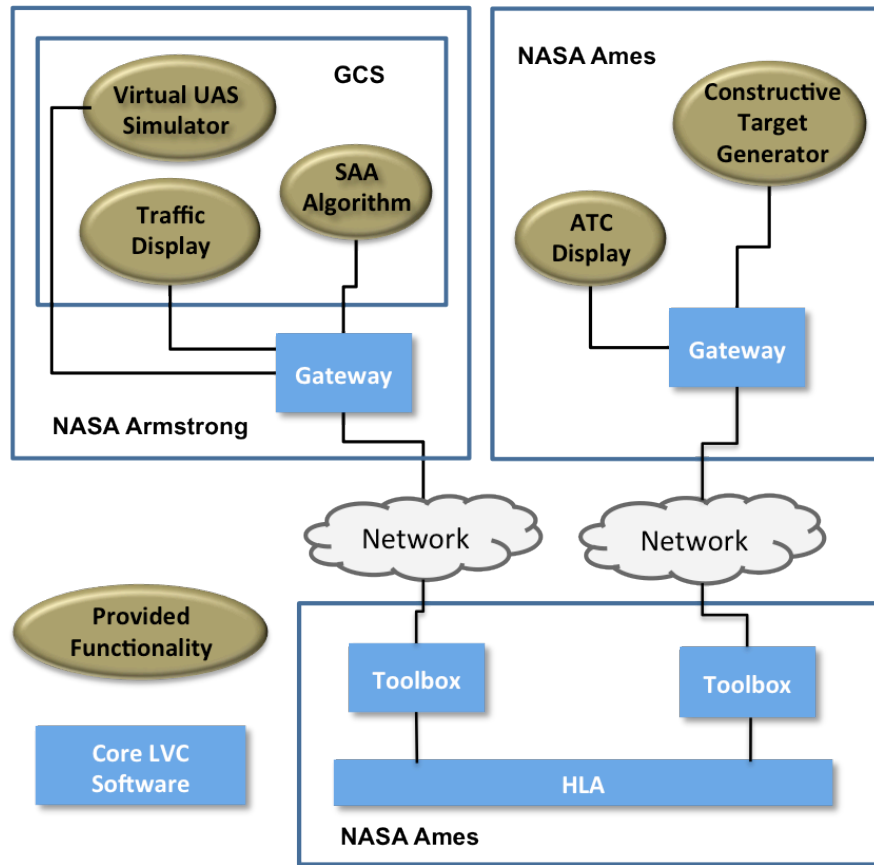


Figure 2. System Configuration 1.

Figure 3 shows a high-level diagram of the IHITL System Configuration 2. As with System Configuration 1, the System Configuration 2 DTE was designed to provide connectivity among the LVC components, specifically a virtual UAS GCS, constructive manned traffic generators, and virtual ATC. In this case these virtual and constructive components were provided via facilities at NASA Langley. In addition, a flight simulator with TCAS installed ran at NASA Ames providing the primary intruder aircraft via HLA. A UAS GCS at NASA Langley contained a combined Virtual Simulator, GCS-TD, and SAA system (self-separation and CA) for testing.

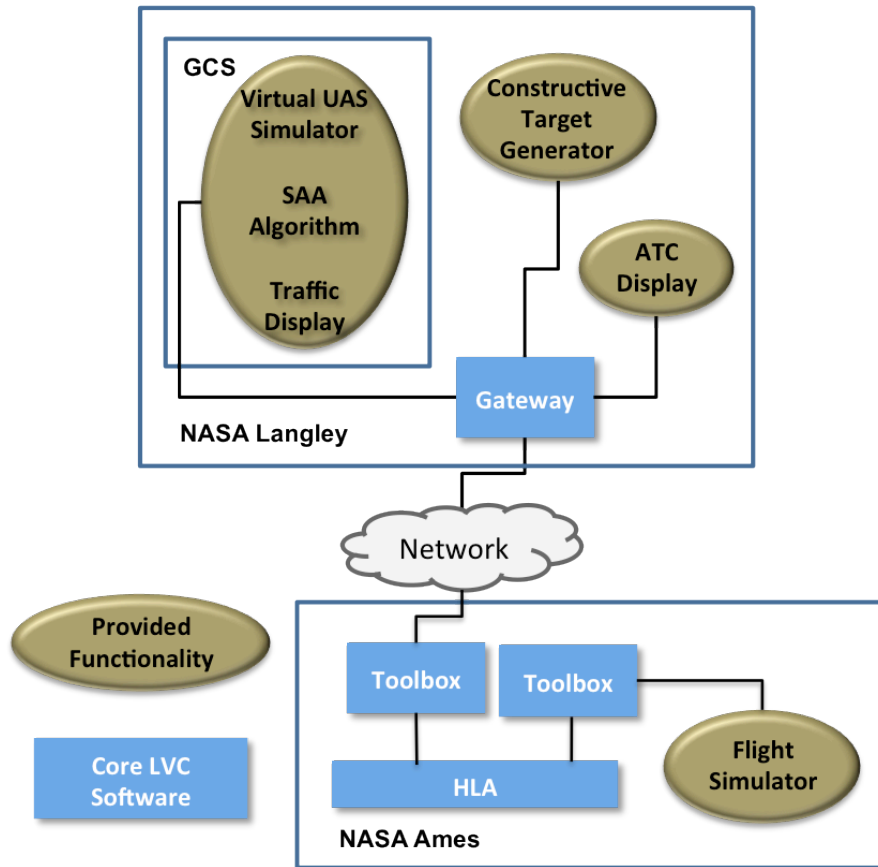


Figure 3. System Configuration 2.

The high-level system architectures shown in Figure 2 and Figure 3 provided the basis for the specific LVC simulation environment that was developed for each of the three test setups conducted during the IHITL:

- 1.) Air Traffic Controller (or Controller) Acceptability of SAA Maneuvers (Test Setup 1)
- 2.) Pilot Acceptability of SAA Maneuvers (Test Setup 2)
- 3.) Acceptability of SAA Advisories (Test Setup 3).

It should be noted that Test Setup 3 was divided into two test conditions using subsets of the system configuration shown in Figure 3. The first test condition utilized the connection between NASA Ames and NASA Langley to connect the flight simulator with the GCS. The second condition, focusing on controller response to the SAA advisories, was conducted stand-alone at NASA Langley using only the components shown in the upper box in Figure 3. The descriptions for each test setup are further detailed in Section 2.

2 Test Resources

Each test setup had distinct associated LVC components interconnected into a distributed test environment instantiation; however, many of the LVC components (located in laboratories) are common among the setups. This section provides detailed background descriptions of the distributed test environment LVC components and other test resources. Explicit detail regarding how these resources were used during test is captured in the Test Methodology sections for each Test Setup.

2.1 High Level Architecture (HLA) and LVC Gateway

The framework for the simulation environment was supplied via the High Level Architecture (HLA) messaging infrastructure. The connections used a version of the IEEE 1516 standard Pitch portable Real Time Infrastructure HLA and Federation Object Model (FOM) middleware to exchange information about the air traffic environment (aircraft state, flight plans, etc.) among the participants operating from distributed facilities.ⁱ The HLA utilized Toolboxes to convert data from simulation components (e.g. flight simulator, or air traffic control display) into its expected format. Messages sent to a distributed facility were routed to the HLA via a Gateway and corresponding Toolbox.

2.2 Remote User Monitoring System (RUMS)

In order to facilitate the monitoring of the data collection Remote User Monitoring System (RUMS) software was used. The RUMS server connected to the Gateway process and recorded all data messages to a remotely accessible database. Test participants were able to connect to the database via queries from an Internet web browser and display data of interest.

2.3 Multi-Aircraft Control System (MACS)

The Multi-Aircraft Control System (MACS) program was a comprehensive simulation program developed at the NASA Ames Airspace Operations Laboratory (AOL) to support research in air traffic operations in the current and NextGen environment.ⁱⁱ The underlying MACS software was used extensively in the IHITL to provide aircraft control emulation, aircraft target generation, and a standalone UAS ground control station with integrated SAA algorithms. The following sections provide more detail on each of the functionalities.

2.3.1 Air Traffic Control Display

The Multi-Aircraft Control System (MACS) program provided the ATC display functionality for the IHITL simulation. An instance of the MACS was used for each ATC sector position. Depending on the start-up configuration, it provided an emulation of the En Route Automation Modernization (ERAM) environment or Standard Terminal Automation Replacement System (STARS) environment. Figure 4 shows MACS configured as an ERAM sector display.

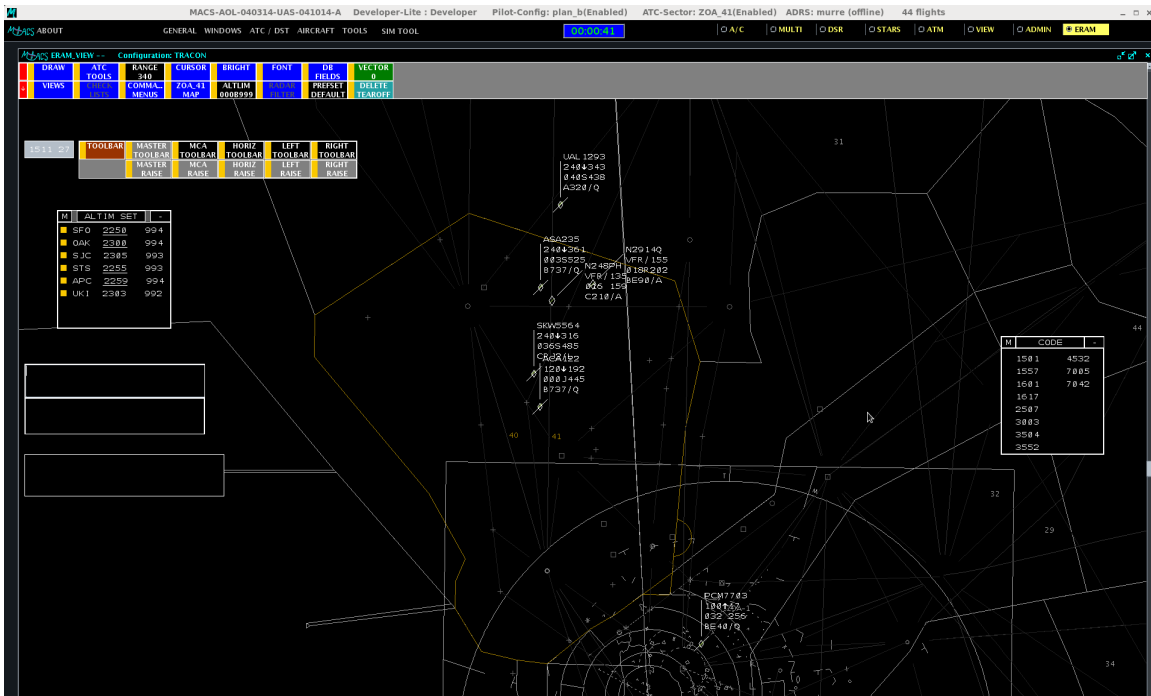


Figure 4. Multi-Aircraft Control System (MACS) Air Traffic Control displays.

2.3.2 Aircraft Target Generation

The MACS SimMgr and MACS pseudo pilot programs provided simulated aircraft targets during testing (see Figure 5). At the beginning of each IHITL simulation MACS SimMgr read the initial conditions and flight path from an input scenario file. Aircraft were then assigned to the MACS pseudo pilot stations where the aircraft position updates were generated based on the flight paths and aircraft model data. This aircraft data was distributed to each test participant as required. MACS used a four degree-of-freedom trajectory engine to update the location of the aircraft on a one second frequency (emulating ADS-B). The simulated targets emulated either IFR or VFR aircraft and provided background traffic that flew a predetermined flight path.



Figure 5. Multi-Aircraft Control System (MACS) pseudo pilot displays.

2.3.3 UAS GCS

In order to support display development for the project, MACS was expanded to function as a standalone Pilot Station with built-in UAS characteristics providing a virtual GCS, called the MACS GCS (see Figure 6). This version of MACS had the NASA Langley Stratway+ self-separation system integrated into its software. The MACS GCS was used for both test conditions for Test Setup 3 and provided the position updates for the primary UAS aircraft of interest in each scenario.



Figure 6. MACS Ground Control Station displays.

It should be noted that the MACS program interfaced with the test environment through an associated gateway called the Aeronautical Data link and Radar Simulator (ADRS). The use and connectivity of the MACS programs to the test environment via the ADRS is shown in the connection diagrams in Section 2.1, when it was connected and not operated stand-alone.

2.4 Vigilant Spirit Control Station (VSCS)

Air Force Research Lab (AFRL)'s Vigilant Spirit Control Station (VSCS) was a UAS simulator that modeled the virtual flight of a UAS aircraft (See Figure 7)ⁱⁱⁱ. It connected to the test environment via the HLA, providing position updates based on flight plan and maneuvers. VSCS also had a separate traffic display, which provided the GCS-TD functionality. The traffic display showed self-separation and collision avoidance conflict advisories in addition to intruder information such as call sign (if available), relative altitude, vertical velocity, and ground speed. The VSCS traffic display also showed resolution maneuvers and supported "vector-planning". Vector-planning allowed the pilot to test various horizontal or vertical vectors to help determine appropriate trajectories to avoid potential conflicts. Maneuver resolutions and vector-planning were facilitated by the SAA system, which was derived from the AutoResolver technologies developed by NASA Ames to support resolution advisories for manned aircraft. AutoResolver connected via a Gateway, receiving data from VSCS and MACS SimMgr, and sending advisories back to the VSCS and presented on the traffic display for the UAS pilot.



Figure 7. Vigilant Spirit Control System (VSCS) Integrated Traffic and Tactical Situation Display.

2.5 B747 Flight Simulator

The existing B747 Flight Simulator at NASA Ames provided an additional manned virtual aircraft and connects to the other LVC components via the HLA. The simulator has an on board Flight Management System (FMS), which allowed for flight plans to be flown in simulation. The virtual position updates were generated internally, incorporating a realistic flight model and winds. The B747 Cab was equipped with the

TCAS II version 7.0 algorithm and was used to test interoperability between the UAS SAA algorithm and existing manned aircraft tactical avoidance algorithms. Data used by TCAS to determine alerts was automatically recorded and available for post processing by the researchers. Figure 8 shows pictures of the inside and outside of the B747 flight simulator.



