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Space Administration**

UAS Integration in the NAS Project

Integration Test and
Evaluation (IT&E)

Flight Test Series 6

Live Virtual Constructive -
Distributed Environment
(LVC-DE) Test Report

ITE-FT6-LVCTR-01



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Executive Summary

The goals of the Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS) (also UAS-NAS) Project are to reduce the barriers for UAS access and its integration into the NAS. The UAS-NAS project and industry stakeholders conducted a series of flight tests integrating technologies from the Modeling & Simulation (M&S), Human Systems Integration (HSI), and Communication and Control (C2), and Integration, Test & Evaluation (IT&E) research areas.

The last of the flight test series, Flight Test Series 6 (FT6) was conducted in late 2019 and focused on evaluating the interaction of the airborne non-cooperative surveillance system and the Detect and Avoid (DAA) technology. The DAA system generated conflict alert and guidance for pilots using a Research Ground Control System (RGCS) to avoid intruder aircraft. The conflict alerting and guidance information was presented on the RGCS's display using symbology developed by the human factors team. The objective of FT6 was to investigate the interoperability of Low Size, Weight, and Power (Low SWaP) sensors with the DAA alerting, guidance, and display requirements.

To support this goal, the distributed test environments (DTE) were developed at Ames Research Center (ARC) and Armstrong Flight Research Center (AFRC) and securely linked over a Virtual Private Network (VPN). These environments took advantage of existing Live Virtual Constructive (LVC) technologies to support research observation at both Centers with the insertion of live UAS and manned intruder aircraft into a simulated NAS environment with Air Traffic Control (ATC) and constructive manned aircraft.

The experiment was distributed between AFRC flight operations and research facilities and the Distributed Simulation Research Laboratory (DSRL) and Software Development Laboratory (SDL) in building N243 at ARC. The Air Traffic Controller and pseudo pilots operated from the DSRL and SDL, respectively, using the Multi-Aircraft Control System (MACS). The test subject and researchers operated from the Research Ground Control Station (RGCS) at AFRC using the Vigilant Spirit Control Station (VSCS) and associated DAA software and displays. Flight Operation for the unmanned aircraft (UA) and manned intruder traffic was conducted at AFRC. Virtual traffic was managed by ARC. Voice distribution was accomplished using a combination of disparate communication systems at ARC and AFRC.

The purpose of this document is to record the development, design, and execution of activities in support of the FT6 efforts from the perspective of the ARC IT&E team. Furthermore, the Armstrong IT&E team has published a thorough FT6 Test Report, with emphasis on flight test support, facilities and vehicle development; this report complements the Armstrong report.

Analysis of collected FT6 data will be conducted and reported by the M&S and HSI teams and will be published in separate reports.

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List of Acronyms

AFRC	Armstrong Flight Research Center
ARC	Ames Research Center
ARDS	Aeronautical Data Link and Radar Simulator
ATC	Air Traffic Control
C2	Command and Control
CPA	Cloest Point of Approach
DAA	Detect and Avoid
DAIDALUS	Detect and Avoid Alerting Logic for Unmanned Systems
DAPA	Digital Active Phased Array (radar)
DSRL	Distributed Simulation Research Laboratory
DTE	Distributed Test Environments
DWC	Detect and Avoid Well Clear
FAA	Federal Aviation Administration
FM	Full Mission
FOR	Field of Regard
FPG	Flight Plan Generator
FT5	Flight Test Series 5
FT6	Flight Test Series 6
HAT	Human Autonomy Training
HON	Honeywell International Inc.
HSI	Human Systems Integration
IT&E	Integration, Test and Evaluation
JADEM	Java Architecture for Detect and Avoid Extensibility and Modeling
LaRC	Langley Research Center
LoDWC	Loss of Detect and avoid Well Clear
Low SWaP	Low Size, Weight, and Power
LVC	Live Virtual Constructive
LVC-DE	Live Virtual Constructive – Distributed Environment
M&S	Modeling and Simulation

MACS	Multi-Aircraft Control System
NAS	National Airspace System (NAS)
NASC	Navmar Applied Science Corp.
RGCS	Research Ground Control Station
SCO	System Check-Out
SDL	Software Development Laboratory
SE	Scripted Encounters
SME	Subject Matter Expert
SPUT	Subject Pilot Under Test
SSA	Sensor Sureilance Adapter
TD	Test Director
TFR	Temporary Flight Restriction
UA	Unmanned Aircraft
UAS	Unmanned Aircraft Systems
UAS-NAS	Unmanned Aircraft Systems Integration in the National Airspace System
VFR	Visual Flight Rules
VIDS	Visual Ingest and Distribution System
VPN	Virtual Private Network
VSCS	Vigilant Spirit Control Station
ZLA	Los Angeles Air Route Traffic Control Center
ZOA	Oakland Air Route Traffic Control Center

1 Introduction

The Unmanned Aircraft Systems Integration in the National Airspace System (UAS-NAS) project collaborated with industry partners and stakeholder to conduct the Flight Test Series 6 (FT6) in late 2019. The FT6 activity helped to design, develop, and implement a prototype Low Size, Weight and Power (Low SWaP) airborne non-cooperative surveillance system with a Detect and Avoid (DAA) technology. This system was installed onto an unmanned aircraft (UA) in a live flight environment in order to provide supporting research to Radio Technical Commission for Aeronautics (RTCA) Special Committee 228 (SC-228) to support their effort to develop Phase 2 minimum operational performance requirements (MOPS) for such a system. FT6 focused on evaluating the interaction of the airborne non-cooperative surveillance system and the DAA algorithm. The detection, alerting and guidance calculations generated by the DAA algorithm were relayed to the display system of the ground control system (GCS) for evaluation by the subject pilot under test (SPUT) during the flight test.

The Ames Research Center (ARC) played two roles in supporting the flight test. ARC laboratories provided: 1) a platform for researchers at ARC to observe in real-time the ownship and intruder interactions for both scripted encounters, and 2) a complete air traffic control (ATC) test environment. The scripted encounters (SE) focused on evaluating the interaction of the airborne non-cooperative surveillance system and the DAA algorithm through a series of preplanned encounter trajectories developed by the research teams. ARC provided support for the FT6 Full Mission (FM) encounters by providing virtual ATC services in Oakland Air Route Traffic Control Center (ZOA) Sector 40/41 airspace with representative traffic and complexity. ARC also provided audio recording capabilities for FT6 Full Mission.

2 Purpose

This document provides a descriptions of the requirements and details the level of effort by the Ames IT&E team to support of the flight test. Including in this reports are the description of the laboratory, software systems and networking architecture, procedures to conduct the test, data collection, and includes verification and validation criteria. While this report focuses on the development and support provided by the Ames IT&E team, a complementary FT6 Test Report produced by IT&E team at AFRC provides additional details on their test facilities, vehicles development, and the conduct of the flight test, as referenced in document *ITE-FT6-FTR-01*.

3 Stakeholders, Participants, and Responsibilities

This section gives an overview of various participants and their roles in supporting the FT6 activities. Some descriptions in this section were taken from the Armstrong's FT6 Test Report "*UAS-NAS IT&E Flight Test Series 6 Flight Test Plan Document – ITE-FT6-FTP-01*".

3.1 NASA Ames Research Center (ARC)

NASA Ames provided a diverse set of research team in supporting the FT6 efforts. The DAA team provided the algorithm for calculating the detection of intruders and alerting logic for the pilot to evaluate. The HSI team developed the user interface for displaying of the alerting

symbology to the subject pilot under test. Ames' IT&E team provided the M&S and HSI teams with a platform to test and verify their respective technologies. During flight tests the IT&E team also delivered the simulated airspace, staffing, and air traffic control (ATC) environment in which to integrate and inject actual flying assets during the Full Mission phase of the live testings.

3.2 NASA Armstrong Flight Research Center (AFRC)

NASA Armstrong IT&E subproject was responsible test organization for conducting FT6 test missions. IT&E was responsible for planning, coordinating, executing and reporting on the flight test. AFRC provided facility and logistical support for the Tiger Shark UAS and be the source of intruder aircraft for the test. AFRC designed, tested, and assisted ARC with integration of the Low SWaP surveillance system payload onto the Tiger Shark test UA. AFRC provided, qualified and current, aircrew through the Pilot's Office and Dale Reed Subscale Flight Research Laboratory.

3.3 NASA Langley Research Center (LaRC)

NASA Langley was responsible for providing the technical research content for Flight Test 6. LaRC provided the Principal Investigator, along with a flight simulation team, who supported the preparatory simulations required to develop the Low SWaP DAA algorithm.

3.4 Honeywell International, Inc. (HON)

Honeywell developed the Low SWaP Digital Active Phased Array (DAPA) Lite Surveillance Radar. Honeywell was responsible for providing hardware, software and technical support for a DAPA Lite radar, DAA processor, and sensor fusion and target tracking algorithm.

3.5 Navmar Applied Sciences Corp. (NASC)

NASC was responsible for providing a Tiger Shark XP UA integrated with the NASA provided Low SWaP system to serve as ownship during flight test and a ground control station for launch and recovery. NASC also provided technical support and operations resources to support flight test activities at Edwards AFB.

4 Overall Test Goals and Objectives

4.1 UAS-NAS Project Office Objectives

The goal of UAS-in-the-NAS project is to explore capabilities designed to reduce technical barriers related to safety and operational challenges associated with enabling routine UAS access to the NAS. The project objectives are focused on integration of a Low SWaP airborne non-cooperative surveillance system onto a UAS in a live flight environment in order to inform the

development of minimum operational performance requirements (MOPS) for such a system. NASA is working and industry stakeholders to develop these MOPS¹. These objectives include²:

- Inform Phase 2 MOPS development of requirements for Low SWaP airborne non-cooperative surveillance system.
- Inform Phase 2 development of DAA Well Clear (DWC), alerting and guidance requirements.
- Characterize pilot response data in a full mission environment to validate Low SWaP HITL.

4.2 IT&E Objectives

AFRC and ARC IT&E teams shared the common objectives of building a distributed test environment to conduct human-in-the-loop (HITL) simulations and flight tests. Data collected from the HITLs and flight tests allowed the M&S and HSI researchers a mean to refine the DAA algorithm and demonstrate the alerting and guidance symbology and application. The IT&E teams developed several specific tests to collect data of interest to the researchers.

- Building upon the flight test series 5 (FT5), AFRC set out to build an architecture that facilitated the output and measurement of slant range, azimuth, and elevation in the field of regard (FOR) of the ownship during an encounter.
- ARC and AFRC, using upgrades to the Sense And Avoid processor (SaaProc) from the M&S team, developed a distributed environment that included data logging by the SaaProc and Live Virtual Constructive (LVC) gateway. These logs recorded alert timing, guidance displays, DAA well clear violation status, closest point of approach (CPA), and the type and timing of the avoidance maneuver flown by the pilot.
- ARC designed and integrated the virtual ATC environment for the Full Mission test. This required the development of a sustained virtual traffic scenario in which the ownship and intruder traffic were inserted. The objective was to create an immersive environment for the SPUT. The data and recordings from this environment allowed direct comparison of the SPUT performance with previous HITL UAS-NAS simulations.
- AFRC took the lead for FT6 data collection and achieving. ARC supported this effort by providing local data and audio recordings.

5 Requirements

In support of Flight Test 6, the Ames' IT&E team captured, met, and verified the various set of requirements from our stakeholders, as identified in the following subsections' tables under the *Stake Holders* columns. AFRC had additional requirements unique to their facilities and staffing, which are not captured in this report. The stakeholders are: HSI researchers, the Armstrong Flight Research Center Pilot Office (AFRC-PO), and the IT&E team.

¹ RTCA SC-228 website: <https://www.rtca.org/content/sc-228>

² Integrated Testing and Evaluation (IT&E) Flight Test Series 6, Concept of Operations Document, ITE-FT6-CONOPS-01, NASA Armstrong Flight Research Center, April 2019.

5.1 Personnel

5.1.1 Subject Pilot-Under-Test (SPUT) Requirements

The ARC's IT&E team was responsible for the recruitment of the SPUT, using requirements supplied by the HSI and AFRC teams.

#	<u>Stake Holders</u>	<u>Requirements</u>
1	HSI	Pilots shall be active military with a fixed wing license.
2	HSI	Pilots shall have had recent flying experience including flying medium to large fixed wing remotely piloted aircraft within the last year.
3	AFRC-PO	Pilots shall be required to have a current Federal Aviation Administration (FAA) Medical or Department of Defense flight physical. This included having vision corrected to normal and have full color perception
4	AFRC-PO	Pilots shall be required to provide a copy of their medical qualifications for review by the AFRC flight surgeon and the pilot office.
5	HSI	Pilots shall be recruited from nearby, California or Nevada, military facilities
6	HSI	Pilots shall be scheduled for three days (Training, Flight, and back-up days).
7	HSI	Pilots shall be right-handed. (Removed prior to Full Mission flights)
8	HSI	Pilots shall be restricted from prior participation in UAS-in-the-NAS projects. (This requirement was removed prior to the Full Mission flights)

5.1.2 Pseudo Pilot Requirements

#	<u>Stake Holders</u>	<u>Requirements</u>
1	HSI	Pseudo Pilots shall have at least a private pilot license with an instrument rating.

5.1.3 Air Traffic Control (ATC) Specialist Requirements

#	<u>Stake Holders</u>	<u>Requirements</u>
1	HSI	Controllers shall be active or retired less than 5 years after their FAA retirement date.
2	HSI	Controllers shall have been qualified as a Certified Professional Controller and have held an area rating at ZOA.