Figure 8. Boeing 747-400 Flight Simulator at NASA Ames.

2.6 Research Ground Control Station (RGCS)

The UAS Ground Control Station (GCS) capability was provided by the RGCS at NASA Armstrong for Test Setups 1 and 2. The RGCS was a hardware test-bed for UAS GCS information display and human factors concepts. It contained the monitors and computer systems that run the display systems under test. The RGCS used the VSCS as the UAS aircraft simulator, as well as the VSCS traffic display for its GCS-TD instantiations. A graphical representation of the RGCS is depicted in Figure 9.



Figure 9. Research Ground Control Station layout.

3 Test Setups

The IHITL had three distinct test setups tracing back to the two system configurations shown in Figure 2 and Figure 3 corresponding to the specific objectives, hardware, and software required to conduct the experiment. The first two test setups utilized the RGCS UAS pilot station developed at NASA Armstrong, the first with controllers (stationed at NASA Ames) as subjects and the second with UAS pilots as subjects. The third test setup integrated a flight simulator with a TCAS II system stationed at NASA Ames into an existing simulation environment at NASA Langley. Distributing the simulation among the NASA Centers allowed the project to utilize the existing simulation infrastructure resident at those facilities.

3.1 Test Setup 1 - Controller Acceptability of SAA Maneuvers

The experimental goal of this study was to evaluate the controller acceptability of maneuvers performed for “self-separation” to remain well clear without a new clearance. System Configuration 1 provided the baseline architecture for this test setup, which utilizes a virtual UAS aircraft flown on an IFR flight plan with constructive background traffic scenarios containing a mix of manned IFR and VFR aircraft. In this setup, UAS and manned aircraft pilots acted as confederates and controllers were the test subjects. The VFR traffic included non-cooperative (non-squawking) aircraft, which allowed for the UAS to interact with manned aircraft in close proximity to its area of operations without ATC resolution. Encounters between the UAS and the manned background traffic were scripted to trigger the self-separation algorithm to send alerts and advisories to the GCS-TD. The UAS pilot used the advisories to coordinate with controllers to strategically mitigate potential conflicts.

The Sense and Avoid system under test included a modified version of the AutoResolver, developed by researchers at NASA Ames. The AutoResolver was first developed to support air traffic controllers with advisories to maneuver aircraft in the en route and Terminal airspace based on predicted Loss of Separation (LOS).^{iv,v} This algorithm was modified to work with pilots to support alerts and maneuvers in response to LOS predictions and included a model of an airborne sensor that applied a filter to restrict the inputs to the AutoResolver based on predicted airborne sensor performance (range and field of regard). Though not a focus of this test, to help determine cases where the self-separation algorithm failed to properly predict and resolve conflicts, a collision avoidance algorithm (based on TCAS parameters) was used to alert the UAS pilot of impending collision.

3.1.1 Test Methodology

Test setup 1 utilized a virtual UAS aircraft flown under an IFR flight plan in scenarios with a mix of manned IFR and VFR traffic. During test setup 1, pilots acted as confederates and controllers were the subjects. VFR traffic allowed for the UAS to interact with the manned aircraft, which enabled the SAA system to provide advisories to the pilot based on the definition of the Well Clear Violation (WCV) parameters. In order for “well clear” to be violated all of the following conditions must be met:

- a. The horizontal Closest Point of Approach (CPA) or the current horizontal range was less than 0.8 nmi
- b. The time to horizontal CPA was below 40 seconds
- c. The time to co-altitude was below 40 seconds or the current vertical separation distance is below 500 ft.

The UAS pilot used the advisories to work with controllers to strategically mitigate potential conflicts.

The ConOps for this test setup was a UAS being controlled by a GCS located in southern California, with the aircraft deployed under various missions in the San Francisco Bay area. In this test, traffic scenarios running on MACS at NASA Ames provided background traffic in Oakland Center (see section 3.1.1.1 for an airspace description). The MACS pseudo pilot stations sent position updates every second. The UAS was flown by an instance of VSCS running on the RGCS at NASA Armstrong following a prescribed flight

plan. Controllers, the subjects of these tests, managed the traffic on MACS running as an ERAM display at NASA Ames. The SAA system was connected to the RGCS and provided advisories to the UAS pilot who was able to trial plan different maneuvers via the VSCS traffic display and negotiate an appropriate resolution to any predicted conflict with the controller. The simulated UAS sensor suite provided position data for each intruder aircraft to the SAA algorithm based on its aircraft equipment and flight plan type (see Figure 10):

1. ADS-B:
 - a. Range 80 nm
 - b. Altitude +/- 5000 ft
2. Non-Cooperative:
 - a. Range: 6 nmi
 - b. Azimuth: +/- 110 degrees (from nose)
 - c. Elevation: +/- 20 degrees (from horizontal)

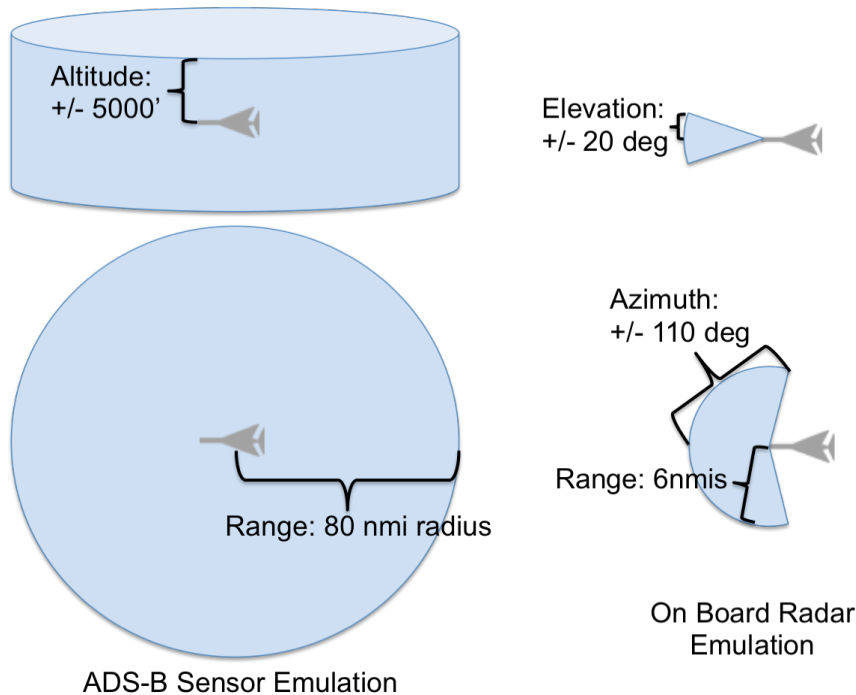


Figure 10. Aircraft sensor emulation values used for Test Setups 1 and 2 (not to scale).

Since the ConOps for the test was chosen to mirror the physical instantiation of the distributed system (UAS operating near central California and UAS GCS located near southern California), no additional communication system modeling was required to emulate the latencies. However 93ms uplink delay and 115ms downlink delay were added to VSCS to emulate latencies associated with data message passing between the GCS and aircraft. No winds were modeled for this Test Setup.

Controllers were instructed to separate traffic as they normally would, issuing traffic advisories and alerts to appropriate pairs of aircraft whenever separation was projected to decrease below the applicable minimum. Four scenarios of 40 minutes each were used, two with a high traffic load, two with a nominal traffic load. See Section 5 for a detailed description of the four scenarios. During each scenario, the pilot was instructed to either request a maneuver from the controller or maneuver without controller

coordination. Three “types of VFR traffic” were present in every scenario, and each encounter listed below was between an IFR aircraft and one of these three types of VFR aircraft:

- non-cooperative, non-participating VFR aircraft (primary targets only)
- cooperative, non-participating VFR aircraft (transponder-equipped, not talking to ATC)
- cooperative, participating VFR aircraft (transponder-equipped, talking to ATC)

3.1.1.1 Airspace

Figure 11 shows the simulation airspace, which was an emulation of Oakland Center (ZOA) Sectors 40 and 41 as a combined en route sector. Sector 40/41 extends to the California coast and coastal mountains in the west to the western Travis Air Force Base in the east. The sector overlies the Napa and Sonoma valleys from Mendicino to Sausalito. Sector 40/41 airspace included all classes of airspace from the surface to Flight Level 240.

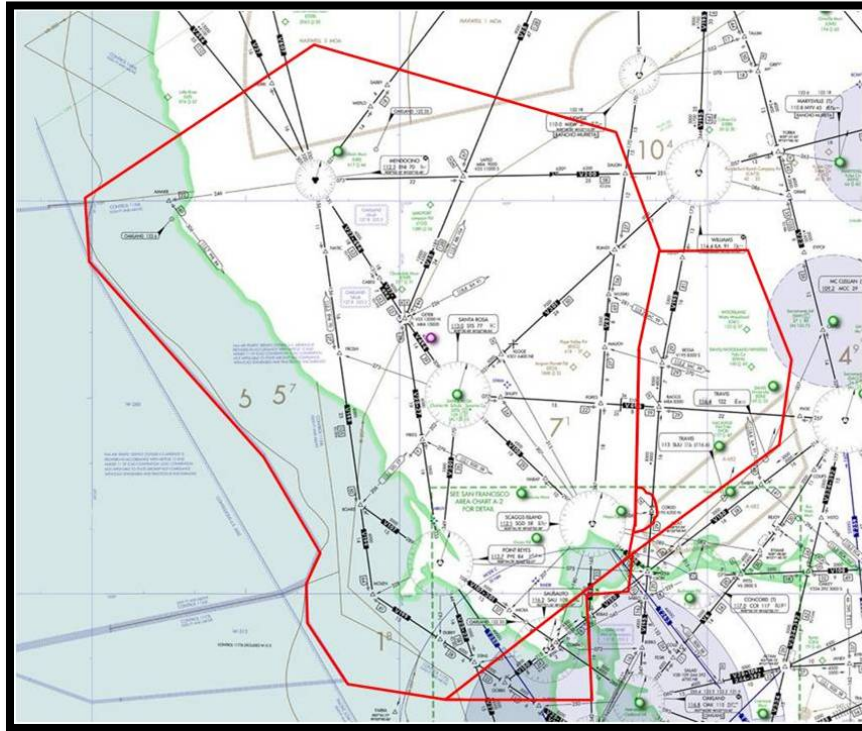


Figure 11. ZOA 40/41 airspace.

3.1.1.2 Scenarios

There are four explicit aircraft scenarios, which include aircraft executing specific mission profiles as well as transitioning to and from a major Terminal Radar Approach Control (TRACON). Each scenario contained scripted aircraft encounters running for approximately 40 minutes and was designed to trigger the SAA alerting logic in order to capture the appropriate data.

3.1.1.2.1 Search and Rescue

This scenario simulates UAV flight operations in support of search and rescue of a group of hikers reported lost in the wilderness area in the Mayacmas Mountains between Clear Lake and Lake Berryessa. The aircraft enters the scenario at 15,000 feet and starts a descent to 7,000 feet to enter a grid search pattern. The UAV then simulated visual reconnaissance from 6,000 feet to 7,000 feet. Upon exiting the grid the UAV climbed to 17,000 feet and proceeded direct to Williams VORTAC enroute to Beale AFB. All operations were conducted in Class E airspace using instrument flight rules. This profile was designed to conform with the FAA CONOP, UAS National Plan (Initial), September 2012, 5.5 Grid Pattern. Refer to Table 1 and Figure 12 for a description and diagram of the UAS flight path.

Table 1. Search and Rescue Flight Profile (Route 1)

Point #	Fix	Lat/Long	Altitude
1	Sim Start Point	3826.71/-12217.51	15,000
2	OZIEE	3829.53/-12223.18	Descend to 12,000
3	WUSHU	3845.81/-12219.25	Descend to 7,000
4	3847.03/-12225.23		7,000
5	3830.77/-12229.92		7,000
6	POPES	3829.15/-12220.75	Descend to 6,000
7	3836.53/-12218.70		6,000
8	3845.18/-12216.35		6,000
9	3846.43/-12222.06		6,000
10	NOFTE	3830.46/-12226.62	6,000
11	STS	3830.48/-12248.63	Climb to 17,000
12	ILA	3404.36/-12201.81	Descend to BAB

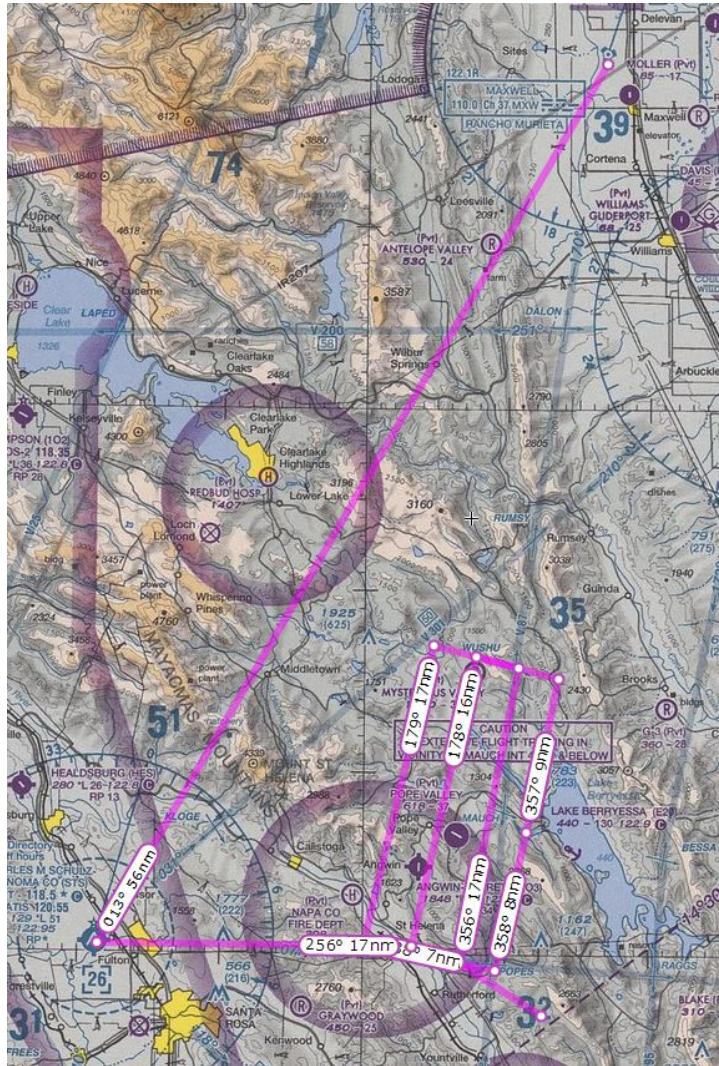


Figure 12. Projected flight path of UAV on the search and rescue mission in the ZOA airspace.

3.1.1.2.2 CDF Fire Line

These routes simulated a UAV as an air asset in support of fire fighting operations with the California Department of Forestry (CDF). In this scenario, a large fire had been burning in the Mayacmas Mountains north of Clear Lake. The fire line had been moving rapidly driven by strong northwesterly winds. CDF command needed information on existing fire lines in order to better allocate resources. The UAV entered the track at Flight Level 200 and immediately descended to 8,000 feet. The aircraft returned to Flight Level 200 after transiting WUSHU intersection and remained at that altitude for the remainder of the scenario. Flight operations began and ended in Class A airspace. Mission altitudes and the associated encounters were conducted in Class E airspace. The UAV remained at the same altitude throughout the scenario to facilitate traffic encounters at lower altitudes. This profile was designed to conform to the FAA CONOP, UAS National Plan (Initial), September 2012, 5.3 Loiter for Surveillance. Refer to Table 2 and Figure 13 for a description and diagram of the UAS flight path.

Table 2. CDF Fire Line Flight Profile (Route 2)

Point #	Fix	Lat/Long	Altitude
1	Sim Start (VICOR)	3924.83/-12322.10	FL200 descending to 8,000
2	WEPLO	3914.26/-12305.63	8,000
3	FOWND	3905.76/-12257.80	8,000
4	LAPED	3903.70/-12247.64	8,000
5	WUSHU	3845.81/-12219.25	Climb to FL200
6	DALON	3904.14/-12215.99	FL200
	3912.19/-12243.62		FL200
	3907.78/-12250.30		FL200
	3914.62/-12252.31		FL200
7	SABBY	3917.53/-12302.44	FL200
8	HUPTU	3930.00/-12244.65	Descend to BAB

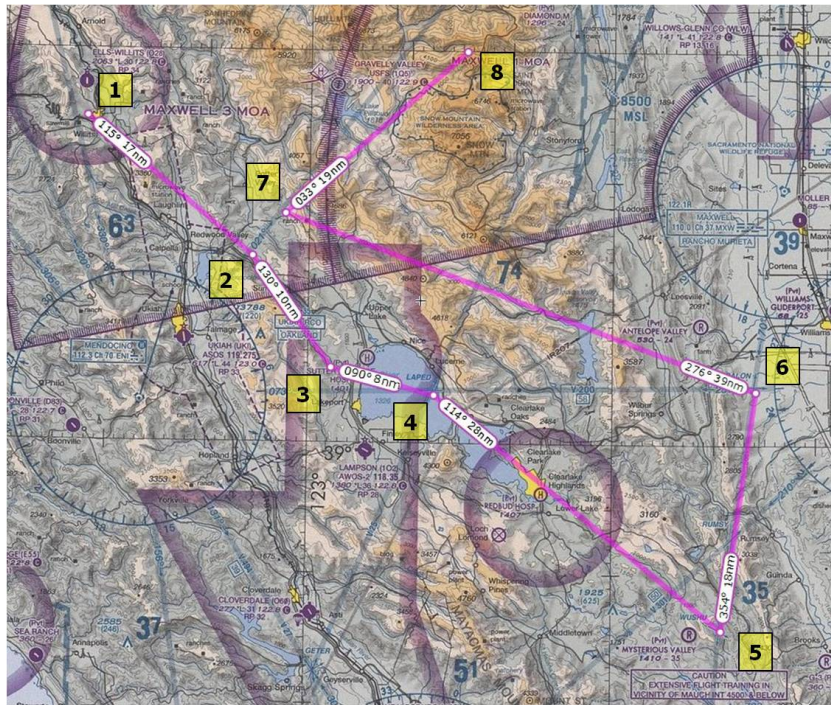


Figure 13. Projected flight path of UAV on a fire line mission in the ZOA airspace.

3.1.1.2.3 USCG Coastal Watch

In this simulation, the UAV conducted flight operations in cooperation with the USCG. The Coast Guard had requested that the UAV conduct routine surveillance of the beach areas from Point Reyes to Point Arenas. Upon arrival at Point Arenas, the UAV was requested to perform a visual search for a small craft near Point Arenas that had requested assistance from the USCG. The UAV flew a single orbit southeast of AMAKR intersection to search for the vessel then proceeded on course. The UAV entered the simulation at 10,000 feet and descended to 8,000 feet to conduct the beach surveillance. The aircraft climbed to 14,000 feet 10NM west of FROSH intersection to conduct the search for the small vessel. Once the surveillance was complete the aircraft descended to 7,000 feet en route to Santa Rosa airport. Flight operations were conducted in Class E airspace using instrument flight rules. This profile was designed to conform to the FAA CONOP, UAS National Plan (Initial), September 2012, 5.3 Loiter for Surveillance. Refer to Table 3 and Figure 14 for a description and diagram of the UAS flight path.

Table 3. USCG Coastal Watch Flight Profile (Route 3)

Point #	Fix	Lat/Long	Altitude
1	Sim Start Point	3753.30/-12235.45	10,000
2	LOZIT	3753.96/-12240.40	10,000
3	MOLEN	3759.86/-12305.20	Cross @ 8,000
4	BOARS	3813.64/-12307.62	Descend to 4,000
5	AMAKR	3900.00/-12345.00	Cross @ 14,000
6	3902.21/-12340.72		14,000
7	3849.29/-12329.73		14,000
8	3846.89/-12334.30		14,000
9	AMAKR (outbound)	3900.00/-12345.00	Descend to 7,000
10	FROSH	3836.84/-12311.74	

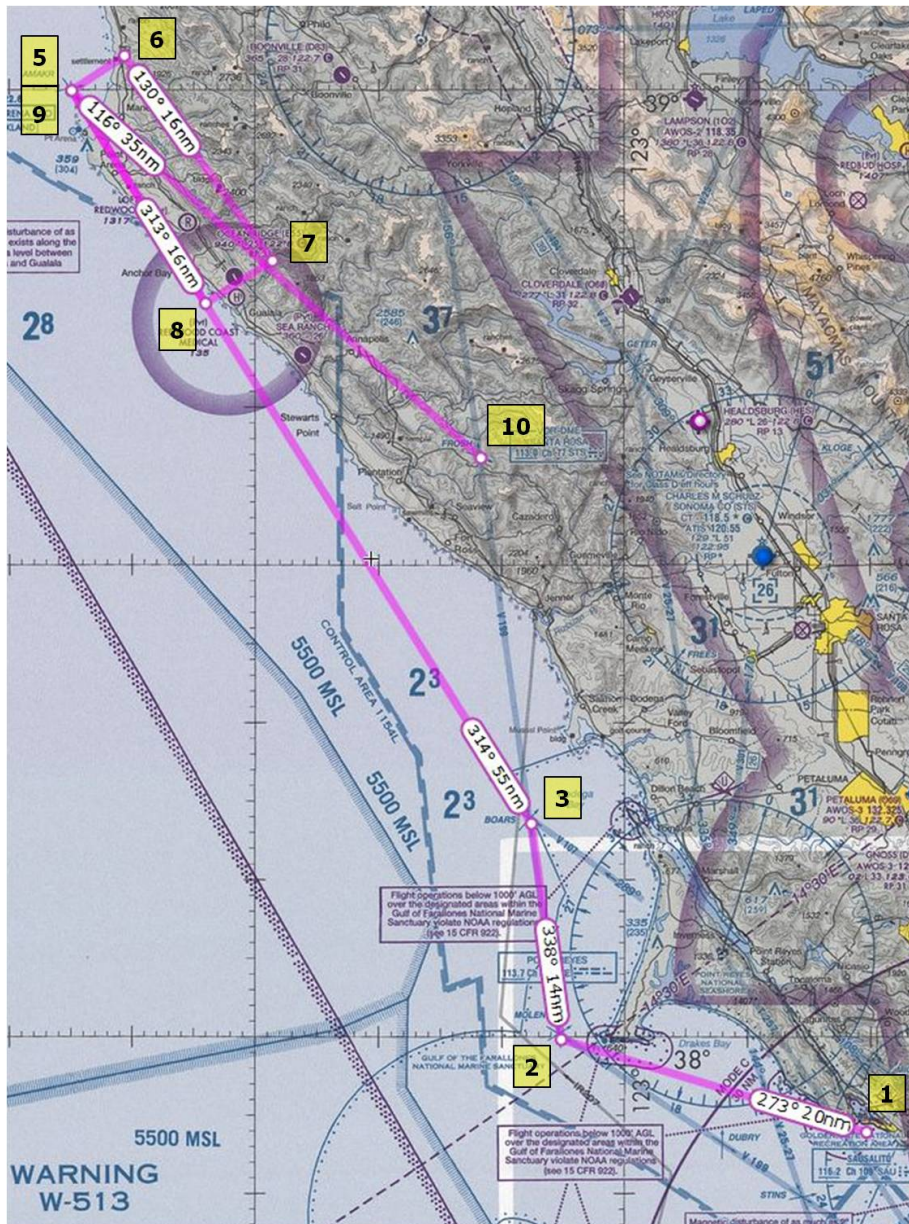


Figure 14. Projected flight path of UAV on a US Coastal Watch mission in the ZOA airspace.

3.1.1.2.4 Freighter

The UAV simulated a Cessna Caravan, an aircraft contracted to Federal Express. The UAV was conducting a regularly scheduled flight from Redding Airport to the FedEx nexus at Oakland International Airport. Letters of Agreement (LOAs) between Oakland ARTCC, Northern California TRACON and FedEx dictated that passenger aircraft have priority over unmanned freighters. This required the UAV to execute a turn in holding at STIKM waypoint on the RAIDR3 STAR as the OAK airport had several passenger aircraft on approach. The UAV entered the simulation at 16,000 feet and descended to enter holding at 7,000 feet. After completing the turn in holding the aircraft continues to Oakland Airport via the RAIDR4 STAR at 7'000 feet. Flight operations were conducted in accordance with FAR Part 121 and in Class E airspace using instrument flight rules. This profile was designed to conform to the FAA CONOP, UAS

National Plan (Initial), September 2012, 5.6 Point-to-Point. Refer to Table 4 and Figure 15 for a description and diagram of the UAS flight path.

Table 4. FedEx Freighter Flight Profile (Route 4)

Point #	Fix	Lat/Long	Altitude
1	Sim Start Point	3918.95/-12226.65	16,000
2	STIKM	3832.00/-12239.00	Cross @ 7,000
3	3832.87/-12232.00		7,000
4	3845.91/-12234.02		7,000
5	3845.09/-12241.49		7,000
6	STIKM	3832.00/-12239.00	7,000
7	RAIDR	3801.95/-12233.45	7,000

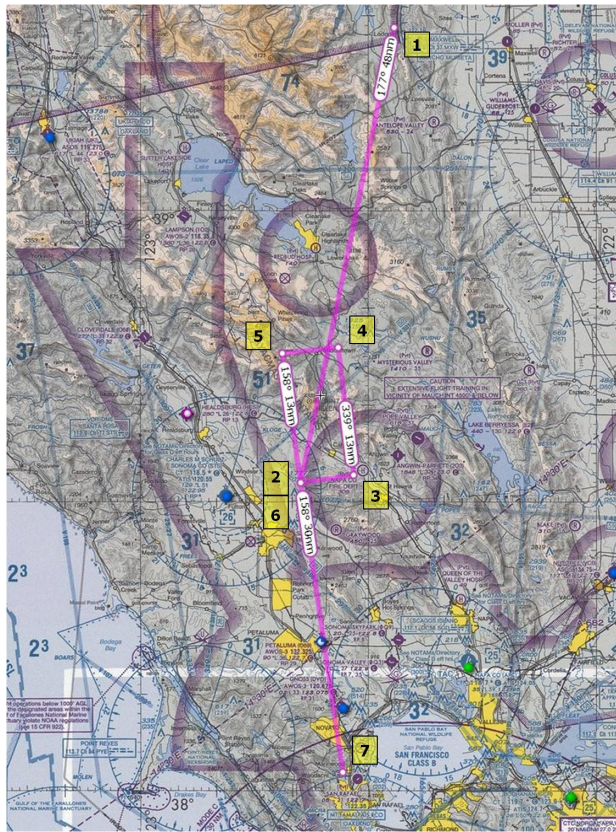


Figure 15. Projected flight path of UAV on a FedEx Freighter mission in the ZOA airspace.

3.1.2 Test Participants

Air traffic controller subjects were retired en route controllers, experienced with using the ERAM display. Controllers were trained by the test team controller SME on the specific aspects of the ZOA 40/41 sector aircraft flow. Non-subject pilot participants manning the pseudo pilot stations had the appropriate IFR experience to communicate with ATC and experience running the MACS pilot software. The UAS pilots (non subjects) were experienced UAS pilots with prior training on using the VSCS and the RGCS system.

3.1.3 Test Environment Architecture

The focus of this study was to gather data to help determine whether the pilot is required to coordinate a self-separation maneuver with ATC or whether they are allowed to maneuver to remain well clear without a new clearance. Metrics to determine the impact of coordinating (or not) self-separation maneuvers to remain well clear included time alert was presented to the UAS pilot, maneuver type (vertical, horizontal), perceived controller workload (measured post-scenario via questionnaire), the amount of time spent negotiating avoidance maneuvers, and an acceptability assessment questionnaire administered to the controller at the end of each collection run.