5.2 Sense and Avoid Processor (SaaProc) Requirements

#	<u>Stake Holders</u>	<u>Requirements</u>
1	IT&E	ARC's IT&E team shall integrate and test the SaaProc v9.0.1 within the Live Virtual Constructive-Distributive Environment (LVC-DE).

5.3 Video Streaming Requirements

#	<u>Stake Holders</u>	<u>Requirements</u>
1	IT&E	The Visual Ingest and Distribution System (VIDS) shall ingest all available broadcasts from Armstrong Flight Research Center and make the data available to the Display Systems Research Laboratory (DSRL).
2	HSI	ARC IT&E shall provide the Human Autonomy Training (HAT) laboratory with the capability to access the VIDS.

5.4 Multi-Aircraft Control Simulation (MACS) Requirements

#	<u>Stake Holders</u>	<u>Requirements</u>
1	IT&E	The virtual traffic scenario shall be 4 hours in length.
2	HSI	The virtual traffic scenario shall be developed with traffic consistent with moderate quantity and complexity representative of traffic typical for ZOA Sector 40/41 combined (14-16 aircraft per 15 minutes).

3	HSI	The Controller display shall depict an appropriate, high fidelity ZOA-40/41 airspace presentation including airspace routing structure and traffic density and complexity.
4	IT&E	Waypoints and fixes depicting holding points and, primary and contingency routes shall be displayed on the controller, ghost, and observer positions.
5	IT&E	Transformation of airspace (waypoints and fixes depicting holding points and, primary and contingency routes) error tolerance shall be within 0.1 nautical miles.
6	IT&E	All National Airspace System (NAS) and simulation information and displays shall be relocated to a position over R-2515 and be centered on the Full Mission route.
7	IT&E	Weather shall be updated once per hour based on National Oceanic and Atmospheric Administration (NOAA) wind aloft forecasts during AFRC Full Mission flight operations.
8	IT&E	Weather shall be adjusted when intruder Pilot Report (PIREP) deviates by more than five degrees or 5 knots.
9	IT&E	ARC's IT&E team shall provide AFRC IT&E team with a current copy of MACS.

5.5 Live Virtual Constructive Distributed Environment (LVC-DE) Requirements

#	Stake Holders	Requirements
1	IT&E	ARC IT&E shall implement the UAS-NAS Core LVC System capabilities in accordance with the Interface Control Document (ICD), revision H.
2	IT&E	The ARC LVC system shall provide two-way data interface with the AFRC LVC system.

5.6 Voice over IP Requirements

#	Stake Holders	Requirements
1	IT&E	ARC IT&E team shall establish audio communications with AFRC via the NickRoselli tunneler.

5.7 Vigilant Spirit Control Station (VSCS) Requirements

#	Stake Holders	Requirements
1	HSI	Three to five simulated aircraft shall be displayed on the Vigilant Spirit Control Station within 10NM laterally and +/- 4000 feet vertically from the ownship during Full Mission.
2	HSI	IT&E shall provide one or two preventive-alert, virtual encounters during Full Mission under the following conditions: a) between live intruder encounters and b) after the HSI research team has completed debriefing the SPUT following a live encounter.
3	HSI	No simulated preventive-alert encounters shall intentionally result in a maneuver by the SPUT.
4	IT&E	A map display of ZOA-40/41 shall be added to VSCS using the Full Mission route as the center point reference.

5.8 Data Collection

#	Stake Holders	Requirements
1	IT&E	ARC ITE shall collect audio recordings, binary files, and text files for all activity on the Virtual ATC frequency, 125.85, during Full Mission.
2	IT&E	ARC ITE shall collect the LVC Data Logger outputs.
3	IT&E	All data collection file shall be forwarded to AFRC as soon as possible following the conclusion of the day's activity

6 Reference Documents

The documents listed in Table 1 below were either referenced or developed specifically to support Flight Test 6. The links in the “File” column provide a method of downloading and reviewing the document for those with NASA Ames Confluence accounts.

Table 1: Flight Test 6 Documents

<u>#</u>	<u>Title</u>	<u>Description</u>	<u>File</u>	<u>Publication Date</u>	<u>Authors</u>
1	LVC ICD	This document describes the messaging specifications for LVC integration.	<u>LVC ICD-03 Rev H</u>	3/21/18	IT&E: Jovic, Srba
2	SWDD	This document provides the Software Design Description for the core software components (LVC Gateway, LVC Gateway Data Logger) and the SAA Processor (SaaProc).	<u>LVC SWDD-03 Rev D (PDF)</u>	10/20/2018	IT&E: Jovic, Srba
3	UAS in the NAS Flight Test 6 Procedures for ARC	This document addresses the systems that will be used at ARC and establishes the procedures for preparing and participating in the Flight Test. LVC systems in use at the NASA Armstrong for Flight Test 6 are not included in this document.	<u>FT6 Procedures for ARC v2.2</u>	9/18/2019	IT&E: Pfeiffer, Jacob Bridges, Wayne
4	FT6 LVC Startup Procedure	This document contained the step by step startup procedures for startup and shutdown of FT6 laboratories and components	<u>FT6 LVC Startup Procedure</u>	7/3/2019	IT&E: AFRC, ARC
5	Flight Test Series 6 Flight Test Plan Document	This document describes the flight planning for all phases of the FT6. It includes information on procedures and methods that will be used during the flight test.	<u>Flight Test Plan Document ITE-FT6-FTP-01</u>	6/2019	IT&E: Marston, Michael
6	Flight Test Series 6 Concept of Operations Document	The document is used to convey concepts, system characteristics, and operational principles to the project stakeholders.	<u>IT&E FT6 Concept of Operations, ITE-FT6-CONOPS-01</u>	4/2019	IT&E: Marston, Michael

#	Title	Description	File	Publication Date	Authors
7	UAS-NAS ITE FT6 Data Management Plan	This document addresses the management of data from the Unmanned Aircraft Systems (UAS) Integration into the National Airspace System (NAS) project, herein referred to as UAS in the NAS or UAS-NAS, Flight Test 6 (FT6) campaign, from the time of data collection, to data distribution, and data archival.	<u>ITE-DMP-01 (Draft)</u>	6/13/2019	IT&E: Loera, Victor
8	AFRC Flight Test Series 6 Test Report	This document is a flight test report from the operational and evaluation perspective for the Flight Test Series 6 flights	ITE-FT6-FTR-001	2/28/2020	AFRC

7 Laboratory Infrastructure

Sections 7.1 and 7.2 provide a visual depiction of the laboratories used at ARC for FT6. The DSRL hosted the Ghost, Ghost Support and Contoller positions while the SDL hosted the Ghost Pilot and Pseudo-pilot positions.

7.1 DSRL

Figure 1: DSRL Layout depicts the layout of hardware and personnel in support of the FT6 flights. Details of the equipments shown in Figure 1 are described in Table 2.

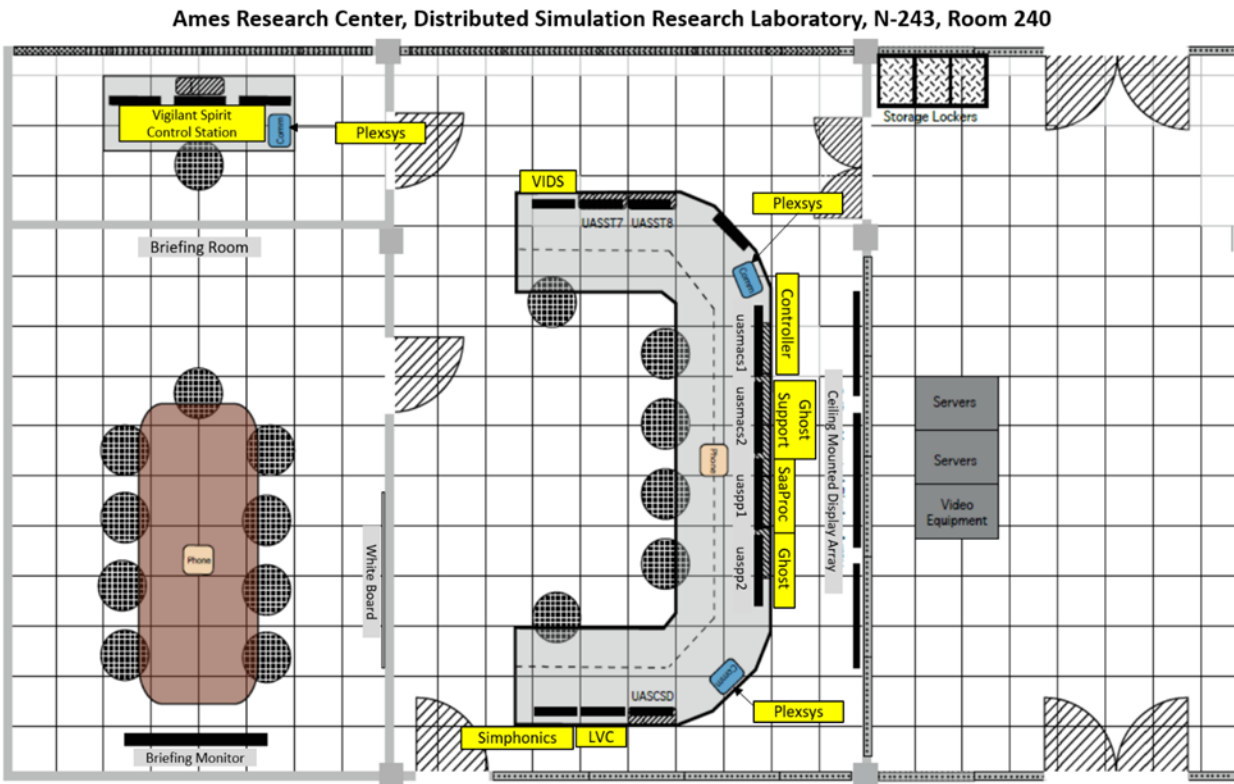


Figure 1: DSRL Layout

Table 2: DSRL Control Room Operating Positions

<u>Position Name</u>	<u>Hardware</u>	<u>Operating System</u>	<u>Software Application(s)</u>
UASMACS1	Dell Precision T5500	Windows 7 Professional	MACS – Controller, PLEXcommVR
UASMACS2	Dell Precision T5500	Windows 7 Professional	MACS - Ghost
UASPP1	Dell Precision T5500	Windows 7 Ultimate	MACS – Sim Manager, SaaProc
UASPP2	Dell Precision T5500	Windows 7 Ultimate	Firefox, Pfeiffer Weather Converter
Linx™ Prime Matrix Switchers (not shown)	RGB Spectrum 3400 Linx	32 X 32 DVI	Linx Digital Matrix Switcher System
uasgw3 (not shown)	Dell Precision R5500	CentOS Release 6.10	LVC Gateway, LVC Logger, SSA, FPG, Roselli Tunneler
uasst6 (not shown)	Dell Precision R5500	CentOS Release 6.10	ADRS
SMPC201674	SMPC201674	Windows xp	SimPhonics SMx
ATCCOMRP (not shown)	SimPhonics SMx	Windows xp	Recorder (V+)
UASVSVR (not shown)	HP Z820	CentOS Release 6.10	VIDS
UASVSCS2	Dell Precision T7910	Windows 7 Professional	VSCS GCS
Station 1, Station 6, Station 10	Plexsys Plexcomm T3	Windows xp	Plexcomm

7.2 SDL

Figure 2: SDL Layout depicts the layout of hardware and personnel in support of the FT6 flights. Details of the equipments shown in Figure 2 are described in Table 3.