Figure 16 shows the test environment design for the Controller Acceptability of SAA Maneuvers test setup. The core connectivity infrastructure was provided by the HLA messaging system running at the DSRL lab at NASA Ames. A UAS pilot utilized the RGCS functionality at NASA Armstrong's RGCS lab. The UAS simulation functionality was provided by the VSCS instantiated in the RGCS along with the VSCS traffic display, which provided the display of the surrounding air traffic and SAA advisories to the pilot. The SAA algorithm was derived from the AutoResolver technologies developed by NASA Ames to support resolution advisories for manned aircraft and was connected to the RGCS via a Gateway. The MACS SimMgr and Pseudo Pilot stations running out of the CVSRF provided virtual and constructive manned background and intruder aircraft. The ATC subjects utilized the MACS ATC environment, which was run out of the CVSRF at NASA Ames. The MACS processes communicated to each other and the rest of the LVC components via the ADRS, which in turn connected to HLA. A distributed monitoring system consisting of an instance of MACS ATC was connected in the LVC lab at Armstrong for situation awareness of the traffic presented to the air traffic controllers.

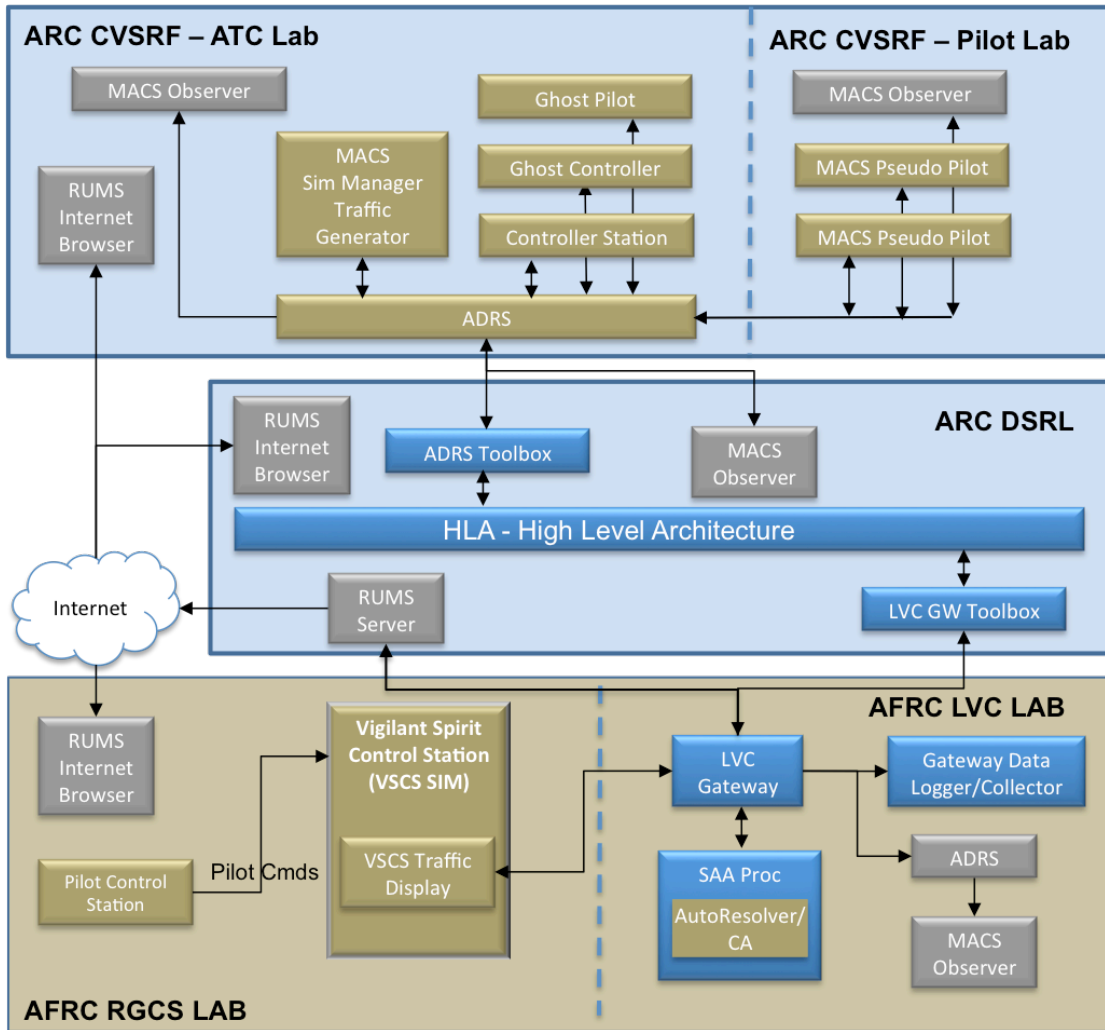


Figure 16. IHITL LVC system with components for the Controller Acceptability of SAA Maneuvers Test Setup 1 (including observer positions)

3.1.4 Simulation Voice Comm

The IHITL configurations used a combination of Simphonics and Plexsys voice communication systems that utilized Distributed Interactive Simulation (DIS) IEEE 1278.1A-1998 v6 Standard Protocol. The system was comprised of hardware and software that distributed multicast packets voice over a local area network. Packets were routed to specific receivers based on a simulated “frequency” that each station monitored. At NASA Ames, test subject, confederate, researcher, test-engineering, and control room positions located within the CVSRF utilized Simphonics systems, and test-engineering positions located within the DSRL utilized PlexComm systems. Voice recording for test setup 1 were accomplished using the Simphonics Recorder in the CVSRF ATC Lab. Eight Plexsys PlexComm Virtual Radios were installed on at NASA Armstrong for use by the RGCS pilot, researchers, test engineers, and control room.

The firewall configuration that establishes a VPN connection between Ames-Armstrong did not permit UDP (multicast) packets to pass through the VPN. Therefore, tunneling software that converts the UDP packets to TCP/IP and back to UDP on each end was installed.

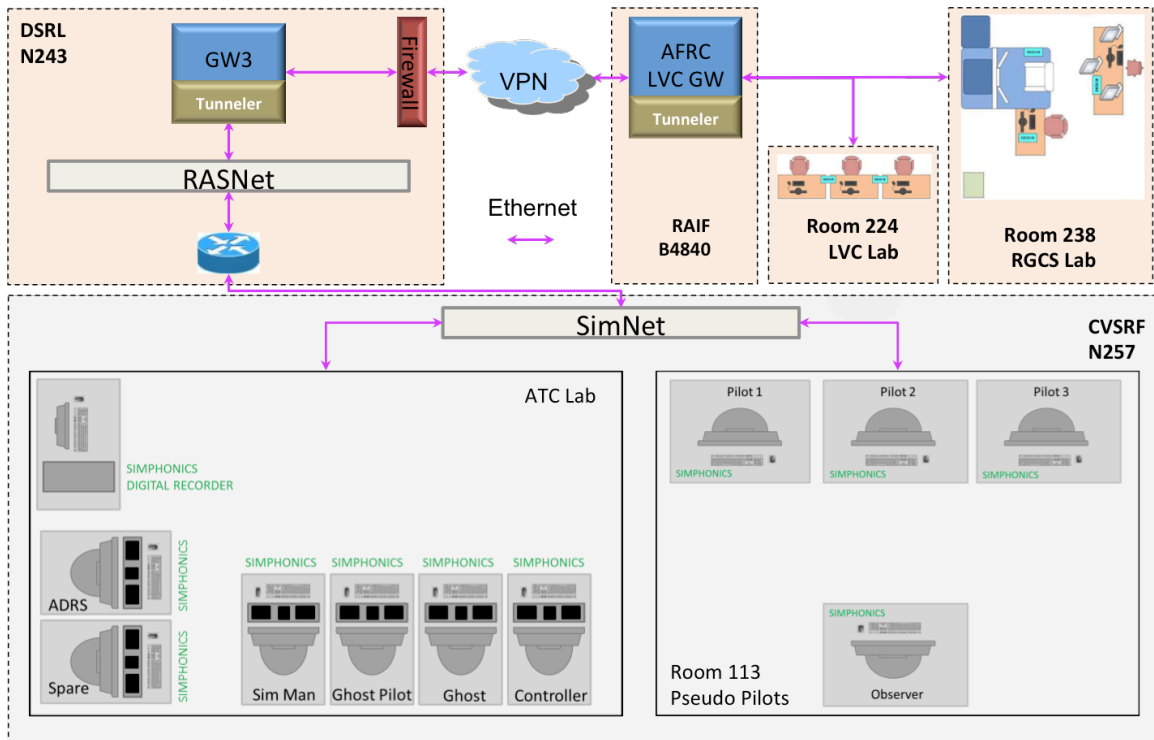


Figure 17. IHITL LVC Voice Communication connectivity for System Configuration 1

3.2 Test Setup 2 - Pilot Acceptability of SAA Maneuvers

The experimental goal of this study was to continue the evaluation of candidate SAA displays and algorithms with respect to self-separation and collision avoidance, based on results and lessons learned from previous internal simulations. System Configuration 1 also provided the baseline architecture for this test setup, which was run with the UAS pilot as the subject. The virtual UAS aircraft was flown on an IFR flight plan with scenarios containing a mix of manned IFR and VFR (squawking) aircraft. In this setup, controllers acted as confederates, allowing for interaction between the manned and UAS aircraft. The SAA algorithm provided alerts and advisories for display to the pilot on the GCS-TD. The pilot used the display information to negotiate maneuvers to avoid the traffic with ATC. A collision avoidance algorithm was used under this test setup to test the SS-CA time boundary.

As with the previous test, AutoResolver and the collision avoidance algorithms provided the SAA capabilities for this test set-up.

3.2.1 Test Methodology

The UAS pilot was the subject for this test setup. The virtual UAS aircraft flew under an IFR flight plan in scenarios with a mix of manned IFR and VFR traffic. With controllers as confederates, allowing for interaction between the manned aircraft and the UAS, the SAA system provided advisories to the pilot based on the definition of Well Clear Volume (WCV) parameters. In order for “well clear” to be violated all of the following conditions were met:

- a. The horizontal CPA or the current horizontal range was less than 0.8 nmi
- b. The time to horizontal CPA was below 40 seconds
- c. The time to co-altitude was below 40 seconds or the current vertical separation distance was below 500 ft.

The ConOps for this test setup was a UAS being controlled by a GCS stationed in southern California, with the aircraft deployed under various missions in the San Francisco Bay area. In this test, traffic scenarios running on MACS at NASA Ames provided background traffic in Oakland Center (see Section 5 for an airspace description). The UAS was flown by an instance of VSCS running on the RGCS at NASA Armstrong following a proscribed flight plan. The controllers managed the traffic on MACS running as an ERAM display at NASA Ames. The SAA system ran on a machine that was connected to the RGCS via a Gateway and provided advisories to the UAS pilot. The pilot vector planned different maneuvers via the VSCS traffic display and negotiated appropriate resolution to the predicted conflict with the controller. Since the ConOps for the test was chosen to mirror the physical instantiation of the distributed system (UAS operating near central California and UAS GCS located near southern California), no additional voice Comm modeling were required to emulate the appropriate latencies. However 93ms uplink delay and 115ms downlink delay were added to VSCS to emulate latencies associated with data message passing between the GCS and aircraft. No winds were modeled for this Test Setup.

The proposed design of the experiment design includes four levels of advanced Vigilant Spirit display information:

- D1. Advanced display with information only
- D2. Advanced display with information + vector planner
- D3. Advanced display with information + auto resolutions
- D4. Advanced display with information + vector planner + auto resolutions

For each subject, two scenarios of 38 minutes each were used, and each was replayed twice. During repetitions of the scenario two different levels of VSCS displays were tested (randomized over the subject pool). Scenario 1 represented a high workload (high traffic density, arrival sequencing for local Terminal airspace). Scenario 2 represented a nominal workload (average traffic density, non-arrival push to local Terminal). As with Test Setup 1, these scenarios were developed by the test team controller SME reviewed and rated as high and nominal by an independent controller SME.

The simulated sensor suite provide position data for each intruder aircraft to the SAA algorithm based on its aircraft equipment and flight plan type were the same as used for Test Setup 1 (See Figure 10 above):

- 1. ADS-B:
 - a. Range 80 nm
 - b. Altitude +/- 5000 ft
- 2. Non-Cooperative:
 - a. Range: 6 nmi
 - b. Azimuth: +/- 110 degrees (from nose)
 - c. Elevation: +/- 20 degrees (from horizontal)

3.2.1.1 Airspace

The pilot acceptability test setup used the identical airspace as the controller acceptability tests, namely Oakland Center sectors 40 and 41 combined. See Figure 11 in Section 3.1.1.1 for a diagram of the airspace.

3.2.1.2 Scenarios

Each of the data runs for Test Setup 2 was based upon the CDF Fire Line mission described in Section 3.1.1.2, with changes to the UAS aircraft flight levels and associated background traffic. (See Figure 13.) Table 5 and Table 6 describe the “high” and “low” altitude flight paths of the UAS aircraft in these scenarios.