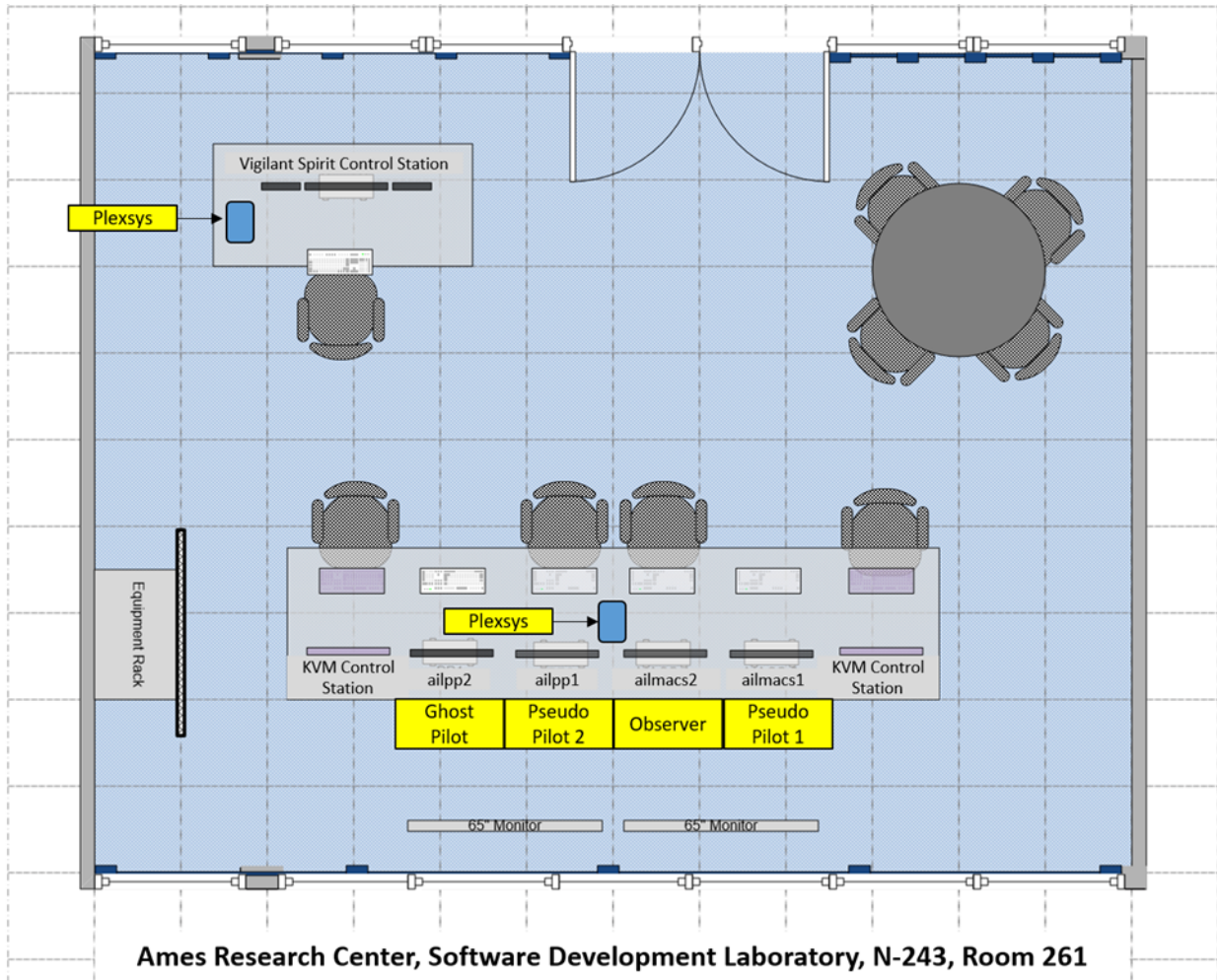


Figure 2: SDL Layout

Table 3: SDL Control Room Operating Positions

<u>Position Name</u>	<u>Hardware</u>	<u>Operating System</u>	<u>Software Application(s)</u>
AILMACS1	Dell Precision T5600	Windows 10 Pro for Workstations	MACS - Pilot
AILMACS2	Dell Precision T5600	Windows 10 Pro for Workstations	MACS - Observer
AILPP1	Dell Precision T5600	Windows 10 Pro for Workstations	MACS - Pilot 2
AILPP2	Dell Precision T5600	Windows 10 Pro for Workstations	MACS - Ghost Pilot
Linx™ Prime Matrix Switchers (not shown)	RGB Spectrum 1800 Linx	16 X 16 DVI	Linx Digital Matrix Switcher System
Station 9, Station 12	Plexsys Plexcomm T3	Windows xp	Plexcomm

7.3 AFRC LVC

NASA Armstrong was the responsible test organization for conducting FT6 test missions. The AFRC IT&E team was responsible for planning, coordinating, executing, and reporting on the flight tests. The ARC IT&E team provided remote support and services to the research teams at ARC and the virtual environment with support for the Full Mission portion of the test.

The figures below present the distributed environments used for the required data transfer between the centers. The Scripted Encounters (Figure 3) shows the layout used to support the ARC research environment for the paired encounters. The Full Mission (Figure 4) shows the extended layout that supported the virtual ATC environment.

Briefed at Phase I CDR

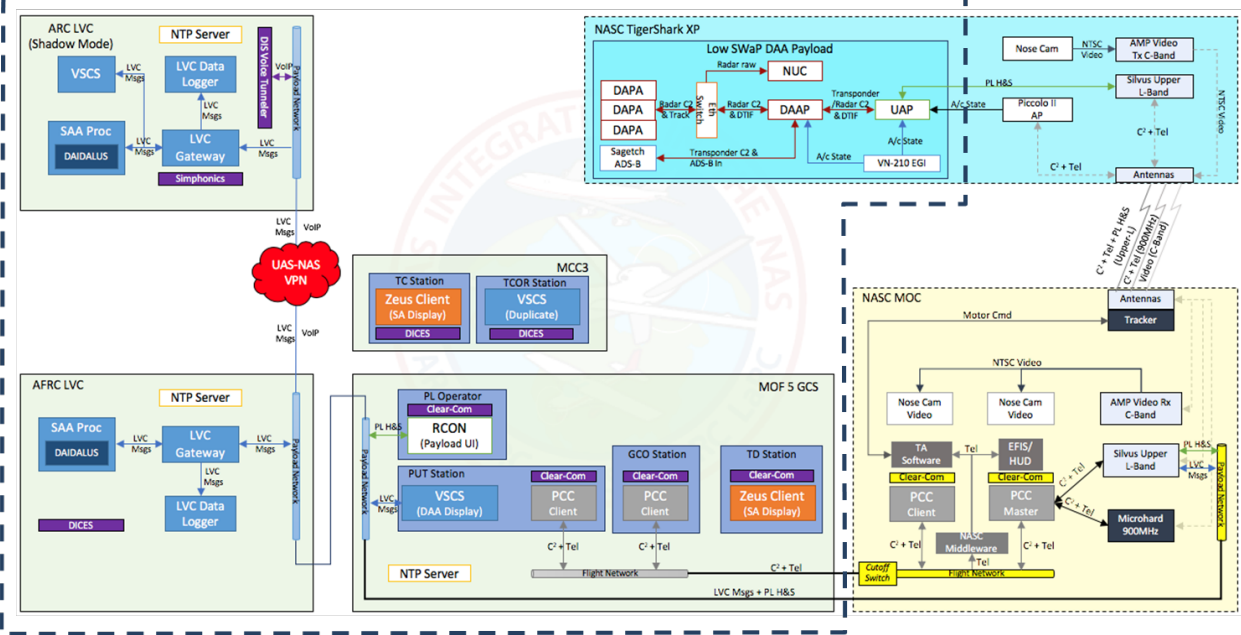


Figure 3: FT6 Configuration 1 – Scripted Encounters

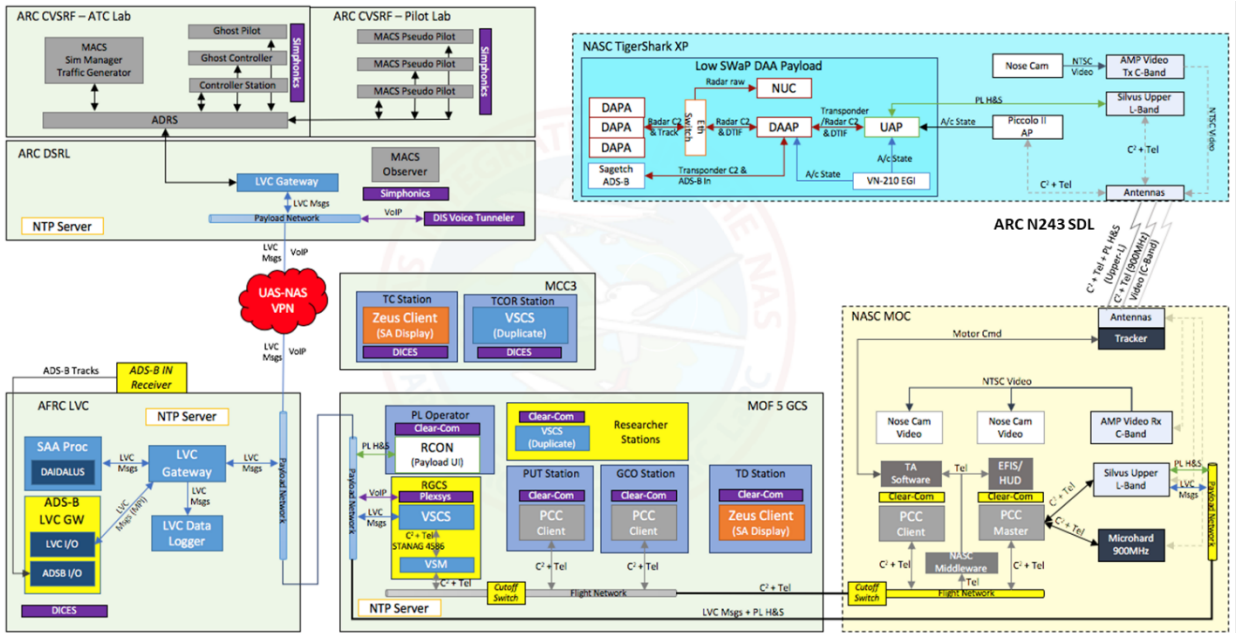


Figure 4: FT6 Configuration 2 – Full Mission

8 Live Virtual Constructive - Distributed Environment (LVC-DE) Architecture

Using the Live Virtual Constructive Distributed Environment (LVC-DE), the FT6 flight tests inserted live aircraft, N1750X (ownship) and NASA865 (intruder) into the virtual Air Traffic Control (ATC) environment. This environment allowed NASA researchers at Langley Research Center (LaRC) and ARC to assess the Detect and Avoid capabilities of an UA equipped with sensors to detect uncooperative aircraft of Low Size, Weight, and Power (Low SWaP).

The major sub-systems that comprise the LVC-DE infrastructure at the Ames Research Center supported the overall LVC environment at ARC and AFRC. These systems facilitated data collection of audio, LVC, and MACS data. The Visual Ingest and Distribution System facilitated streaming of the VSCS, Zeus, and Piccolo video streams provided from AFRC. These video streams were capable of being accessed remotely by ARC researchers. The VSCS, located in DSRL, provided ARC researcher a comparable view in real time with the VSCS stream from AFRC. VSCS operated in “external” configuration, which allowed the system to process data supplied from AFRC, and provided a Ground Control Station traffic and DAA display.

Background traffic during the FT6 Full Mission was provided by the MACS constructive traffic generator. MACS was configured to emulate the ATC environment at Oakland Air Route Traffic Control Center, Sector 40/41. Background traffic consisted of cooperative and non-cooperative aircraft. The Controller, Simulation Manager, Ghost Support, and Ghost positions were located in the DSRL. The associated pseudo-pilot, Ghost Pilot, and Observer positions were located in the Software Development Laboratory. The MACS simulation was managed by the Ghost and Ghost Support positions. The MACS data network was supported by the Aeronautical Data Link and Radar Simulator (ADRS) and MACS messages were forwarded to the LVC gateway through ADRS.

DAA messages and alerts were provided by the SaaProc, which contains the Java Architecture for Detect and Avoid Extensibility and Modeling (JADEM) and Detect and Avoid Alerting Logic for Unmanned Systems (DAIDALUS) algorithms. The DAA outputs at ARC were used for local VSCS displays in the DSRL.

All message and position updates for the live aircraft, virtual aircraft, and DAA messages and alerts at AFRC and ARC were routed to appropriate sub-processes via the LVC Gateway. The Sensor Surveillance Adapter (SSA) and Flight Plan Generator (FPG) were employed at ARC during FT6 Scripted Encounters. The SSA was used to reformat or “translate” AC Track State messages received from AFRC to MPIFlightState messages used by MACS to display traffic. The FPG supplied a preset flight plans for aircraft, which had a flight plan omitted or missing. The LVC data logger recorded time stamped records of each message processed through the gateway.

9 Software Applications and Development

Table 4 lists the various applications needed to run the software and hardware components at NASA Ames (DSRL, SDL, and IT infrastructure) to provide the LVC-DE environment in support the flight test activities at Ames and Armstrong. The applications as listed below provide data, voice communication, and video feeds between the Ames to Armstrong locations. Systems used at Armstrong to capture data between airborne assets and ground station is beyond the scope of this document. As a side note, LVC development was not required to support the FT6 efforts because it used the protocols developed from the prior version, Revision H.

Table 4: Software used at ARC for FT6

<u>Application</u>	<u>Description</u>	<u>Version</u>	<u>Type</u>	<u>Lab(s)</u>	<u>Location</u>
Aeronautical Data Link and Radar Simulator (ADRS)	Central communications process that enables data transfer between all MACS stations and other external components.	ADRS-082514-042815-A	Linux	DSRL	uasst6
LVC Gateway	Communications hub for message processing between components of the LVC/DE	v.0.1.19_20180308_R2	Linux	DSRL	uasgw3
LVC Logger	Records all message data processed by the LVC Gateway and creates a log file for data collection	v.0.1.19_20180308_R2	Linux	DSRL	uasgw3
Multi-Aircraft Control System (MACS)	High fidelity environment for conducting real time controller and pilot simulations	MACS-AOL-2015-TOM	Windows	DSRL/S DL	uasmacs2, uasmacs1, uaspp1 ailmacs1, ailmacs2 ailpp1, ailpp2
Plexsys Sonomarc	Voice over IP system for virtual ATC Air/Ground communications	v2.3.0.206 (T3 Stations) v3.5.0.31 (soft clients)	Windows	DSRL/S DL	Station 6, Station 9, Station 10, Station 11, Station 12, uasmacs1, (Entity 5)

<u>Application</u>	<u>Description</u>	<u>Version</u>	<u>Type</u>	<u>Lab(s)</u>	<u>Location</u>
SaaProc (JADEM / DAEDALUS)	Processes information for aircraft in the vicinity of the ownship for DAA threats and generates alert and guidance messages to subscribers	v9.0.1	Windows	DSRL	uaspp1
Sensor Surveillance Adapter (SSA)	Translates LVC messages to/from AcTrackState to/from MPIFlightState	v.0.1.19_20180308_R2	Linux	DSRL	uasgw3
Flight Plan Generator (FPG)	Initiates an MPIFlightPlan for aircraft lacking a flight plan for MACS propagation.	FPG 2.0	Linux	DSRL	uasgw3
Simphonics Recorder	Voice over IP system for recording ATC communications	v4.1.106.0	Windows	DSRL	SMPC201691 (Recorder) SMPC201685 (Receiver)
Voice Tunneler (Ames VPN)	IP tunnel which connects and enables audio transmission between two isolated multi-cast IPs	NickRoselli_20130830	Linux	DSRL	uasgw3
VSCS Control Station	Virtual Ground Control Station (GCS) Display	v2018.2.2.902	Windows	DSRL	uasvscs2
Video Ingest and Distribution System (VIDS)	Web based real-time video streaming and capture solution	v03.2016.06.07	Windows	DSRL	uasvsrv

9.1 MACS Scenario Development

The Multi Aircraft Control System (MACS) scenario used for the FT6 Full Mission evolved from the development of prior high-fidelity simulations to reduce development efforts. Supporting the FT6's Full Mission flights required an extended-duration scenario file, lasting four hours, to accommodate possible airspace contingency plans, ownship holding, equipment outage, weather delays, and C2 failures. The extended-length scenario was accomplished by concatenating two previously developed scenario files (Traffic 1 and Traffic 2). This new

scenario was reviewed and vetted by adjusting the time and or place of aircraft entry, deleting aircraft, and adjusting aircraft speeds to maintain a moderate quantity and complexity level. The final scenario resulting in 300 aircraft over 4 hours and maintaining the desired moderate traffic levels.

Aircraft that were operating under Visual Flight Rules (VFR) in the MACS scenario were indicative of moderate levels of traffic for Sector 40/41. However, VFR aircraft were modified to provide the required traffic around the ownship. VFR aircraft were also modified to remain clear of the depicted Temporary Flight Restriction (TFR) area. These VFR aircraft had their altitudes amended and/or were rerouted around the boundaries of the TFR.

The MACS scenario was programmed with five simulated aircraft identified as Traffic (TFC), TFC1 thru TFC5. These aircraft were modified to ensure that the VSCS displayed an adequate amount of surrounding traffic. Ghost Support also used these aircraft to generate the preventive alerts used in the scenario. TFC1 thru TFC5 were displayed with yellow alphanumeric at the Ghost Support position to assist in identification and reduce frequency congestion.

9.2 Sense and Avoid Processor (SaaProc)

The SaaProc software was used in numerous flight tests and HITL simulations and interfaced with the LVC network as a client process. It received LVC messages such as aircraft states, computes DAA alerts and guidance, and relayed alerts and guidance messages to LVC. A few configurable features of SaaProc were enabled to support Flight Test 6:

1. Intruder altitude offset: this feature can trick the DAA algorithm to think the ownship and intruder aircraft are co-altitude, therefore causing alerts.
2. Surveillance volume filter: this intruder-type specific (cooperative or non-cooperative) filter allows researchers to imitate the limited surveillance of a Low SWaP sensor.

The SaaProc architecture implemented an LVC wrapper that interfaced LVC with the Java Architecture for Detect and Avoid Extensibility and Modeling (JADEM) library. JADEM also used a wrapper layer to interact with the Detect and Avoid Alerting Logic for Unmanned Systems (DAIDALUS) algorithm, which computes raw alerts and maneuver guidance. JADEM's wrapper layer inspected DAIDALUS's output and applied additional logic to modify it for better stability and conformance with external requirements.

9.3 Utilities and Scripts

9.3.1 Pfeiffer Weather Conversion

The Pfeiffer Weather Conversion software created wind files in a MACS readable format to replicate forecasted winds within an area of airspace. The program required the user to have access to pertinent weather data from a specific reporting site.³ This data was copied to a text

³ <http://www.meteo.psu.edu/bufkit/data/RAP/>

file and ran through the script to translate it into a MACS compatible file. This file was loaded into MACS and verified for accuracy by all users.

9.3.2 Airspace Transformation

The Airspace Transformation scripts were used to relocate (overlay) the ZOA-40/41 sectors and surrounding airspace over the Edwards Air Force Base's R-2515 airspace, as shown in Figure 5. The scripts required user knowledge of the MACS airspace file system and formats (airports, waypoints, and boundaries) to ensure the proper program was used on the correct airspace file. Each program translated points of latitude and longitude based on the selected translation origin of Santa Rosa Airport (KSTS) and the destination point, Palmdale Airport (KPMD). Translated files were verified through MACS by SMEs familiar with the airspace.

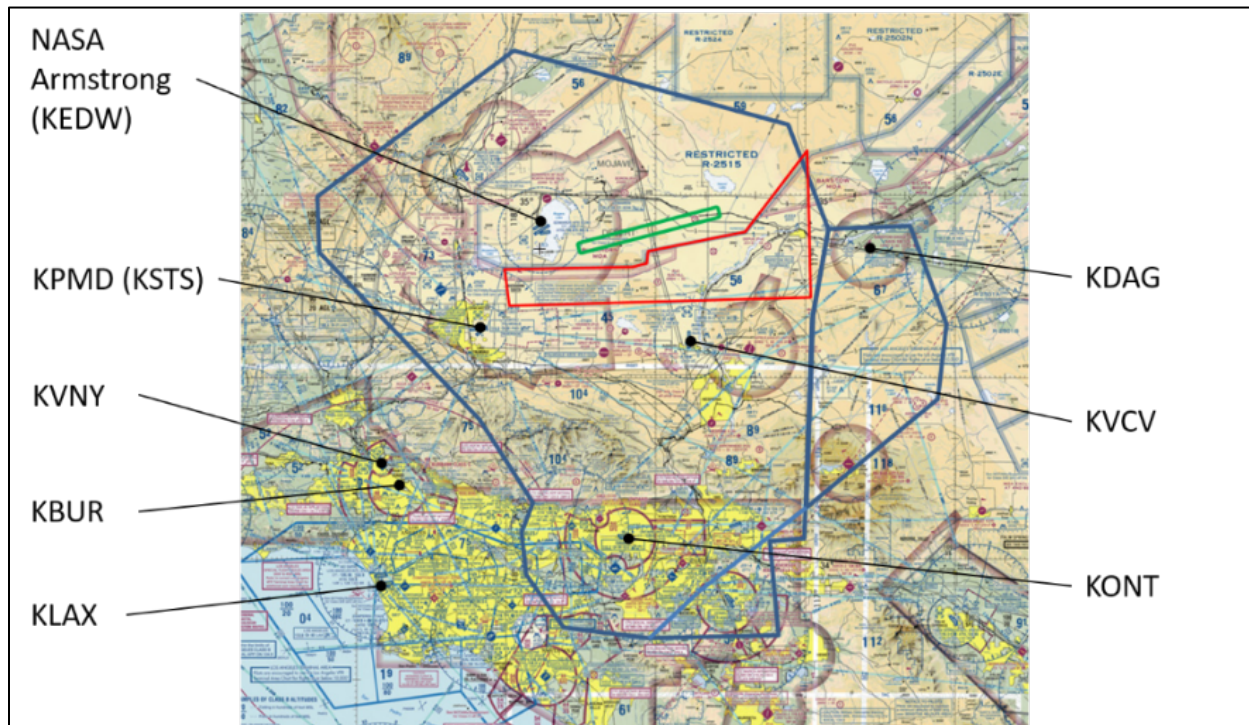


Figure 5: ZOA-40/41 Transformation over R-2515 Airspace

9.4 ARC Voice Communications

Communications between ARC and AFRC was established using a VPN connection. The Nick Roselli Tunneler provided a conduit for communication between the gateways at the respective research centers. Local communications at ARC used standalone Plexsys T3 touch screen computers and computer installed Plexsys soft clients located in the DSRL and the SDL. Figure 6 depicts the communication connection between the two labs.

Audio recording was captured using a Symphonic system that included a single communication station and a specialized Simphonics recorder. The Simphonics recorder was set to record all transmissions on Virtual ATC frequency, 125.85.

The system operated using five independent frequencies. These frequencies were coordinated and agreed upon with the AFRC team in advance of the test. Virtual ATC was established on frequency 125.85. Virtual ATC emulated air-to-ground communications between the VSCS pilot, pseudo-pilots controlling virtual aircraft within ZOA Sector 40/41, and the ZOA air traffic controller. The Ghost Net on frequency 132.2 facilitated communication between Ghost Support, Ghost Pilot, and the Ghost. This frequency was used primarily to manage the scenario traffic and coordinate global instructions, such as Simulation Start and Stop to ARC positions. The LVC Net on frequency 120.55 provided a channel for coordination between the Ghost at ARC and the LVC Laboratory and Payload position at AFRC. System related items were accomplished on this frequency including simulation startup and shutdown, system status reporting and troubleshooting, and LVC system initiation. The Engineering Net on frequency 126.6 provided the communications link for the Test Director and provided direct communication with the Ghost, Payload, and Researcher positions. Overall management of the mission including clearances for the controller, encounter status reports, and mission advisories were provided on this frequency. The TC Net, frequency 120.0, was implemented to allow the TC direct communications with Ghost, but was not used to communicate at or with ARC.

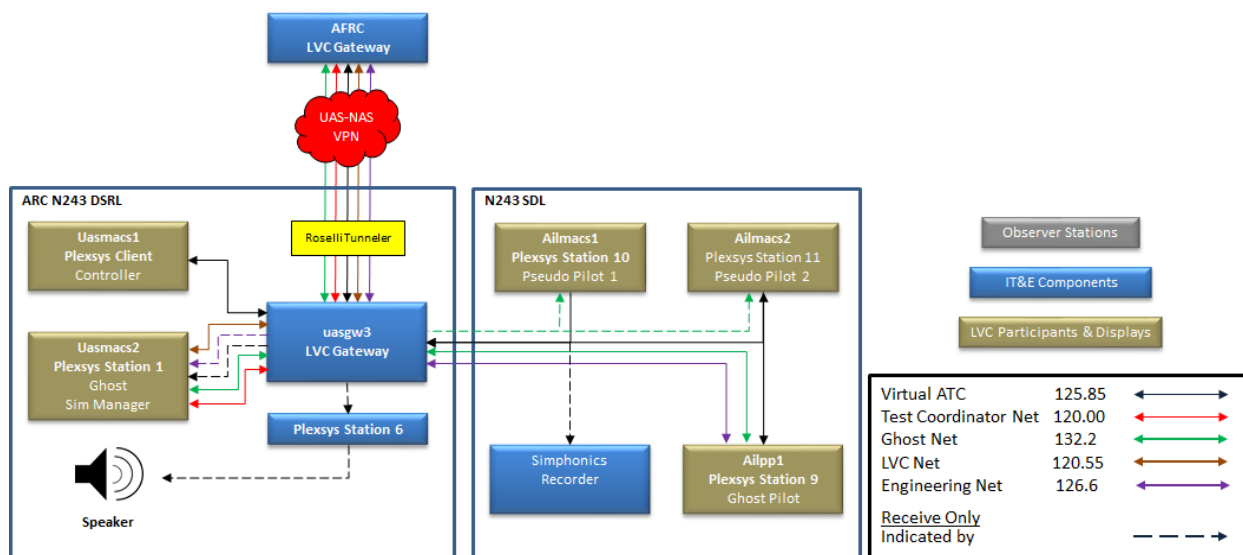


Figure 6: ARC FT6 Communications

9.5 Airspace and Scenario Development

The combined sector 40/41 airspace is located in Area North on the western edge of Oakland Air Route Traffic Control Center domestic airspace. The sector has a northwest to southeast orientation, and overlies the Coastal Range on the California coast to the west and extends over the Napa/Sonoma valley and Lake Berryessa to the east. Sector 41 is a low altitude sector, 8'000 feet up to and including FL230 (see Figure 7). The sector overlies Sector 40 is also a low altitude sector, 8'000 feet and below and shares the lateral boundaries of Sector 41 excluding shelves shared with Northern California Terminal Radar Approach Control (TRACON) and Travis

Radar Approach Control (RAPCON). Sector 41 is bounded to the southeast and east by Northern California TRACON, to the north by domestic Sector 42, and to the west ocean Sector 36. Sector 36 and domestic Sector 31 overlies Sector 41.