Table 5. CDF Fire Line “High” Flight Profile (Route 2)

Point #	Fix	Lat/Long	Altitude
1	Sim Start (VICOR)	3924.83/-12322.10	9'000
2	WEPLO	3914.26/-12305.63	9'000
3	FOWND	3905.76/-12257.80	9'000
4	LAPED	3903.70/-12247.64	9'000
5	WUSHU	3845.81/-12219.25	9'000
6	DALON	3904.14/-12215.99	9'000
7	3912.19/-12243.62		9'000
8	3907.78/-12250.30		9'000
9	3914.62/-12252.31		9'000
10	SABBY	3917.53/-12302.44	9'000
11	HUPTU	3930.00/-12244.65	9'000

Table 6. CDF Fire Line “Low” Flight Profile (Route 2)

Point #	Fix	Lat/Long	Altitude
1	Sim Start (VICOR)	3924.83/-12322.10	7'000
2	WEPLO	3914.26/-12305.63	7'000
3	FOWND	3905.76/-12257.80	7'000
4	LAPED	3903.70/-12247.64	7'000
5	WUSHU	3845.81/-12219.25	7'000
6	DALON	3904.14/-12215.99	7'000
7	3912.19/-12243.62		7'000
8	3907.78/-12250.30		7'000
9	3914.62/-12252.31		7'000
10	SABBY	3917.53/-12302.44	7'000
11	HUPTU	3930.00/-12244.65	7'000

3.2.2 Test Participants

The UAS pilot subjects were active Predator B and Global Hawk pilots familiar with GCSs, but no experience with the VSCS or the RGCS. The air traffic controller participant (non-subject) was a retired en route controller, experienced with using the ERAM display. The test team controller SME trained the participant controller on the specific aspects of the ZOA 40/41 sector aircraft flow used for the scenarios. Non-subject pilot participants manning the pseudo pilot stations had the appropriate IFR experience to communicate with ATC and experience running the MACS pilot software.

3.2.3 Test Environment Architecture

The focus of this setup was to investigate the effect of:

- Advanced traffic display elements and tools to enhance pilots' ability to remain well clear
- Intruder aircraft sensor ranges on the pilots' ability to remain well clear.

Figure 18 shows the LVC design for the Pilot Acceptability of SAA Maneuvers test setup. The LVC test architecture is nearly identical to Test Setup 1, with the addition of an Eye Tracker system added to the RGCS to track UAS pilot display dwell times and feature focus.

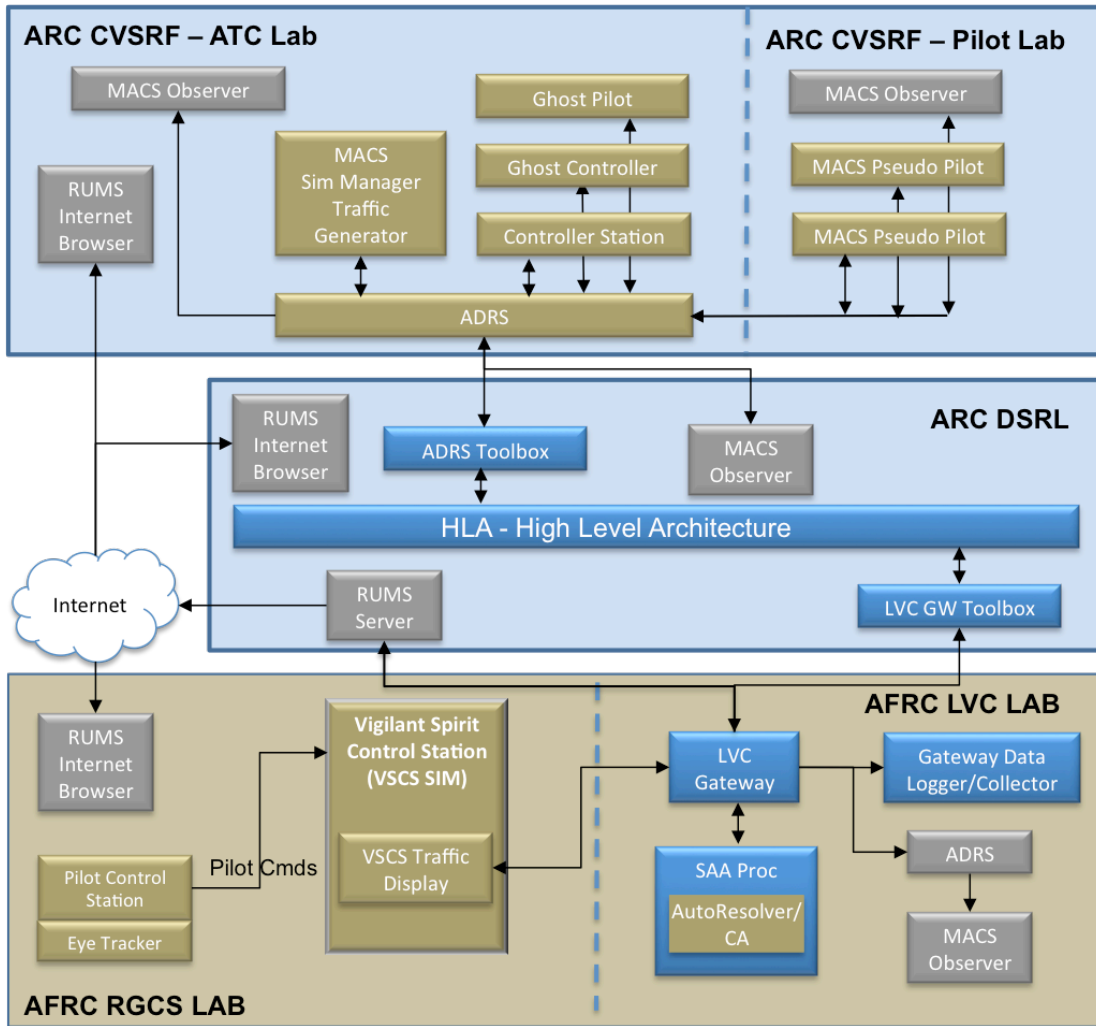


Figure 18. IHITL LVC system with components for the Pilot Acceptability of SAA Maneuvers test setup (including observer positions)

3.2.4 Simulation Voice Comm

The Voice Communication system used for Test Setup 2 was identical to Test Setup 1. Please see Section 3.1.4 for reference.

3.3 Test Setup 3 - Controller Acceptability of SAA Advisories and TCAS Interoperability

Test Setup 3 investigated the advisories generated by the NASA Langley’s Stratway+ SAA Concept. This concept, relies on the Stratway software prototype originally developed to support tactical resolution advisories for manned aircraft, provided SAA informational guidance to the pilot in control in the form of “preventive” advisory bands displayed on the ground control station indicating headings and speeds that could potentially cause a loss of “well clear” separation with other aircraft. The study was divided into two distinct test conditions; the first gathered data to evaluate the interoperability of the SAA advisories and the TCAS II algorithm. The second investigated the controller response to the UAS-ATC interactions, subject to varying communication delays and varying wind fields. The purpose for dividing the data collection

activities was to ensure that the encounters required to test the TCAS alerting could be triggered without ATC intervention (which would have been likely). As described above, the two test conditions derived their architecture from subsets of System Configuration 2. The first test condition utilized the connection between NASA Ames and NASA Langley to connect the Boeing 747 flight simulator at NASA Ames with the UAS GCS at NASA Langley. The second condition, focusing on controller response to the delayed pilot-ATC communications while exercising self-separation procedures, was conducted stand-alone at NASA Langley using only the components shown in the upper box in Figure 3.

3.3.1 Test Condition 1: SAA/TCAS Interoperability

The first test condition gathered data to evaluate the interoperability of the SAA Concept advisories and the TCAS II algorithm. This study exercised the SAA Concept well clear guidance and examined any possible overlap with the TCAS II alerting envelopes. Access to TCAS was provided by an existing NASA Ames flight simulator with a instance of TCAS II version 7.0 made available for testing through use of the LVC distributed environment.

3.3.1.1 Test Methodology

To conduct the TCAS alerting tests, the flight plan for the B747 aircraft was loaded into the B747 flight simulator at NASA Ames and the system at Ames was started. The simulation system at NASA Langley (SGT) including the MACS GCS, MACS SimMgr and the MACS monitoring displays was run, configured for the ZFW airspace, and seeded with the UAS flight plan profiles that were used to provide encounters for SAA and TCAS alerting. Encounters that trigger TCAS resolution advisories (RA) and traffic advisories (TA) alerts in the B747 were documented and provided to the researchers for data analysis. The initial independent variable of interest was the encounter geometry; the second independent variable was the intruder flight path closest point of approach to the unmanned aircraft (0.0, 0.5, and 1.0 NM). In addition, there were three levels of winds (calm, 40 and 80 knots) as headwind, tailwind, and crosswind relative to the aircraft. The horizontal missed distance was set at 1.0 nmi, which should force the self-separation alerting to trigger for all three intruder closest point of approach settings.

Scenarios to test these conditions consisted of scripted encounter situations embedded within a Standard Terminal Arrival profile in the DFW airspace to observe/evaluate DAA algorithm performance. Encounter conditions invoked loss-of-well-clear geometries. This test condition has no subjects, but was run via input files scripted to provide the required encounters.

3.3.1.1.1 Airspace

The simulation airspace was an emulation of Dallas/Ft.Worth Center (ZFW), concentrated an en route sector adjacent to Dallas Ft. Worth TRACON and focused on traffic around McKinney National Airport (TKI). See Figure 19. This airspace encompasses and was adjacent to a primary arrival stream into DFW. When air traffic controller subjects were under test, they performed traffic separation tasks with traffic supplied by pseudo pilots and a single UAS pilot.

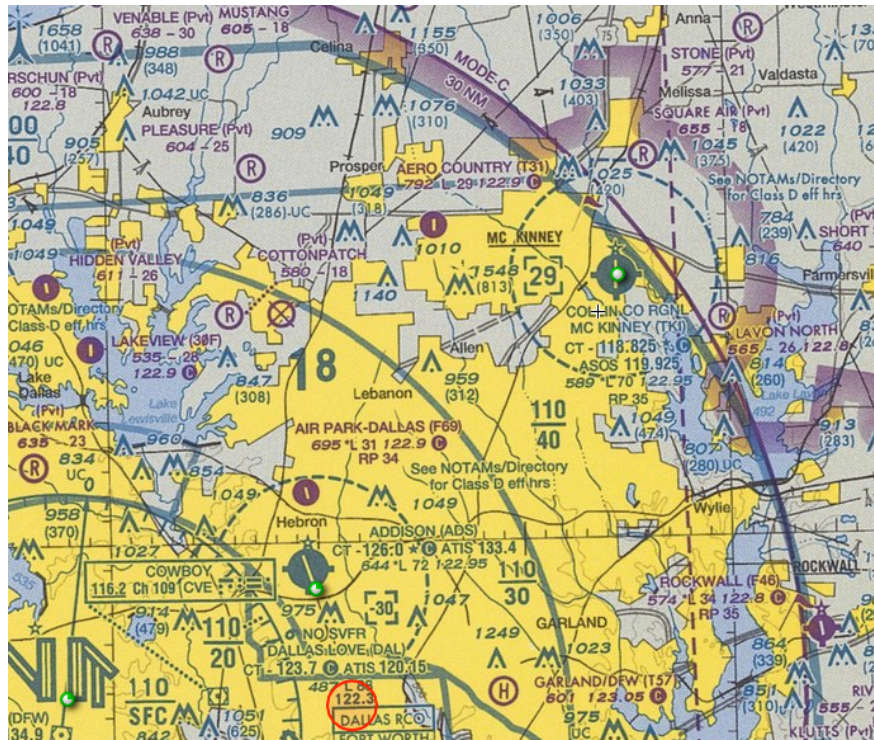


Figure 19. ZFW Airspace near TKI and projected flight path of UAS.

3.3.1.1.2 Scenarios

For the first test condition, where the flight path of the B747 flight simulator encountered various canned UAS aircraft, no specific scenarios were required. These were simple one-on-one encounters to test alerting boundaries. Figure 20 shows the path of the B747 in red and the paths of the UAS aircraft in green. Each encounter that triggered a TCAS alert was documented. Figure 21 also shows the path of the B747 in red and the paths of the UAS aircraft in green. In this case the UAS intruders provided crossing encounters along specific points along the B747 flight path. As before, data was gathered for each of the 747/UAS encounters.



Figure 20. ZFW Airspace head-on collision flight path example.

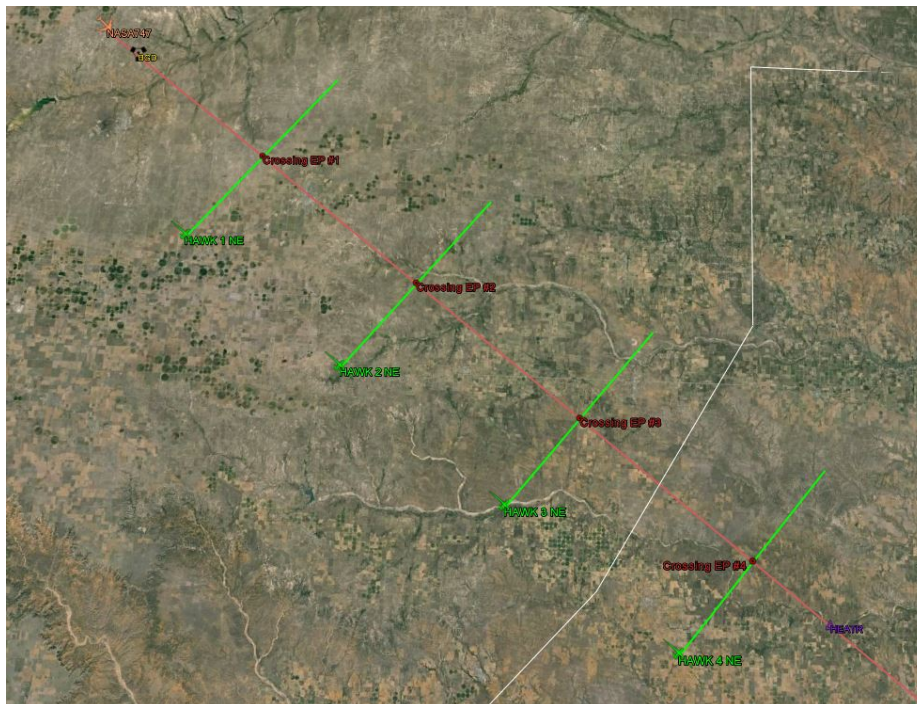


Figure 21. ZFW Airspace crossing collision flight path example.

3.3.1.2 Test Participants

No human subjects were involved in this test condition. Experiment support personnel included:

- B747 pilots in the flight simulator
- Trained IFR pilot in control using the MACS GCS with the SAA informative guidance shown on an engineering display
- Research engineers supporting the simulation manager and controlling the LVC gateway station.