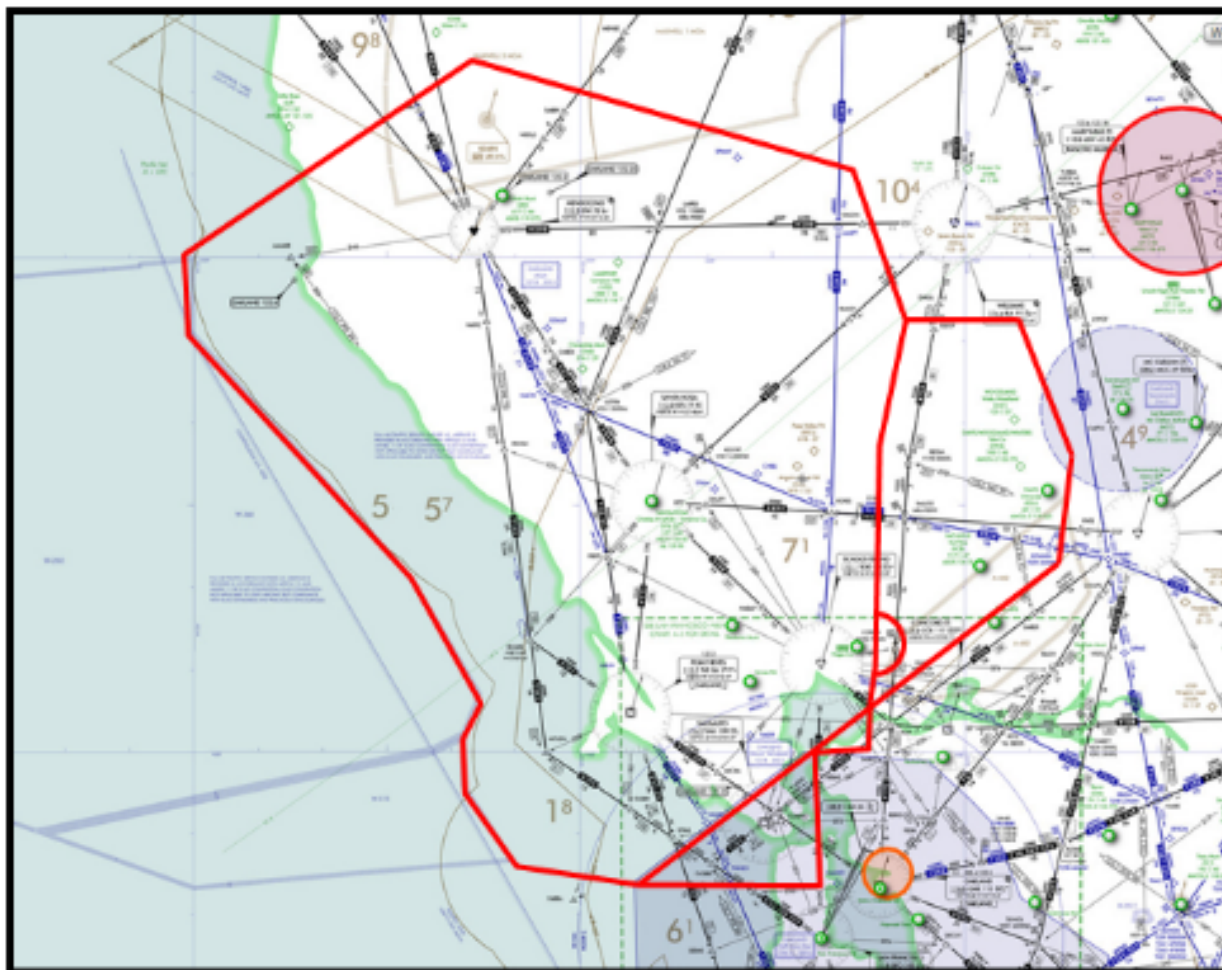


Figure 7: Combined Oakland Center (ZOA) Sectors 40 and 41 (inside red perimeter line)

Sector 41 is primarily an arrival and departure sector for the Bay Area airports including San Francisco, Oakland, and San Jose airports. Sector 41 also provides letdown and departure services to aircraft landing within Sector 40 airspace. Sector 41 works VFR (Visual Flight Rules) traffic below FL180. VFR traffic levels are generally lighter than that found within Sector 40 and ranges from light to moderate workload for the controller.

Sector 40 is primarily an arrival and departure sector for the Santa Rosa and Napa airports. The sector provides approach control services to these airports and other smaller airports in the area. Sector 40 also works traffic into and out of Travis Air Force Base to the west. The sector also works lower altitude arrivals and departures into and out of Bay Area airports from Northern California TRACON. Sector 40 works moderate to heavy VFR traffic arriving, departing, and transiting the Napa and Santa Rosa areas, particularly on the weekends.

Sector 40 is usually combined with Sector 41. Sector 40 is de-combined when traffic loads at Santa Rosa and/or Napa make coordination with the towers unmanageable at the combined sector. Heavy levels of VFR traffic may also mandate that the sector work apart from Sector 41. In the same way, moderate or greater traffic load or holding for Bay Area airports will require that Sector 40 be opened to reduce the workload at Sector 41. This airspace was selected because the sectors interface with Class A, B, C, D, E and G airspace types. This allows the research team to test in both positive control and uncontrolled test environments.

Traffic was developed to provide representative aircraft interactions and air/ground transmissions without creating excessive workload for the air traffic controller. The traffic load on the sector was designed to be equivalent to moderate traffic for the combined sector, ZOA-41/40.

The traffic within the simulation consisted of two types. VFR traffic may include cooperative and non-cooperative targets. Cooperative targets may squawk a beacon code of “1200” and refrain from communicating with ATC or receive VFR advisories from the controller and squawk an assigned beacon code. Non-cooperative targets were designated as primary targets, which do not provide transponder information. Aircraft conditions were based on the actual traffic tracks displayed at sector 40. VFR traffic flew random tracks over and through the Sonoma Valley between the Ukiah, Santa Rosa, and Napa airports. Instrument flight rules (IFR) traffic primarily consisted of commercial traffic in and out of the San Francisco Bay area. These aircraft were assigned routes and procedures using performance based navigation. Aircraft flew the BDEGA2 standard terminal arrival route (STAR) to the San Francisco airport and the WNDSR2 STAR to the Oakland airport. San Jose airport arrivals flew the BR1XX1 STAR. Departure traffic were route east of the arrival tracks. The TRUKN standard instrument departure (SID), and OAK SID transitions were geographically separated to allow aircraft to climb to altitude without speed restrictions or vectoring.

Airspace and flight plan development for FT6 was a cooperative effort between ARC ATC Subject Matter Expert (SME) and the operations group at AFRC. Track location was dependent on the available airspace within R-2515. Consideration was also given to the proximity of the track to the Los Angeles Air Route Traffic Control Center common boundary with R-2515. ARC SME provided input on air traffic procedures that could be applied for ownship maneuvers for mission start, contingency routes, and holding. ARC developed the TFR used to protect the ZLA boundary.

9.6 Flight Test Design

Encounters were generated in order to stimulate the DAA system to provide alerting and guidance to remain DAA well clear (DWC) from the unmanned aircraft. A well clear violation would occur if the subject pilot failed to take action to avoid the encounter aircraft, resulting in loss of DWC. Encounters during Flight Test 6 were “scripted”. A scripted encounter was designed to create a response from the DAA algorithm and provide an alert message and guidance to the subject pilot on the VSCS traffic display. These encounters were constructed based on the parameters provided by the research team. Twenty to thirty encounters were designed for the scripted encounter flights. Scripted encounter flights involved a live UA and one live intruder flying predetermined tracks at various vertical and horizontal approaches to the

ownship. These encounters focused on non-cooperative encounters. Six scripted encounters were designed to interact with the UA during the Full Mission portion of the flight test. Four of the encounters flown by the intruder aircraft presented a non cooperative target to the subject pilot flying the ownship. The remaining two encounters provided cooperative targets. These encounters were designed to create a loss of DAA well clear (LoDWC) if the test subject should fail to respond.

The scripted encounter flights were developed by the Honeywell, and M&S and HSI research teams. Full Mission flight encounters were designed by HSI researchers. The flight planning and scheduling of the encounters were completed by the AFRC operations group.

Previous and ongoing simulations have identified four encounter characteristics: the encounter angle (relative headings of the two aircraft: head-on, crossing, in-trail); the relative velocity (approximately equal or substantially different); the relative altitude and altitude rate (both level, one level and the other climbing/descending, both climbing/descending); and the predicted closest point of approach (a potential well clear violation only, or a collision avoidance encounter). A graphical depiction of the encounter angle definitions is provided in Figure 8.

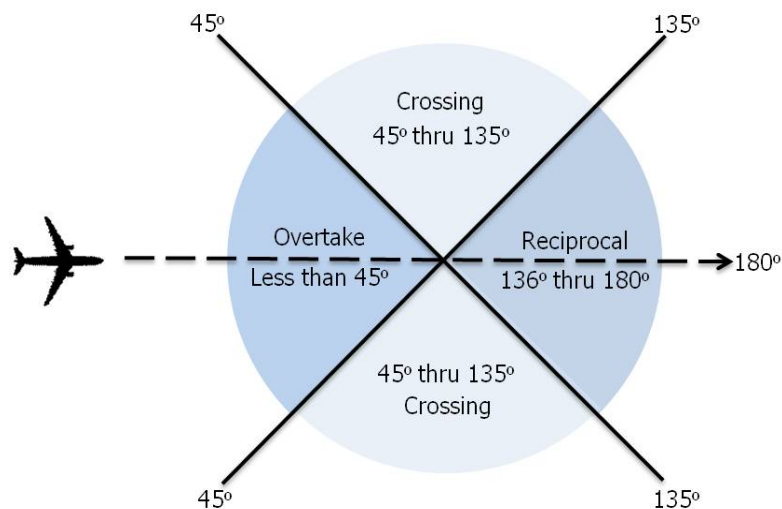


Figure 8: Encounter Trajectories

All encounters were contained within boundaries of ZOA 40/41 airspace and were designed to interact with the ownship along the aircraft's route of flight. Encounters were designed to give the test subject pilot and the alerting algorithms sufficient time to evaluate and act on a confliction. Encounters interacted with the UAS at altitudes below 10'000 feet MSL. The DAA software detected non-cooperative intruders within parameters developed by the M&S research team and configured into the SaaProc.

9.6.1 Temporary Flight Restriction (TFR)

A temporary flight restricted (TFR) area, from the surface up to and including 10,000ft MSL, was implemented over the R-2515 / Los Angeles Air Route Traffic Control Center (ZLA) airspace; as this airspace hosted the transformed ZOA Sector 40/41 airspace. The depicted TFR was located south of the FT6 flight test route and designed to protect the actual R-2515 boundary with ZLA. The ownship was required to remain 1.5 NM away from the TFR to protect the ZLA boundary. Additionally, the depicted TFR was in place to provide simulated air tanker operations/firefighting activity from the Lakeport Complex Fire, located in Lakeport, California. Simulated arriving/departing IFR traffic from the Santa Rosa airport were authorized to transition the TFR. Simulated VFR aircraft were prohibited to operate within the TFR area.

9.6.2 Flight Plan Contingencies

FT6 developed contingency plans for both Scripted Encounter and Full Mission flights. The Scripted Encounters used tracks designed for each flight by AFRC team. FT6 Full Mission flights used the Full Mission Route as the nominal track. The Full Mission Route flew a racetrack pattern that navigated WP1, WP4, WP7, WP10 (see Figure 9) including intermediate waypoints. The Four Corners Extension was applied to the Full Mission Route if more distance and or time was needed to accomplish encounters or complete SPUT debriefings. The Full Mission Route with the Four Corners Extension clearance departed WP4, to WP5, WP6, WP7, and continued on the Full Mission Route. FT6 Full Mission flight test was designed with two route contingencies to mitigate airspace restrictions that forced the ownship to exit the nominal route.

The Mercury Spin route, shown in blue in Figure 9, was designed to contain the ownship within the Mercury Spin operating area in R-2515. The track flew a shortened racetrack pattern consisting of WP1, WP2, WP9, and WP10. The Four Corners route, shown in red in Figure 9, moved the ownship into the Four Corners area of R-2515. The racetrack pattern consisted of WP3, WP5, WP6, WP8, and intermediate waypoints.

Three loiter fixes were designed for the FT6 Full Mission flight test, depicted as circles in Figure 10: ALPHA (left center), BRAVO (not shown, but left of CHRLY), and CHRLY (right). The loiter fixes were utilized to rectify possible technical issues or to allow more time to accomplish the flight test goals.

When required, the test director (TD) advised Ghost to reroute the ownship. The Ghost then requested the controller to issue the appropriate clearance to conform to the TD request. A full list of the clearances used for the Full Mission route and contingency operations is include in Attachment 2, Contingency Clearances. Section 10 provides a full description of roles and responsibilities of personnels supporting FT6.