3.3.1.3 Test Design

Figure 22 shows the test environment design for Test Condition 1. The objective of this data collection effort was to assess the performance of the Stratway+ SAA capability in encounters with a TCAS II equipped aircraft. No human subjects were required, only experiment support personnel consisting of IFR pilots and research engineers executing a series of preplanned flight plans for an SAA equipped UAS and a TCAS II equipped intruder aircraft. NASA Langley's USAR lab at SGT ran the UAS portion of the test, with the MACS SimMgr providing the virtual flight plans and the MACS GCS providing the UAS target generation and SAA algorithm advisories. The SGT lab ran a MACS GCS and MACS ATC monitoring displays all connected to the simulation system via the ADRS. The B747 flight simulator at NASA Ames provided the manned intruder aircraft. The B747 was equipped with TCAS II version 7.0 and was run out of the CVSRF. The connectivity between the flight simulator and the MACS GCS was provided by the DTE infrastructure running out of the DSRL lab at NASA Ames and the Gateway running at SGT. The infrastructure contained the HLA messaging system and associated B747 and Gateway Toolboxes that converted the messages from the client format into the HLA format. The Gateway provided an interface between ADRS and the rest of the simulation environment at SGT.

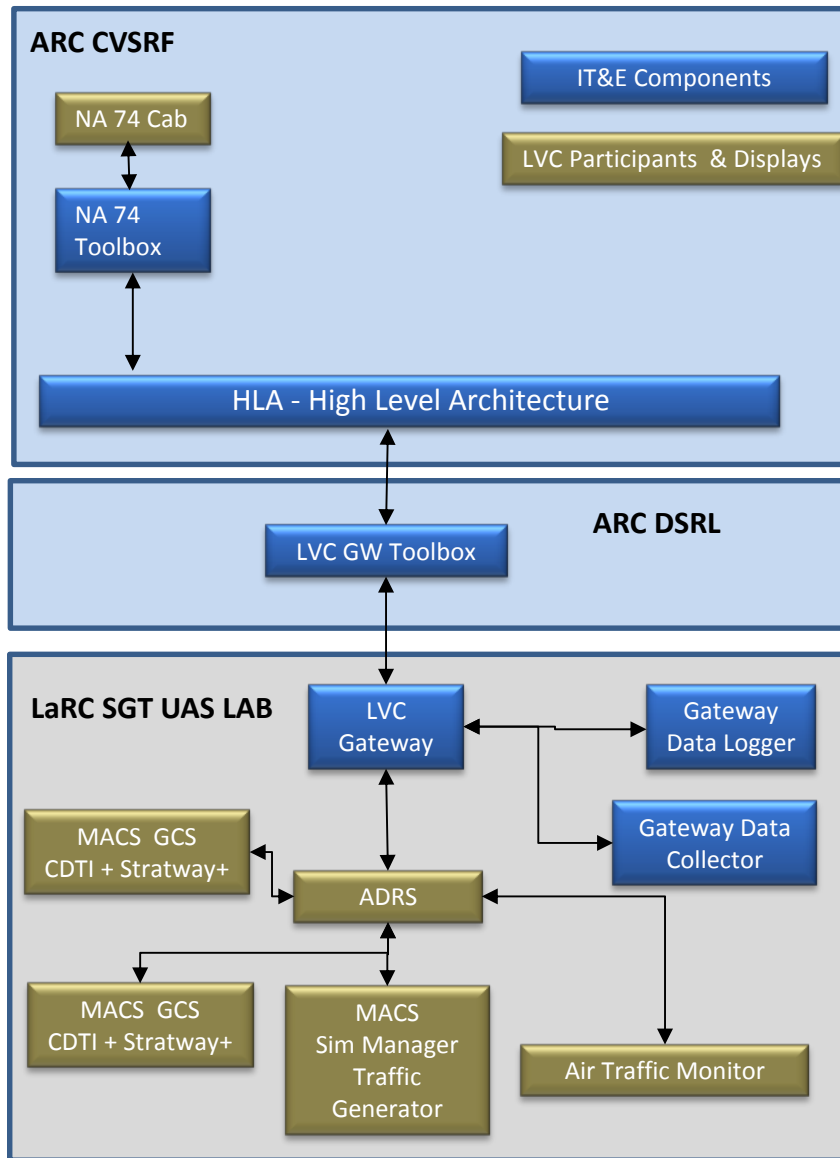


Figure 22. IHITL test infrastructure with components for the Acceptability of SAA Advisories test setup.

3.3.1.4 Simulation Voice Comm

Since no test subjects were required for this test condition, a Voice Comm system was not under test.

3.3.2 Test Condition 2: Controller Acceptability

The second test condition investigated the controller response to the SAA Concept interaction and delays associated with the UAS communication latencies and winds, with the controller as the test subject. This included the need to account for ATC-pilot communication latency as well as the GCS-vehicle communication latency, using configuration values from the Communications sub-project, to execute pilot-initiated SS-requests for trajectory changes.

3.3.2.1 Test Methodology

This test condition also utilized the ZFW airspace in which a virtual UAS aircraft supplied by the MACS GCS interacted with virtual background aircraft supplying the encounters. The air traffic controller subjects managed traffic via an en route controller display configured for the ZFW sector adjacent to the TKI Terminal area. Additional manned displays for the adjacent “handoff” sectors complemented the air traffic environment. The virtual GCS contained the DAA algorithm, which supplied the self-separation advisories that the UAS pilots used to negotiate maneuvers with the air traffic controller. For each data run, the system was loaded with the appropriate scenario files providing virtual aircraft targets to the MACS ATC displays. Voice comm delay was provided by the SimPhonics simulation voice comm and audio card hardware.

During these data runs, three levels of delay were tested, minimal (no added delay above the inherent simulation voice comm delay, which is estimated by the manufacturer to be ~100 msec), 100 msec (plus the 100 msec inherent delay), 1.0 sec (plus the 100 msec inherent delay).

The encounters were scripted to occur at 3,000ft and 6,000ft. Based on the scenario, the winds were varied between calm and moderate:

- Calm: 3000' / direction = 200 / speed = 6
 6000' / direction = 220 / speed = 7
- Moderate: 3000' / direction = 200 / speed = 21
 6000' / direction = 220 / speed = 23

Inside a scenario, the wind speed and direction was interpolated based on altitude.

3.3.2.1.1 Airspace

The simulation airspace was the same as Test Condition 1 (ZFW).

3.3.2.1.2 Scenarios

The controller acceptability of the SAA advisories was tested through 84 traffic encounter scenarios embedded in other traffic operations for each subject. The traffic scenarios represented a mix of IFR and VFR traffic in the ZFW airspace described above. Each traffic scenario had scripted encounters between the UAS aircraft and a manned aircraft. See Figure 23 for an example of one type of encounter (diagram of the UAS flight path and encounter flight path shown for illustration).



Figure 23. ZFW Airspace near TKI and head-on collision flight path example.

3.3.2.2 Test Participants

Air traffic controller subjects were retired en route controllers, experienced with using the ERAM display. Controllers were trained on the specific aspects of the ZFW airspace used in the scenarios. Non-subject pilot participants manning the pseudo pilot stations had the appropriate IFR experience to communicate with ATC and experience running the MACS pilot software. The UAS pilots (non subjects) were experienced UAS pilots with prior training on using the MACS GCS engineering display.

3.3.2.3 Test Design

Figure 24 shows the simulation architecture for the controller acceptability studies. This study was contained solely on site at SGT UAS lab and focused on the controller acceptance of SAA advisories with respect to the UAS communication latencies and varying wind fields. As such, this was run as a standalone simulation without need for LVC connectivity or infrastructure. A UAS pilot utilized the MACS standalone GCS functionality at NASA Langley's UAS lab, which provides the UAS simulation functionality. The MACS GCS provided a built-in traffic display that provides access to the SAA advisories, which had been integrated directly into MACS. The MACS SimMgr provided virtual and constructive manned background and intruder aircraft. The MACS pseudo pilot stations provided the target generation of the background traffic. The MACS ATC functionality provided the air traffic displays, which included the display for the ATC subject, as well as displays for "ghost" controllers that sent and received handoffs for the adjacent

sectors. As with the TCAS testing, the simulation design included a MACS GCS and a MACS ATC monitoring displays. In order to facilitate efficient message passing between the aircraft processes and the ATC processes, the architecture included two versions of ADRS, one that communicated to each of the pilot stations (and the SimMgr) and one that communicated to each of the MACS ATC displays. These instances of ADRS then sent messages to each other as needed. The Voice Comm delay between MACS GCS and MACS ATC were implemented by the Simphonics voice system working with the voice comm audio cards.

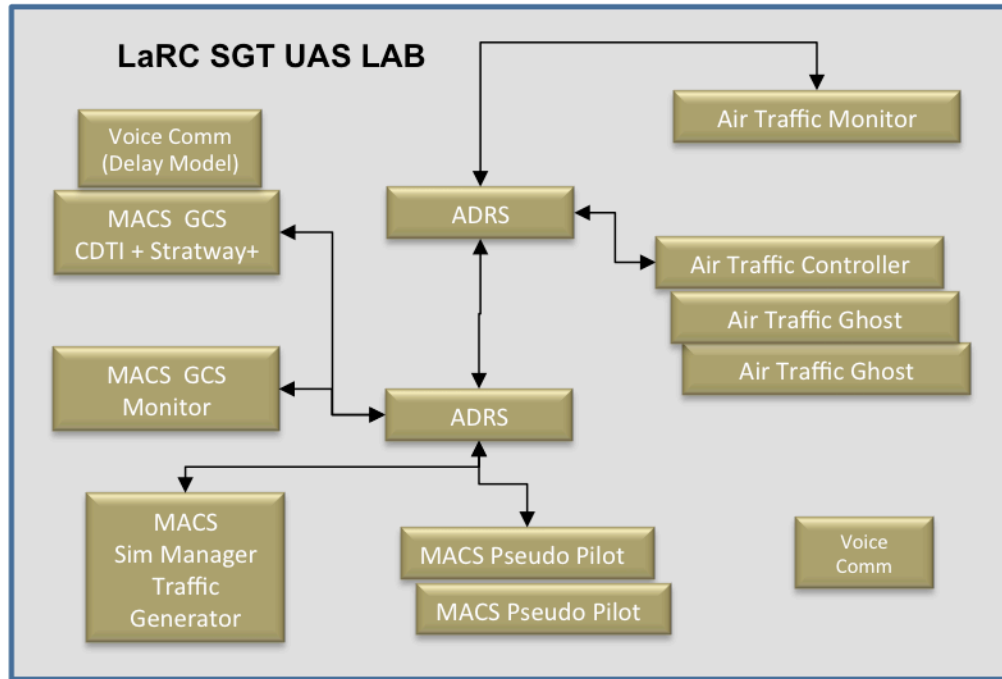


Figure 24. IHITL LVC system with components for the Acceptability of SAA Advisories test setup.

3.3.2.4 Simulation Voice Comm

The UAS lab at SGT used a Simphonics DIS Voice Communication system that was contained within the laboratory. It was configured to add a Voice varying levels of Voice Communication latency to emulate potential latencies from a fielded system.

4 Test Environment Analysis

The relevancy of the test environment is conditional upon the research data that needs to be collected, so hence is dependent on the Test Setups described above. The analyses are divided into two types: 1.) test system latencies, which provides an objective measure of system performance, and 2.) subject matter expert feedback, which provides subjective measure of the system acceptability.

4.1 Test System Latencies

Latencies in and throughout the LVC test system were measured at three key areas to provide feedback to the researchers to ensure the system performed as required. These areas included the latencies between

distributed facilities, between the SAA algorithms and the pilot display, and display of traffic data to the controllers.

In order to calculate these latencies, the time on each computer in the LVC system was synchronized to a GPS device. Network Time Protocol (NTP) was used for clock synchronization between computer systems. NTP provides Coordinated Universal Time (UTC) including scheduled leap second adjustments. The NTP uses a hierarchical, semi-layered system of levels of clock sources. Each level of this hierarchy is termed a stratum and is assigned a layer number starting with 0 (zero) at the top. The stratum level defines its distance from the reference clock and exists to prevent cyclical dependencies in the hierarchy. It is important to note that the stratum is not an indication of quality or reliability. To account for any (even minimal) drift between two computers, a pair of simple programs were created. The programs “tquery” and “timesvr” were used to baseline the time offset between computers residing in two remote facilities of the LVC environment. The tquery program calculates the time it takes to send a message to timesvr and then receive the reply. The offset is calculated by comparing the average of the time a message tquery send and received times to the time the message was originally received by the remote timesvr program. The tquery program has the ability to run large sample pools to determine an average and standard deviation on the final difference output by the program.

4.1.1 Facility Latencies

As described above, the three test setups were derived from the two system configurations shown in figures 2 and 3. For each of the Test Setups, the system was emulating an ADS-B traffic system, which provided the primary determinate for latency acceptability. The ADS-B data transmission and display requirement specified by RTCA and the FAA is 5.0 seconds.^{vi,vii} This provided a maximum threshold to compare the measured LVC system latencies against. There were also other latency requirements to consider. Since the pilot display guidelines are under investigation, for these tests the researchers were looking for less than one second of latency between target location and display to the pilot. This is well below the ADS-B requirement and serves as our benchmark. As the GCS display, DAA algorithm, and Communication research matures, the latency requirement will be readdressed.