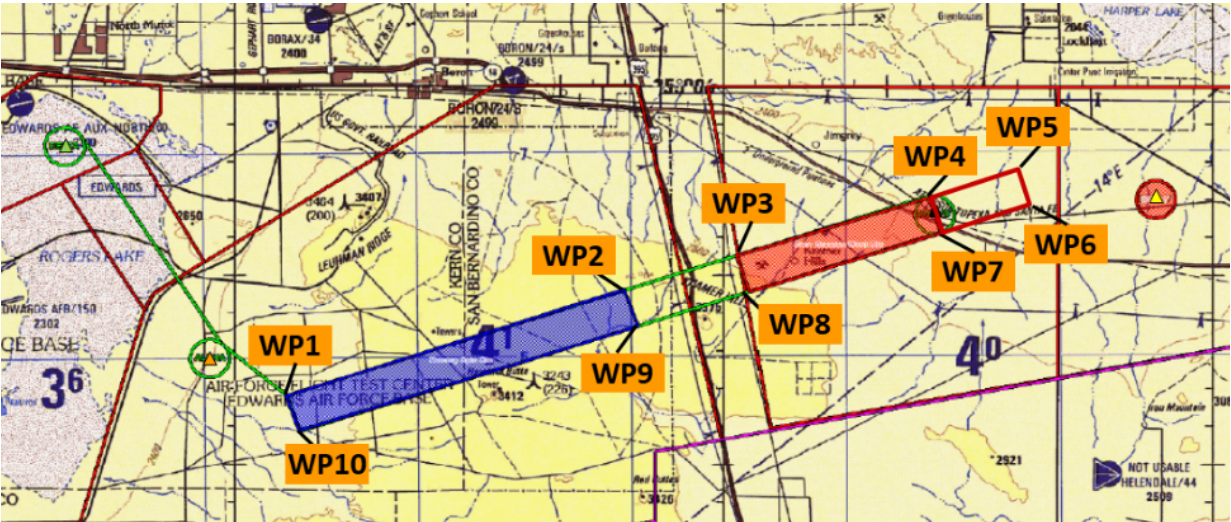


Figure 9: Full Mission Route with Four Corners Extension

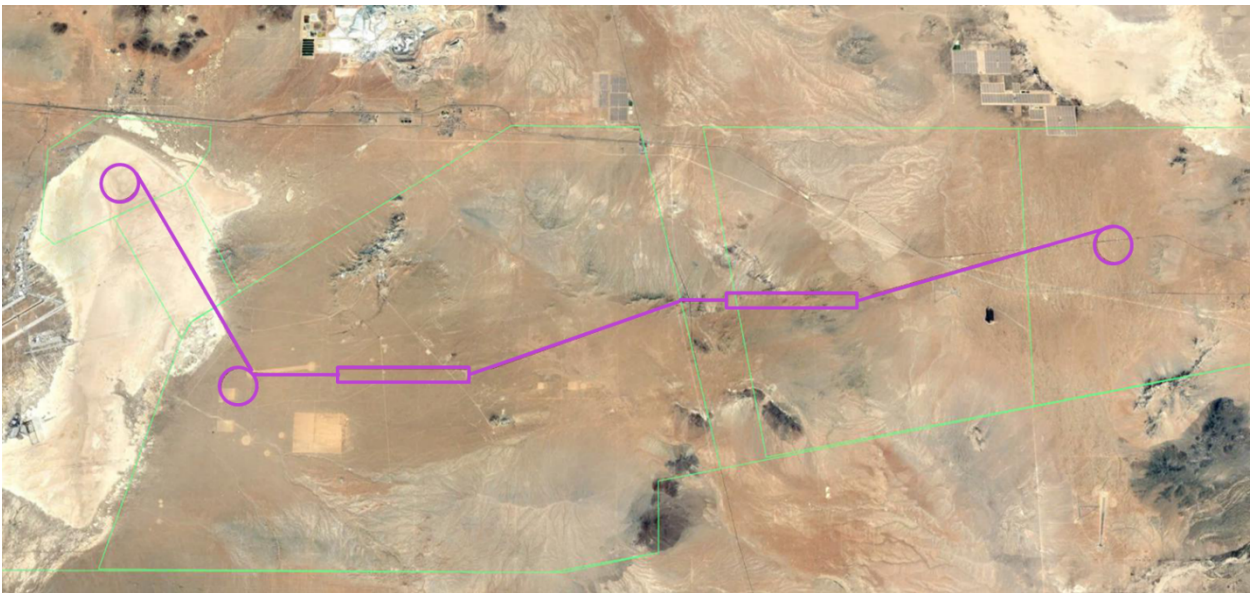


Figure 10: Example of the Scripted Encounter Route

In the event of an ownship C2 failure (lost link or loss of communications and control), an alternate C2 route was pre-programmed into the ownship's on board computer. Thirty seconds following a loss of command and control link, the ownship turned to intercept the lost link route, a set of predetermined points that proceeded to waypoint ALPHA, and then returned to base. Ghost advised the TD of the event when observed by the controller.

10 Roles/Responsibilities

ARC support for the FT6 flight tests included personnel at five operational positions. The Ghost and Ghost Pilot positions were used for all FT6 flights, which included System Checkout, Scripted Encounter, and Full Mission. The Ghost Support, Controller, and Pseudo-pilot positions supported the ATC environment needed for the FT6 Full Mission flights.

10.1 NASA Ames Personnel

10.1.1 Ghost

The Ghost position was responsible for overseeing the ARC test environment and acting as the point of contact with AFRC operations team. Ghost represented ARC in the T-1 (day prior to flight test), T-0 (day of flight test), and post-flight briefings. The Ghost coordinated the startup of local LVC-DE and those procedures for connecting to the AFRC LVC-DE. This position monitored the health of the ARC systems and acted as the focal point for trouble shooting at ARC.

During Full Mission flights, Ghost managed the staffing of the confederate participants, Controllers and Pseudo-pilots. He conducted prelaunch and post-flight briefings to advise on the activities for each flight including weather and anticipated route changes. Ghost also collected feedback from the ARC team on system performance and forwarded relevant information to AFRC.

Ghost coordinated mission operations with AFRC, including simulation startup and shutdown. The position tracked the progress of intruder encounters and reset logs and audio recordings at the direction of AFRC. The ghost ensured that the directions of the Test Director during the Full Mission were accomplished. Ghost also monitored the progress of the flight and made recommendations to the TD on control actions that would enhance mission performance.

10.1.2 Ghost Support

The Ghost Support position primary responsibility was to assist the controller position by acting as other ATC facilities and ZOA sectors, initiating and accepting hand-offs, and issuing control instructions and altitude assignments. This position also acted as an assistant to the Controller providing help with simulated MACS traffic and ownship operations. This position, working with the Ghost pilot, monitored and initiated actions to ensure smooth operation of the MACS scenario. Ghost Support also issued control instructions to maintain the required amount virtual traffic around the ownship, and maneuver this traffic to provide one or two preventive-alerts with the ownship.

10.1.3 Ghost Pilot

The Ghost Pilot was responsible for oversight of the SDL operations. Ghost pilot forwarded instructions from Ghost and Ghost Support to the Pseudo-pilots and provided operational assistance to these positions when needed. This position provided technical support for the ARC test environment and forwarded operational status to Ghost on the health of the ARC system. Ghost Pilot acted on control instructions issued from Ghost Support to maneuver specific virtual

traffic around the ownship to ensure the required amount of traffic on the AFRC VSCS display. Ghost pilot also acted on Ghost Support instructions to ensure that simulated aircraft maneuvered in accordance with normal ZOA procedures.

10.1.4 Controller

The Controller position was used only for FT6 Full Mission flights and controlled the ownship and virtual traffic within the Full Mission scenarios. The controller was in direct communication with the ownship and virtual aircraft. The controller used MACS information as the primary means of separation. Both MACS and the AFRC VSCS were used to provide clearances to the ownship. Controllers managed all traffic during Full Mission flights using standard operating procedures for ZOA-40/41 and procedures designed for the FT6 Full Mission.

10.1.5 Pseudo-pilot

Two Pseudo-pilot positions supported the FT6 Full Mission flights. These positions controlled virtual aircraft within Full Mission scenario. The Pseudo-pilots shared the Virtual ATC frequency with the Controller and ownship. Pseudo-pilots used the MACS pilot displays to monitor and maneuver up to ten aircraft under their control. These pilots followed scripts to ensure scenario fidelity. The positions used a MACS observer position to maintain situational awareness and remained clear of the ownship and the TFR. Pseudo-pilots responded to the instructions of the Ghost Pilot and Controller. They also communicated with each other to ensure equitable distribution of traffic.

10.2 NASA Armstrong Personnel

For completeness, this section includes a description of the AFRC personnel that interacted with the ARC Ghost during FT6 system check-out, Scripted Encounter, and Full Mission flights.

10.2.1 Test Director (TD) Position

The Test Director acted as the primary interface between all the participants at AFRC and ARC. TD forwarded direction to manage the flight of the ownship to ensure that researcher requests were met. The TD would issue instructions for changes to route or holding to facilitate airspace constraints.

10.2.2 Payload Position

The Payload position was responsible for oversight of the complete test environment at AFRC and ARC. Payload managed the startup and shutdown of the test environment. He monitored the health of all components of the FT6 test environment and coordinated troubleshooting and repair of components.

10.2.3 LVC Position

The LVC position managed the AFRC LVC environment and directly interacted with the Ghost to coordinate time synchronization and ensure connectivity between the AFRC and ARC LVC-DEs. LVC initiated and maintained data flow and streaming options between AFRC and ARC.

11 Daily System Startup and Operational Procedures

Detailed startup and shutdown procedures can be found in *Appendix A: UAS in the NASA Flight Test 6 Procedures for ARC*.

11.1 Briefings

ARC support for each FT6 flight began with the T-1 briefing conducted the afternoon prior to the scheduled departure of the ownship. These briefings were attended by the Ghost and provided ARC with the planned schedule and objectives for the flight. Forecasted weather conditions were presented for the flight. The briefing included a review of procedures, mission rules, and flight cards for the planned encounters. The Ghost provided input on the readiness of ARC facilities and personnel. These briefings concluded with a determination of the go/no go status for the flight.

Prior to flight on test day, ARC participated in the T-0 briefing. T-0 briefings for system check-out (SCO) and SE flights were attended by the Ghost. The Ghost, Ghost Support, and Ghost Pilot attended the briefing for the FM flights. Briefings included a complete review of the items covered in the T-1 brief. Any changes to information after the T-1 briefing were discussed. Ghost provided a go/no-go report on ARC readiness and participated in the final decision for the go status of the mission.

11.2 LVC Prestart

Following the T-0 brief, the Ghost, Ghost Pilot, and Ghost Support prepared the DSRL for SCO and SE flights, or the DSRL and SDL laboratories for FM flights. Memory and CPU usage were checked and verified to be within tolerance for all computer systems. All computers using Windows operating systems were checked for time synchronization within the local network.

Local communications checks were performed by Ghost Support and Ghost Pilot between the DSRL and the SDL to ensure connectivity between all ARC participants. Ghost Support then configured the Simphonics Recorder to capture communications on the Virtual ATC frequency, 125.85. Ghost started voice communication with AFRC by connecting the Nick Roselli Tunneler. Ghost performed communications checks from DSRL to Payload, LVC, and the Test Director at AFRC.

Following the establishment of communications with AFRC, the Ghost facilitated time synchronization with AFRC LVC and verified acceptable parameters.

Ghost Support started the VIDS and verified ARC was receiving three video streams from AFRC.

All MACS stations required for the flight were brought to a ready state. For Full Mission flights, Ghost Support loaded/set-up the Virtual ATC Information Monitor, which included pertinent charts. NOAA winds aloft information was copied by the Ghost and processed through the Pfeiffer Weather Conversion to create the forecast winds file. This file was loaded into the MACS and verified for accuracy. This process was repeated hourly until the ownship recovered.

SaaProc was initiated and configured for the planned flight. VSCS was launched in the external mode and brought to ready state.

Once all systems have been started and verified ready for test, the Ghost advised Payload that ARC Pre-start Procedures were complete.

11.3 LVC Startup

Ghost initiated Startup Procedures when advised by Payload. The LVC environment was started and the connection between NASA research centers was verified. The ADRS was launched and the required MACS stations were connected and verified. The SaaProc and VSCS were launched and connections to the LVC gateway verified. Once all ARC systems were online and verified ready for test, Ghost advised Payload that the ARC Startup Procedures were complete.

11.4 Prior to Flight

As the ownship's data systems and onboard sensors were brought online by AFRC, data began to populate the LVC environment, SaaProc and VSCS. VSCS was adjusted to present the desired maps and center the ownship on the VSCS display. The MACS traffic displays were populated. Ghost advised Payload of the status of the traffic displays and the quality of the data received. A radio check from the AFRC VSCS to the Controller on the Virtual ATC frequency (125.85) was conducted for flights flying the Full Mission.

11.5 Post Ownship Departure

For Full Mission flights, Ghost conducted the Controller and pseudo-pilot briefing for the day's flight test. This briefing included the expected weather for the day emphasizing the winds aloft and its possible impact on the ownship. Possible airspace restrictions were briefed and the expected route assignments to accommodate the change. Controller and Pseudo-pilot questions were answered. Controllers and Pseudo-pilots then staffed at their assigned positions for the flight. The Virtual ATC frequency (125.85) was checked again with Pseudo-Pilots and the SPUT.

As the ownship approached waypoint ALPHA for a Full Mission flight, Ghost verified the MACS scenario for Payload. Ghost started the MACS scenario as the ownship climbed through 7500 feet MSL. Ghost reported to the Test Director that MACS traffic and the ownship were displayed on MACS stations in the DSRL and SDL.

Ghost advised the Test Director at his request of the Go/No go status of ARC facilities prior to the start of the Full Mission. The Simphonics recorder was started and logger was recycled by the Ghost at Payload's direction. Ghost provided an advisory to AFRC that the recorder had started and the loggers had been cycled.

11.6 Mission Procedure

At mission start, AFRC had established the ownship in holding at waypoint ALPHA at mission altitude to allow the transfer of the aircraft from the pilot under test to SPUT at the AFRC VSCS. The SPUT operating the ownship checked in with the Controller. The Controller issued a clearance for the Full Mission route and the mission began.

The controller managed traffic in accordance with the procedures outlined in FAA JO 7110.65, Air Traffic Control, Standard Operating Procedures for ZOA-40/41, and the contingency procedures for Full Mission flights. AFRC managed routes and contingency plans by communicating instructions to the Ghost. The Ghost then advised the Controller of the required clearance. Ghost monitored the progress of the ownship and provided recommendations to the TD on routing to ensure that encounters or researcher's ad hoc requests could be met effectively. Airspace availability dynamically determined if the test was to be conducted in the Full Mission Route or one of the two smaller routes, Mercury Spin or Four Corners.