For Test Setups 1 and 2, the primary background traffic and air traffic control displays were stationed at NASA Ames, while the UAS Ground Control Station was at NASA Armstrong. Figure 25 shows a high-level diagram of the facilities used for these tests. To capture the overall system latencies, the latencies between each of the connected labs were measured. The measurements were taken in two ways, first the network latency was calculated using the tquery/tserver programs described above. This method provides an unimpeded latency value. The second method comes from the data recorded during a test run of the LVC system. These data are captured by the LVC Gateway running at one of the facilities and includes delay added by the LVC software. Since the LVC software is consistent among the

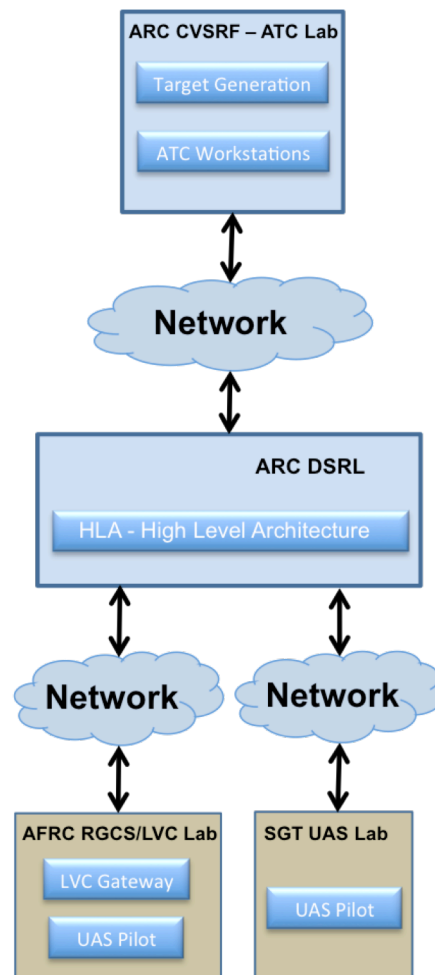


Figure 25. Lab Connectivity for Test Setups 1 and 2.

different labs, once this has been recorded between one of the facility pairs, the tquery/tserver data can be used to estimate latencies between other facilities for future laboratory combinations.

Table 7 contains the average latencies values calculated between the DSRL Laboratory at NASA Ames Research Center and each of the other participating laboratories by the tquery/tserver programs. The unimpeded tquery/tserver latencies were recorded over a 10-minute period with values recorded every 5 seconds. The observed network latencies are very small, with an observed average of 8 ms between Ames and Armstrong and 41 ms between Ames and Langley. The difference in latency magnitude between the two setups can be explained by two differences in the connections. First, the distance between Ames (which is located in Northern California) and Langley (which is in on the East Coast) is much greater then the distance between Ames and Armstrong (which is in Southern California). The fastest networks can send data at approximately 1 ms per 100 miles. So these values are in-line with that measure. Second, the Ames/Armstrong connection was routed over the NASA internal NISN network, while the Ames/Langley connection utilized a Virtual Private Network over the Internet. Even with these differences, these results show a very low overall latency added by the network.

Table 7. tquery latency times between NASA Ames DSRL Lab and participating IHITL laboratories.

Test Name	Average Network Latency (msec)	Standard Deviation (msec)	Max Latency (msec)
Ames to Armstrong	8	0.3	13
Ames to Langley (SGT)	41	0.1	41

Table 8 shows the average latencies as recorded by the LVC software between the DSRL Lab and each of the participating IHITL facilities. The data was captured during system testing prior to the conduct of IHITL and again as a normal recording of the IHITL research data. The numbers calculated during testing show a similar pattern as the results from the tquery/tserver testing, with a slightly faster connection between Ames and Armstrong then Ames and Langley. Even considering the Maximum observed latencies, the values are well within the requirement for display and usage. It should be noted that the observed DSRL to AFRL latency is below to the 100 ms Voice Comm latency estimate that the system was intended to emulate. As we transition to Flight Test, this difference will be discussed with the project researchers and if required additional latency will be added to the system as appropriate.

Table 8. LVC latency times between NASA Ames DSRL Lab and participating IHITL laboratories.

Test Name	Average LVC Latency (msec)	Standard Deviation (msec)	Max Latency (msec)
Ames to Armstrong	24	15	33
Ames to Langley (SGT)	73	12	145

4.1.2 DAA Advisories

The calculation of Self Separation advisories by the DAA algorithm and display of the advisories to the UAS pilot at the RGCS was of concern to the SSI and HSI researchers, who desired to see a smooth display response during trial planning. While the display of the trial planning results was controlled by the VSCS software that was outside the LVC infrastructure, the LVC controlled the passing of the DAA alerts and advisories between the algorithm and display. In order to facilitate rapid prototyping of algorithm and

display interaction, the LVC system was developed to support connection between the algorithms and pilot display through the LVC Gateway process. The LVC was required to pass data between the programs at a 15 Hz rate (~67 msec) to ensure pilot testing of conflict free maneuvers would be smooth.

4.1.3 Controller Displays

While the timing between the facilities is critical to understand whether the LVC infrastructure supports relevant testing, the use of MACS as an ATC display was also tested to ensure that data was presented to the Air Traffic Control subjects in a timely manner. Though the input data for sensor emulation used the 1-second ADS-B update rate, the ATC display was run to emulate present day 12-second update rate of the en route workstations. The MACS software was developed to buffer incoming track data from the input sources and display that data at the required (12-second) rate.

4.2 Subject Matter Expert Feedback

4.2.1 Scenario Development

As described above, Test Setups 1 and 2 were conducted in an emulation of Oakland Center's sectors 40/41. A retired Oakland Center controller with years of operational experience controlling aircraft in this airspace developed the traffic scenarios for Test Setups 1 and 2. Four basic traffic scenarios were created based on live traffic recordings. Two scenarios were developed to be high workload (high traffic density, arrival sequencing for local Terminal airspace), while the remaining two were developed to be nominal workload (average traffic density, non-arrival push to local Terminal). Since high and nominal workloads are subjective, these scenarios were also reviewed and rated as high and nominal by a second retired Oakland Center controller.

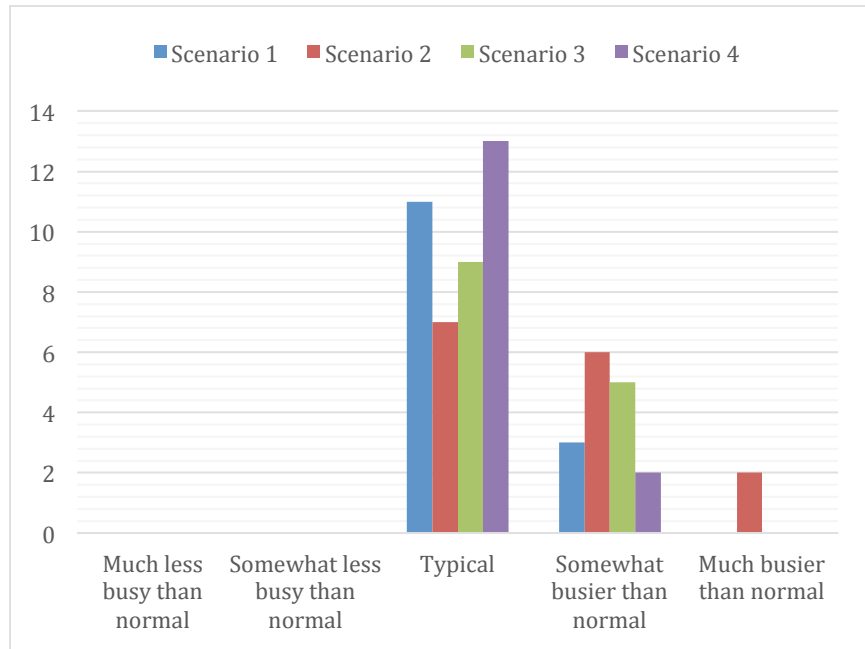
Similarly, the scenarios developed for Test Setup 3 were based on live air traffic data recordings of the Dallas Ft Worth Center and Terminal airspaces. These recordings were used by the SSI research team to populate a set of background traffic in which a candidate UAS aircraft flight path was inserted.

4.2.2 Controller Subject Evaluation

As part of the conduct of Test Setup 1, the test subject was asked to evaluate the realism and relevance of the environment and traffic displays. The results are captured here.

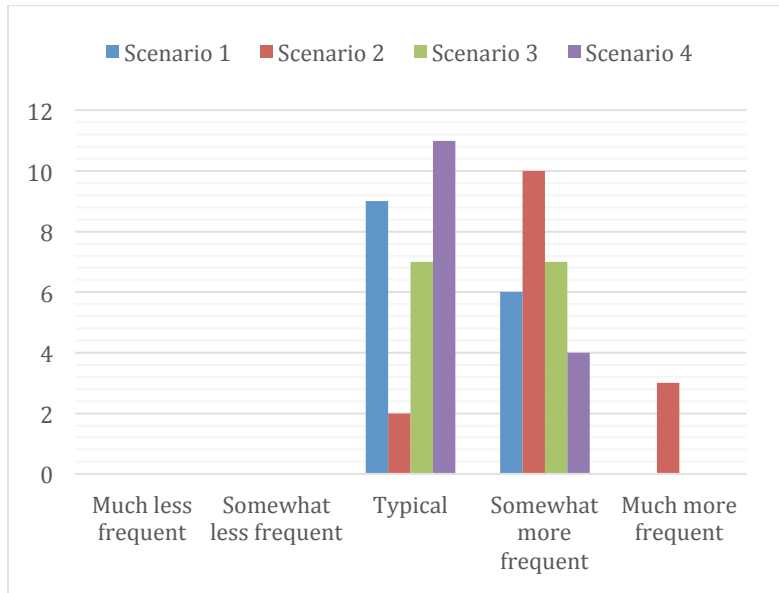
4.2.2.1 Post Scenario Questions

1.) *“The traffic density in my sector was realistic relative to current-day operations:”*



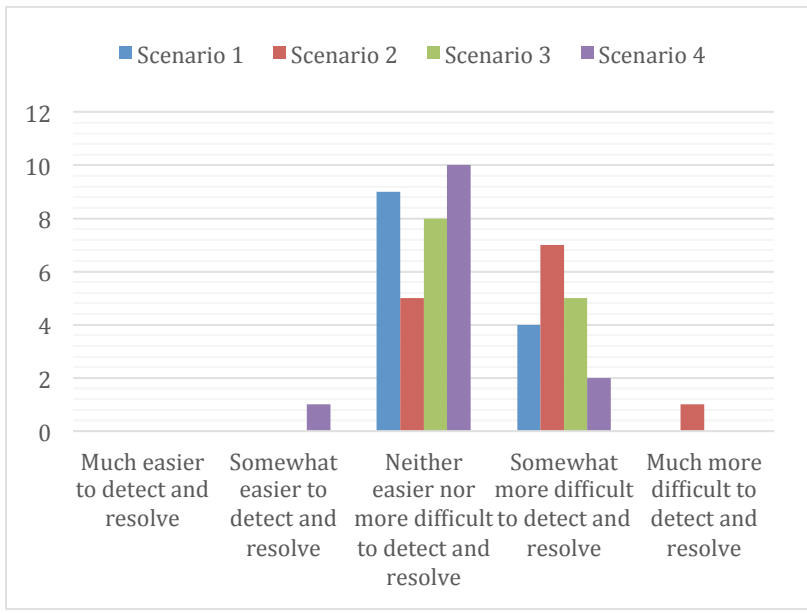
The result of this question is interesting. Scenarios 1 and 4 were scripted to be high workload, but both had the most responses of “typical”, while the nominal workload scenarios (2 and 3) were rating busier.

2.) *“As compared with normal real-world operations, the number of the encounters in this trial was:”*



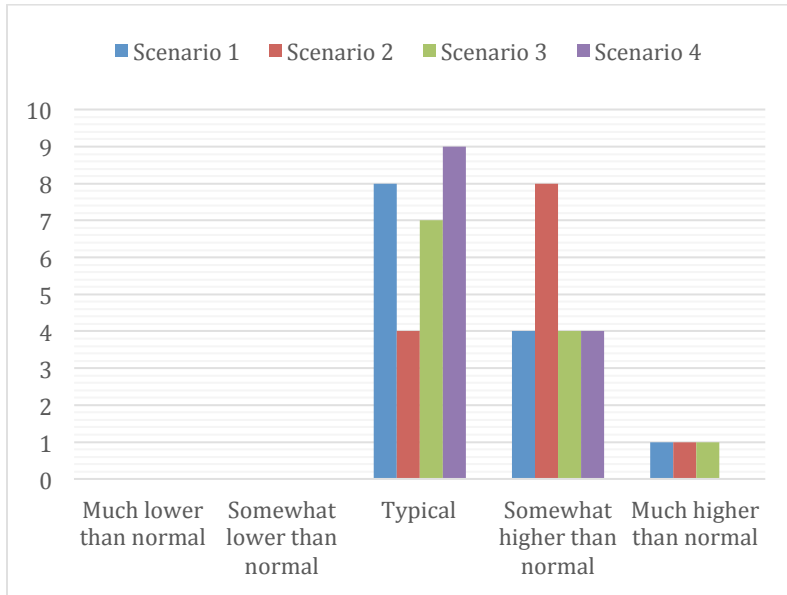
The result of this question mirror results from the previous question. Though scenarios 1 and 4 were scripted to be high workload from an ATC point of view, the subjects had rated the number of encounters, and the perceived traffic density that accompanies those scenarios as lower.

3.) *“As compared with normal real-world operations, the complexity of the encounters in this trial was:”*



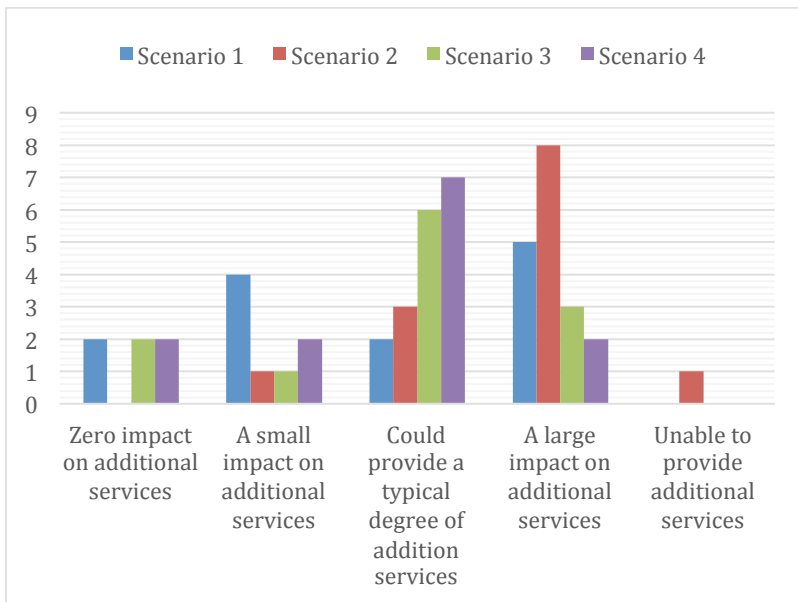
These results also support the perceived lower traffic load results for Scenario 1 and 4 from the first question. Not only were the number of encounters perceived to be lower, but the complexity was also rated lower then scenarios 2 and 3.

4.) “As compared with normal real-world operations, how would you rate your workload during this scenario?”



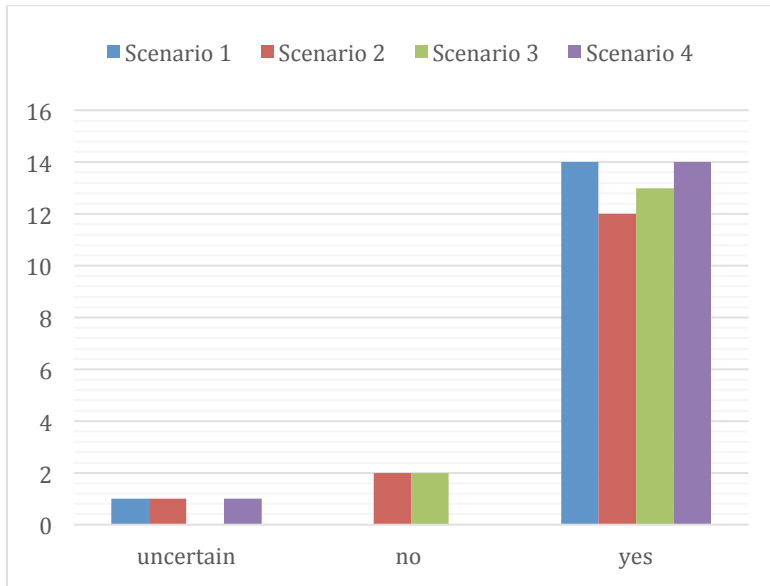
This result substantiates the previous results. The traffic load was perceived to be lower for Scenarios 1 and 4, as was the workload associated with handling the traffic. This underscores the need to include the study of controller workload when assessing UAS encounters with air traffic.

5.) “Did the workload and complexity of the scenario impact your ability to provide additional services (direct routings, traffic advisories, etc.)?”



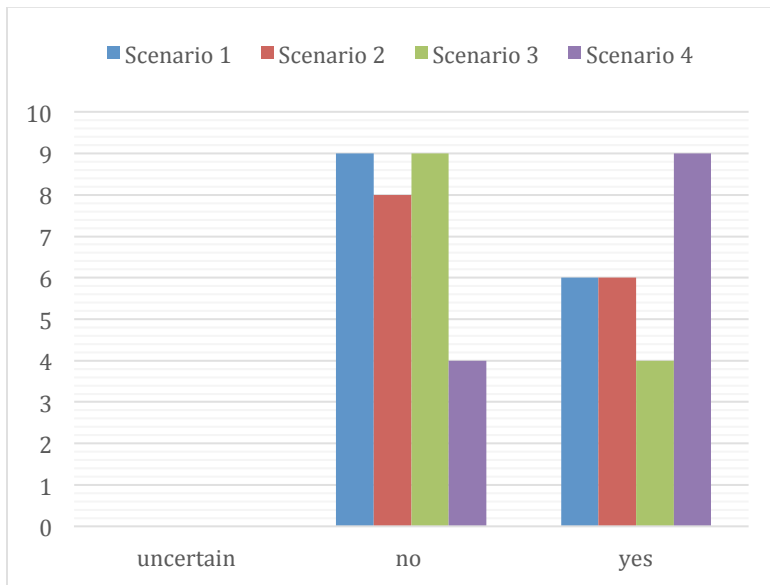
This result substantiates the previous results in terms of a lower workload for Scenarios 1 and 4. This underscores the criticality of supporting controllers with handling encounters with UAS. It also begins to demonstrate potential impacts that controller skill levels and familiarity with the sector can have on the ability to provide additional services.

6.) *“The flow of traffic in my sector was representative of a low altitude en route sector:”*



This question addresses the heart of this study. The vast majority of controllers felt that the scenario design and traffic behavior provided a realistic representation of a real world low altitude en route sector.

7.) *“Did you notice any ghost controller, pilot, or software behavior in the simulation that did not conform to your expectations or that was unlike behavior in the real world?”*



Controller responses to this question focused on actions taken by the UAS pilot and pseudo pilots, and their actions in response to either observed/detected traffic or traffic called out by the controller. The responses provided by those who answered “Yes” are provided below, and indicate a higher than normal number of pilot requests for deviations around traffic. This is not unexpected given the higher than average number of traffic encounters built into the simulation scenario.

“A few too many pilots asking to deviate around known traffic; can we rely on UAS reported altitude of merging aircraft?”

“My [operational] experience was pilots rarely spotted traffic very early and almost never asked for turns around the traffic. They usually spot the traffic and just separate themselves with altitude or laterally. If the UAS detects traffic I would think they would trust their equipment regarding altitude or headings—or—they would ask ATC about the traffic, then respond appropriately.”

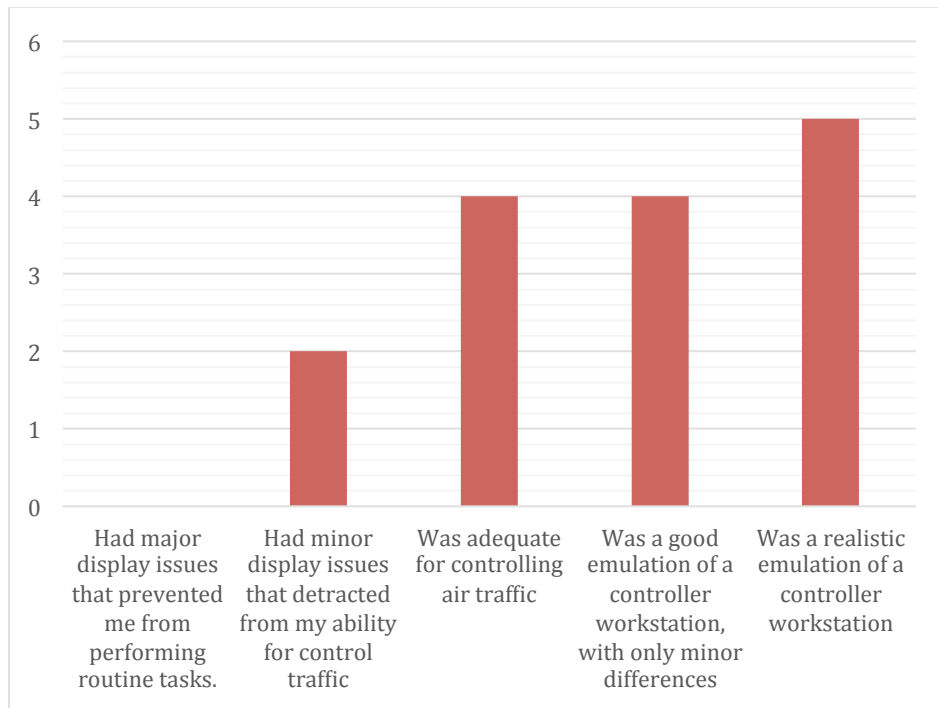
“Most aircraft that I called traffic or had traffic turned—not really true in my experience. Most stay the course especially when they get them in sight.”

“Some handoffs were late, which may have been a result of a lag in the A/C sim start or I didn’t notice them until the AC was already in my airspace. The real world scenario would have a controller calling for a handoff.”

4.2.2.2 Post Simulation Questions

The controller evaluations had only one post relevant post simulation question pertaining to the relevancy of the LVC environment:

“As compared with air traffic control displays used operationally, the ATC display environment used during the simulation:”



Controller responses to this question overwhelmingly indicated that the software simulation was, at a minimum, “adequate” for the assigned control task. The comments below were provided by controllers who indicated that there were minor display issues that detracted from their ability to control traffic.

“I had an issue with my keyboard a couple of times when taking handoffs – I had to resort to my trackball.”

“All data blocks began flashing at once. I couldn’t make any entries while that was occurring (less than 1 minute). Also, I had trouble moving data blocks with the slewball.”

“As noted, flashing cursor, jumping targets around Salsalito, and one dropped data block. Pilots/remote were excellent! Software simulation was excellent. UAS was great; nice addition.”

4.2.3 Pilot Subject Evaluation

No questions regarding the realism of the simulation were included in the UAS pilot surveys. The primary reason is that the pilot subjects were evaluating prototype displays that were designed to understand levels of display information, not necessarily a realistic display. There were, however, remarks made by the pilot participants during the runtime of the study that were relevant to the simulation’s fidelity. Pilots often commented on the maturity of the research ground control station. Multiple pilots stated that the software suite provided by Vigilant Spirit Control Station presented them with a more flexible, intuitive and robust system than they typically fly with. Pilots also consistently commended the realistic environment provided by the controller and pseudo-pilots. Several pilots remarked that the chatter over the frequency reached a realistic density, which often forced them to make a realistic decision: do they postpone a maneuver around traffic until they can find an opening on the frequency, or do they start the maneuver without prior approval? Pilots also commented on the professional nature of the communications from the controller and pseudo pilots, noting that all the parties sounded experienced in flying and controlling aircraft.

While the remarks from the pilot participants were largely positive, there were several comments during simulation that were more critical. For instance, pilots felt that the controllers in this portion of the study were too passive, either missing critical encounters between the UAS and other aircraft, or never refusing a request by the pilot to maneuver around traffic. Pilots also felt that the number of encounters they experienced during the course of a single trial was far higher than they would expect in the real world. While the number of generated encounters and the behavior of the controller were purposefully scripted to accommodate research goals, it should be noted that these decisions impact the level of realism experienced by participants.

5 Environment Relevancy

Based on both controller and pilot feedback as well as the methodical approach that was used to construct the scenarios using recorded traffic as the baseline, we are satisfied that the simulation met the requirement to be “realistic”. Controller-identified issues primarily focused on equipment or pseudo pilot procedures. Equipment issues were, for the most part, isolated anomalies. However, several issues were identified by our team that will be addressed in future versions of MACS ERAM software in order to provide console capabilities that controllers are used to having access to.

Feedback on pseudo pilot deviations for either pilot observed or controller reported traffic was the primary criticism from both controller and UAS pilot test subjects. The construction of the scenario encounters between the UAS and other traffic was intentionally designed to place aircraft in close proximity if they did not deviate in order to provide data for the researchers on the performance of the self-separation algorithms and UAS operator displays. The requirement for a higher than normal frequency of close proximity encounters was expected to generate responses such as these, but were a necessary part of the scenario to support the research.

Based on the feedback from the controllers and pilots and since the relevancy of the environment depends on the data to be collected to support the research, the LVC test environment was deemed relevant.

Appendix A: Acronyms

ADRS	Aeronautical Data link and Radar Simulator
ADS-B	Automatic Dependent Surveillance-Broadcast
AFRC	Armstrong Flight Research Center
AFRL	Air Force Research Lab
APG	Annual Performance Goal
ARC	Ames Research Center
ATC	Air Traffic Control
ATWIT	Air Traffic Workload Input Technique
CA	Collision Avoidance
CDF	California Department of Forestry
CDTI	Cockpit Display of Traffic Information
CNPC	Comman and Non-Payload Control
ConOps	Concept of Operations
COTS	Commercial Off-the-Shelf
CSD	Cockpit Situation Display (A specific type of CDTI)
CVSRF	Crew Vehicle Systems Research Facility
DFW	Dallas/Ft. Worth Airport
DSRL	Distributed System Research Laboratory at NASA Ames
DTE	Distributed Test Environment
ERAM	En Route Automation Modernization
FAA	Federal Aviation Administration
FDDRL	Flight Deck Display Research Laboratory at NASA Ames
FMS	Flight Management System
GCS	Ground Control Station
GCS-TD	Ground Control Station – Traffic Display

GOTS	Government Off-the-Shelf
HLA	High Level Architecture
HSI	Human Systems Integration
HITL	Human-In-The-Loop
ICD	Interface Control Document
IEEE	Institute of Electrical and Electronics Engineers
IFR	Instrument Flight Rules
IHITL	Integrated Human in the Loop simulation test series
IT&E	Integrated Test and Evaluation
LaRC	Langley Research Center
LOS	Loss of Separation
LVC	Live Virtual Constructive network system
MACS	Multi-Aircraft Control System
MOPS	Minimum Operation Performance Standards
NASA	National Aeronautics and Space Administration
ORD	Objectives and Requirements Document
RAIF	Research Aircraft Integration Facility at NASA Armstrong
RFDP	Research Flight Data Processor
RGCS	Research Ground Control Station
RTCA	Radio Technical Commission for Aeronautics
RUMS	Remote User Monitoring System
SA	Separation Assurance
SAA	Sense and Avoid
SC-228	RTCA Special Committee 228
SGT	Stinger Gaffarian Technologies outside of NASA Langley
SME	Subject Matter Expert
SSI	Separation Assurance-Sense and Avoid Interoperability
SS	Self Separation
STARS	Standard Terminal Automation Replacement System

TC	Test Conductor
TCAS	Traffic Collision Avoidance System
TD/MD	Test Director/ Mission Director (interchangeable)
TKI	McKinney National Airport
TRACON	Terminal Radar Approach Control
UAS-NAS	Unmanned Aircraft System in the National Airspace System
UASR	UAS Sense and Avoid Research
UAV	Unmanned Aerial Vehicle
VFR	Visual Flight Rules
VSCS	Vigilant Spirit Control Station
WCV	Well Clear Volume
ZFW	Dallas/Ft. Worth Center
ZOA	Oakland Center

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