Ghost Support vectored simulated VFR traffic, with callsigns TFC1 thru TFC5 (Figure 11), in real time around the ownship and its assigned route. At the start of the MACS scenario, TFC1 thru TFC5 were vectored towards the Full Mission Route and airspeed increased to arrive on or near the assigned route of the ownship in a timely manner. Aircraft speeds were reduced, when Ghost Support was satisfied the aircraft would be able to populate the VSCS display. TFC1 thru TFC5 were vectored to remain within the ownship's vicinity. The altitudes of one to two aircraft were adjusted to force and trigger a DAA alert, in which the subject pilot was instructed to monitor the intruder aircraft and maneuver was not necessary.

11.9 Streaming Procedure

Ghost Support accessed a web browser with access to the VIDS stream and verified VIDS functionality. Another machine would then be accessed for the VIDS configuration interface to verify the three streams from AFRC were active. All streams would be visually inspected for activity. Ghost would then inform AFRC that the streams were functioning properly.

11.10 ATC Procedures

ATC was working moderate levels of simulated traffic at Mission Start. Weather conditions within ZOA-40/41 were ceiling and visibility OK (CAVOK), clear sky with greater than 10 NM visibility. The ownship was on an IFR flight plan and the controller provided clearances and additional services in accordance with FAA JO 7110.65. The aircraft was handled using standard operating procedures for ZOA-40/41. ATC provided a clearance to the ownship onto the Full Mission Route. The Full Mission route had an extension which could be used by the Test Conductor or the research team to enhance the effectiveness of planned encounters. ATC would provide a clearance for this extension when requested. Airspace availability in the Mercury Spin and Four Corners areas of R-2515 determined required reroutes and ATC would clear the ownship to either Mercury Spin route or Four Corners route at the direction of the Ghost. Holding clearances to loiter fixes were provided to the ownship when additional time was required for researcher debriefing of the SPUT.

ATC did not issue traffic calls to the ownship during planned encounters until the ownship responded to a DAA alert and a maneuver was initiated.

The ownship responded to DAA alerts and guidance for the six intruders it encountered. The SPUT would request a maneuver for a corrective alert and the controller would clear the aircraft to deviate as requested. When responding to a warning alert, the SPUT would take action and inform the controller that action had been taken to avoid traffic. In every case the SPUT would request a clearance to return to current route following an encounter.

The Full Mission MACS scenario was designed to run up to four hours accommodate extended mission time. This required controllers and pseudo-pilots to provide position relief. The position relief briefings were performed in accordance with established procedures to maintain the integrity of the operation.

11.11 Data Collection Procedure

Ghost Pilot processed the audio recording output and consolidated it with the LVC Logger and MACS outputs. This collection was sent via NASA Large File Transfer to Payload at AFRC. The data was combined with data collected at AFRC and returned to ARC Ghost Pilot. Ghost Pilot placed the complete dataset into the UAS Data Archive.

12 Training

Training objectives focused on ensuring the confederates (controllers and pseudo-pilots) were knowledgeable about the UAS research under study for the Flight Test 6 Full Mission. They ensured each confederate was familiar with the materials, laboratory layout, and equipment used at ARC to conduct the simulation. Each air traffic controller and pseudo-pilot was expected to know the ATC procedures used for the Full Mission including startup procedures, contingency plans, and holding.

Virtual ATC training for FT6 Full Mission confederate was conducted over five days. The first day provided eight hours of classroom instruction. The second and third days consisted of sixteen hours of laboratory training including four three-hour simulated practice runs. Days four and five were scheduled as rehearsals with the full system under test and the ownship and intruders in flight.

The classroom instruction provided confederates with a series of briefings. The curriculum included the following:

- **Safety Briefing.** The Safety briefing informed the confederates of the requirements and information included in the FT6 Mishap Preparedness and Contingency Plan and the ARC N-243 Building Emergency Action Plan.
- **Project overview.** The Project Overview familiarized the confederates of the project research, and experiment goals and design. The characteristics of the live aircraft were discussed and DAA and radar field of view (FOV) were explained.
- **System layout.** Confederates learned how the laboratories and communications systems were configured. Support materials and their locations were reviewed.
- **Roles and responsibilities.** The confederate participants were informed of the roles and responsibilities of all of the players at AFRC and ARC. Emphasis was placed on how these positions interacted and how they were incorporated into the overall experiment.
- **FT6 procedures.** Confederates received information on the airspace environment including arrival and departure routes, traffic flow, and VFR operations. The transformation process and operations area for ZOA Sector 40/41 was detailed. Flight test procedures were taught explaining how flight test operations interacted with ATC and other members of the test environment. The confederates learned the simulation procedures and terminology specific to the flight test. A thorough explanation of nominal and contingency operations with the associated clearances and ATC procedures was provided. Pseudo-pilots were taught procedures for VFR interactions with ATC and flight operations near a temporary flight restriction.

The curriculum included training questions to ensure that confederates understood and retained the information being presented.

The main focus of hands-on MACS training was ensuring that the controllers' and pseudo-pilots' skill level provided quality of service comparable to the NAS environment in and around ZOA-40/41. During these practice runs, the pseudo-pilots had the opportunity to familiarize themselves with the scripts that supported the FT6 scenario. The scripts provided tasks the pseudo-pilots had to initiate or request at specific times during the simulation. These tasks

included checking in departures, requesting VFR flight following, and changing the altitude and/or routes of various aircraft throughout the simulation. The controllers applied and practiced the air traffic procedures in accordance with FAA JO 7110.65, Air Traffic Control and procedures specific to the Full Mission flights. Controllers issued clearances to the ownship for the Full Mission and contingency routes, startup procedures, and holding. Controllers also observed the ownship C2 failure (lost link) procedure. All confederates used these training runs to practice controller and pseudo-pilot relief briefings.

The Full Mission rehearsals provided all confederates from ARC and AFRC the opportunity to practice operations with the live aircraft flying in the Full Mission environment. Confederates worked the MACS traffic around the ownship and intruder aircraft. This training exposed the confederates to actual flight conditions and the expected length of typical flight operations. Confederates were able to apply the training they received and the practice the skills they learned in the classroom and simulated problems.

13 Verification and Validation (V&V)

IT&E conducted software verification and validation (V&V) tests to ensure functionality, performance, and data quality at the system and sub-system levels; and documented prior to software release. The test system consisted of the LVC gateway, LVC Logger/Player, SaaProc, ADRS, MACS, VSCS, SSA, and FPG sub-systems.

Tests and report documentation consisted of the:

1. Set of required test systems and sub-systems
2. Respective software tags/versions
3. Lab procedures used to perform the tests
4. Specific configurations
5. Verification test cases
6. Expected results
7. Actual observations
8. Output data log files generated
9. Analyses of performance, data quality, and supporting data plots
10. Test discrepancies

IT&E evaluated data captured from the output log files of the respective software applications. IT&E calculated and plotted system latencies and messages' update rates for the relevant message types published and subscribed by the sub-systems. IT&E analyzed sub-systems' performance and data quality by generating plots of the relevant state attributes' data published and subscribed to by the sub-systems. Sub-systems were evaluated as either pass or fail using the observed results, input from SMEs and research teams, in conjunction with the data analyses as criteria. For tests cases which were evaluated as having failed, a detailed description of the incorrect behavior was made for observations. Upon address of the bug, the V&V testing process was repeated. For tests cases which were evaluated as having passed, the software was released.

14 Schedules

The following schedule (Table 5) provides a summary of inclusive dates for software development, integration, system check-outs, radar characterization verification and validation activities, shakedown, training/rehearsal and data collection dates for Flight Test 6:

Table 5: Development Schedule

<u>Dates</u>	<u>Activity</u>
14 Sep 2018 – 13 Jun 2019	Systems Integration and V&V Activities
1 Oct 2018 – 20 July 2019	Software Development
24 Jun 2019 – 27 Jun 2019	Shakedown
9 Jul 2019 – 16 Oct 2019	System Check Out Flights
30 Sep 2019 – 9 Oct 2019	Scripted Encounter Flights (Data Collection)
21 Oct 2019 – 23 Oct 2019	ATC/Pseudo Pilot Training
24 Oct 2019 – 29 Oct 2019	Full Mission Flights (Rehearsals)
31 Oct 2019 – 21 Nov 2019	Full Mission Flights (Data Collection)
2 Dec 2019 – 31 Jan 2020	Data Analysis
28 Feb 2019	Results Dissemination

The flight test mission timeline (Table 6) was applicable during the data collection period. The schedule provided ample time for pre-flight briefings to prepare flight crews and the test teams for the missions. Post flight briefings evaluated the strengths and areas for improvement for the flight test. SPUTs received a briefing and hands-on training to practice procedures specific to flying the UA with the VSCS. Adequate flight time ensured that encounters were captured and researchers had time to gather data from the SPUT between encounters.

Table 6: Mission Timeline

<u>Time of Day</u>	<u>Activity</u>
<u>Day Prior to Flight Test</u>	
1200	T-1 Briefing (detailed flight briefing for all participants; Full Mission Subject Pilot training)
1700	Crew Rest Starts
<u>Flight Test Day</u>	
0500	T-0 Briefing (pre-flight review of T-1 briefing with changes)
0530	System preparation and startup
0630	Ownship takeoff

0650	Intruder takeoff
0700	Mission execution
0900	Aircraft return to base
0930	Aircraft land
1200	Post-flight Briefing (review of mission, lessons learned, issues, future planning)
1700	End of Test Day

15 Data Management

AFRC IT&E was responsible for data collection and storage for the FT6 experiment. ARC IT&E supported the AFRC effort by recording and providing data in accordance with the *UAS-NAS ITE FT6 Data Management Plan (DMP), ITE-DMP-01*. ARC Data sources included the LVC Gateway, Data Logger, and Simphonics Voice Recordings. MACS output files were forwarded on request.

Systems that recorded FT6 data used their own file naming conventions and preset schemes for automatically naming files. To ensure proper ordering of the experiment data, the recorded files were deposited into predefined folders with a directory structure delineated and named by data source then by date. These files were gathered immediately following the conclusion of flight operations for the day. The data files were compressed and forwarded to AFRC IT&E via Large File Transfer. AFRC then transferred ARC data to a central data repository. Local data collection procedures are documented as part of the UAS in the NAS Flight Test 6 Procedures for ARC, version 2.2.

16 Results

This report focuses on the functionality of the system and not the results of the research itself. Technical results will be provided by the HSI researchers and reported separately after data analysis has been completed.

16.1 Confederate ATC Feedback

The two air traffic controllers felt that the overall performance of the SPUT was satisfactory. The SPUTs responded appropriately to the various encounters they faced. Neither controller identified performance issues requiring correction or further training. All participants used standard phraseology or phraseology designed for operations on Full Mission or contingency tracks. No issues regarding phraseology were identified.

Both controllers agreed that the DAA must allow time for the pilot to coordinate maneuvers against non-cooperative aircraft with ATC before effecting a change of route. The controllers require knowledge of an instrument flight rules (IFR) aircraft's intentions to ensure positive separation from airspace boundaries and other aircraft.

The controllers and pseudo-pilots both felt that the airspace design and traffic within ZOA-40/41 was realistic. The pseudo-pilots indicated that scheduled position relief allowed them to maintain high performance during two-hour plus flights. All participants felt the training they received prepared them adequately for the Full Mission flight tests.

16.2 Lessons Learned

Through all phases of planning and flight for FT6, twenty-eight lessons learned items identified by the ARC IT&E team were gathered and recommendations have been made. Some of the main lessons learned are described below. For a full list of the lessons learned, refer to *Appendix C: Lessons Learned*.

16.2.1 Subject Pilot Recruitment

A complete list of requirements for the SPUT was not forwarded to the recruiting agency. Requirement from the AFRC pilot came very late requiring additional documentation to meet AFRC directives for flying the UAS from the RCGS.

Recommendation: Gather all requirements for Subject Pilots from research teams, IT&E, and associated stakeholders at the outset of the project. Forward these requirements to the recruiting agency at the earliest point possible. Forward any changes to requirements as they occur.

16.2.2 Software Assurance Process

Software integrity assurance was compromised when established testing and release procedures in accordance with the UAS-in-the-NAS SDMP were not followed. SaaProc software sent directly from ARC to AFRC without completing the V&V process. Installed software resulted in incomplete data output. The incident occurred during a rehearsal test run, therefore did not impact the formal data collection process.

Recommendation: Sign off by the technical leads to facilitate software delivery and acceptance. Ensure that the CCB process is completed for any change to software prior to installation. Ensure that software at both centers remain in sync throughout testing.

16.2.3 Evacuation Procedures

A fire alarm required evacuation of both the DSRL and the SDL during a Full Mission flight. A quick determination was required to route the ownship to a holding point until participants could reenter the building and get the simulation up to date for further testing.

Recommendation: An evacuation of facilities should be anticipated as a possibility and procedures for determining the disposition of the ownship planned in advance.

16.2.4 Pilot Reports (PIREP) Requirements

PIREP information received from the intruder aircraft indicated that actual winds aloft sometimes varied significantly from forecasted wind conditions causing the ownship to adjust its heading to fly the assigned route of flight. This impacted radar data collection as the radar parameters shifted with the actual heading of the aircraft. MACS weather information required updating to ensure that MACS traffic performed in a manner consistent with the ownship.

Recommendation: Require regular PIREPS from the intruder aircraft. Information received should be forwarded for updates to the MACS. The information should also be logged to provide research teams information on the impact of winds on flight data.

16.2.5 Loss of Target Data

During development of the LVC environments at ARC and AFRC, loss of target data was experienced at both centers on sub-components of the systems. Changes to some of the components in the system impacted data flow. Confusion about how the data feeds were flowing created the problem. These issues resulted in several changes to the configuration of the LVC Client.

Recommendation: Early communication between ARC and AFRC about the expected data flow should occur at the start of LVC development. Subsequent development, which impacts the planned data flow, should be vetted as it occurs and changes to the LVC Client should be made and tested in real time. Requirements for specific testing, such as Scripted Encounters vs. Full Mission, should be addressed separately.

16.2.6 Loss of Ownship and Intruder Target displays on MACS

During Full Mission flights, the MACS intruder target often disappeared from the MACS presentation. The same issue occurred with the ownship but much less frequently. A review of the LVC logger files indicated that ACDelete messages were transmitted for the aircraft during the flight. This problem was unable to be corrected without a restart of the MACS and ADRS subsystems.

Recommendation: Identify the source of the ACDelete messages and prevent transmission. Workaround using alternate presentation (AFRC VSCS display) allowed for continuous testing without a system restart.

16.2.7 Variance between VSCS and Piccolo Fix Numbering System

The differences between the Piccolo and VSCS numbering systems created confusion for the PUT during SCO flights testing the Full Mission flight plan. Controllers during testing had a

different display of waypoints based on VSCS waypoints developed at ARC. This resulted in an unexpected maneuver by the ownship when the controller cleared the PUT to a specific waypoint and the aircraft proceeded to a waypoint with the same number assignment in Piccolo during Full Mission flights,

Recommendation: Correlate VSCS waypoints with the Piccolo fixes for the flight. Use the VSCS fixes for the flight to identify waypoints and fixes.

16.2.8 Four Corners Route Extension

The Four Corners contingency route was shown to be too short to accommodate encounters and allow for adequate debriefing time for the research team. This track was further impacted by the intermittent loss of command and control signal in the vicinity of WPT7.

Recommendation: The Four Corners Extension was created to extend the length of the Four Corners route allowing sufficient time to complete encounters. This extension also benefited the Full Mission route when UA or intruder maneuvers caused encounter near WPT4.

16.2.9 Requirements Gathering Process

Requirements gathering has always been challenging across technical teams and throughout various activities. A universal template, process, or procedure has not been implemented to maintain consistency of how requirements are gathered, transmitted, and documented for verification and validation. Requirements are relayed in many forms and are sometimes assumed to be delivered. Traceability of requirements, from source to V&V procedure can be much improved. Requirements by PowerPoint or delivered verbally are not appropriate and suitable, requirements are delivered to too many points of contact (POC are not identified or requirements are not going through POC).

Recommendation: Recommend Project Office develop a Requirements Gathering framework and set the tone for all subproject to follow. Developed a standardize form (i.e. source of requirements, requirements description, receiver of task, related activities, V&V/test procedure, success criteria, priority, completion date). The requirements format shall be applicable across Centers, project, and sub-team. (The concept is to have a consistent format throughout the teams.) Identify and broadcast the requirements POC to all team. Train everyone on how to initiate, write a 'good' requirement, and submit a requirements ticket for any activities, to the appropriate POC at any team and Centers. Provide a system for all team members to search and obtain the status of any relevant requirements.

16.2.10 Backup System Testing

The ISA between AFRC and ARC established the primary and backup servers that established the LVC environment between the DSRL at ARC and the LVC laboratory at AFRC. uasgw4 replaced uasgw3 in a single session during integration testing of the full LVC environment with

ARC and AFRC. However, due to the robustness of the primary system, a complete test of possible combinations of the primary and backup hardware was not initiated.

Recommendation: Incorporate testing of the backup systems into the test schedules for the LVC environments and SCO flights to ensure connectivity and proper configuration of the backup systems. Develop procedures for switching to back up system(s) during flight.

16.3 Overall Performance

All data was successfully collected.

The LVC components, the SaaProc, VSCS, Simphonics, and Plexsys all performed at high fidelity.

Interactions between ATC, simulated aircraft, the VSCS ownship and traffic performed as expected.

Appendix A: Flight Test 6 Operational Procedures for Ames IT&E

Presented in this appendix are the procedures developed and used by the ARC IT&E team to start, operate, and conduct test during the FT6 test. Topics include:

1. Laboratory Setup
2. Communication Setup
3. Software Application Descriptions
4. Laboratory Set-up and Shutdown Sequence
5. FT6 Startup Procedures
6. Shut Down Procedures
7. Data Transfer Procedures

UAS in the NAS Flight Test 6 Procedures for ARC VERSION 2.2 AS OF 10/4/2019

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1.0 Laboratory Setup

The Live Virtual Constructive Distributed Environment (LVC-DE) for the UAS in the NAS Flight Test 6 (FT6) will use live aircraft to allow research teams to assess the Detect and Avoid capabilities of an UAV equipped sensors found on an aircraft of low size, weight, and power (SWaP).

This document addresses the systems that will be used at Ames Research Center (ARC) and establishes the procedures for preparing and participating in the Flight Test. LVC systems in use at the NASA Armstrong Flight Research Center (AFRC) for Flight Test 6 are not included in this document.

The major sub-systems that comprise the LVC-DE infrastructure at the NASA Ames Research Center support the overall LVC environment at ARC and AFRC. These systems will facilitate the data collection of audio and MACS data. The Distributed Systems Research Laboratory (DSRL) in Building N-243, room 240 will facilitate video streaming to the HAT laboratory. The Vigilant Sprit Control Station (VSCS), located in DSRL, will operate in “external” configuration and provide a Ground Control Station (GCS) traffic display at ARC.

Background traffic during the Full Mission Simulation will be provided by the Multi-Aircraft Control System (MACS) constructive traffic generator. MACS is configured to emulate Air Traffic Control (ATC) at Oakland Air Route Traffic Control Center Sector 40/41 (ZOA- 40/41). Background traffic consists of cooperative and non-cooperative aircraft. The Controller, Observer, and Simulation Manager/Ghost positions are located in the DSRL. The associated pseudo-pilot positions, ghost pilot position, and an additional observer position will be located in the Software Development Laboratory (SDL) in building N-243. The simulation and specific aircraft within the scenario will be managed by the Simulation Manager. DAA messages and alerts will be provided by the SaaProc, which contains the JADEM and Daedalus algorithms. The messages and those providing position updates for the manned and unmanned aircraft will be routed to the appropriate sub-processes via the LVC Gateway and ADRS processes. The DAA outputs at ARC will be used for local VSCS displays in the DSRL.

Figures 1 and 2 shows a representation of the configurations used to support FT6.

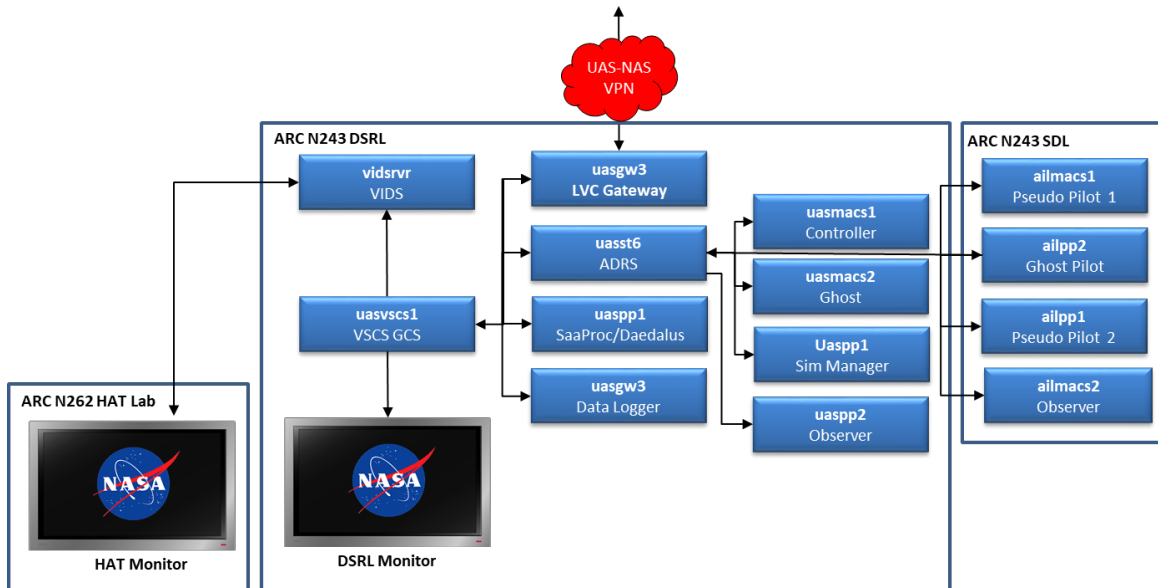


Figure 1: FT6 Full Mission Layout

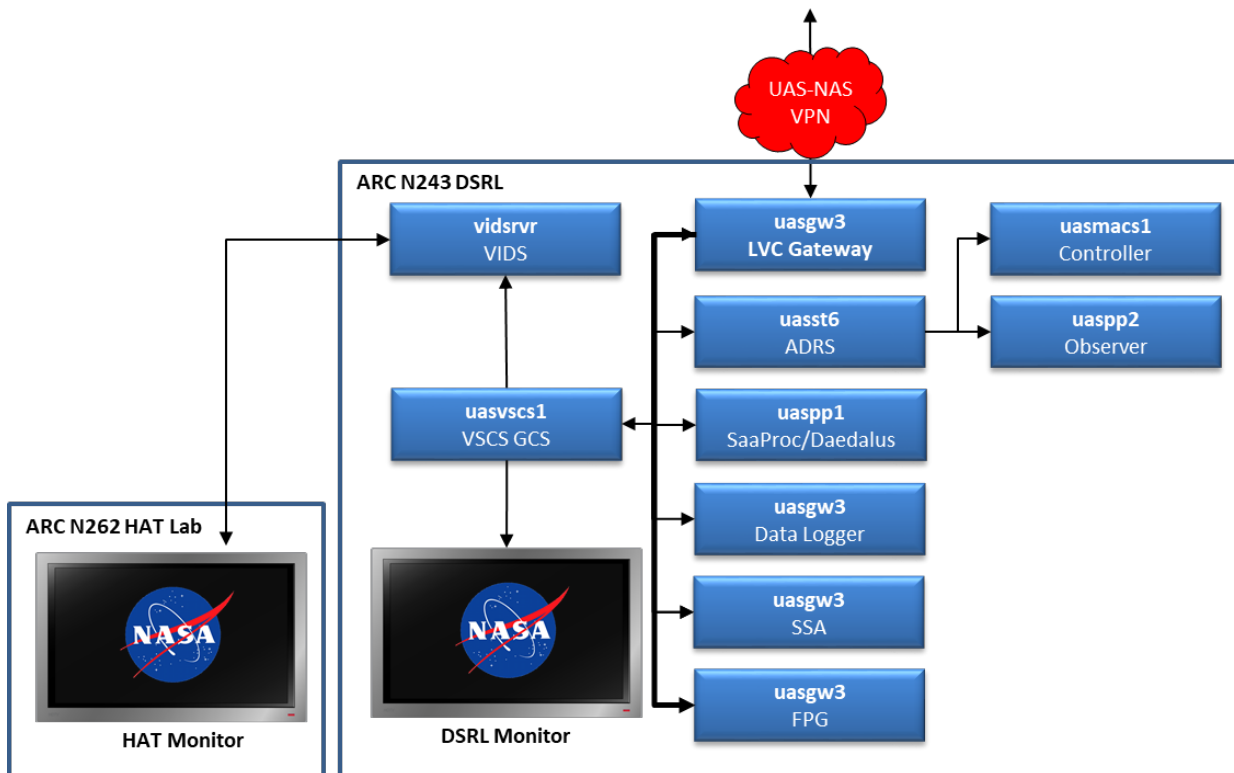


Figure 2: FT6 Scripted Encounter Layout

2.0 Communication Setup

Communications between laboratories use a combination of Simphonics, located in the ATC laboratory in CVSRF, and Plexsys, located in the DSRL in N243, HAT Laboratory in N-262, and AFRC. ARC and AFRC are linked via VPN using LVC gateways located at each site. HAT Laboratory communications are routed between gateways in the ATC Laboratory and the HAT Laboratory. The Roselli Tunneler provides a conduit for communication between the gateways connecting DSRL and AFRC and the ATC Laboratory and the HAT Laboratory.

The system operates on five communications networks with a spare network held in reserve. The Virtual ATC network uses frequency 125.85, which emulates Air to Ground (A/G) communications between the VSCS pilot, the ZOA 40/41 pseudo-pilots, and the ZOA Sector 40/41 air traffic controller. The Ghost network on frequency 132.2 facilitates communication between the Simulation Manager, Ghost Pilot, AFRC LVC engineering, Test Conductor, and researchers. The engineering net on frequency 126.6 provides a conduit for the technicians to communicate repair issues. The frequency 120.55 acts the researcher net and provides communication between the research team, Ghost Sim Manager, and the test director. The Test Conductor network, frequency 120.0, connects the Test Conductor with the Ghost/Sim Manager, Test Director, and the AFRC Engineering team. Connectivity for the primary networks are shown in Figure 3.

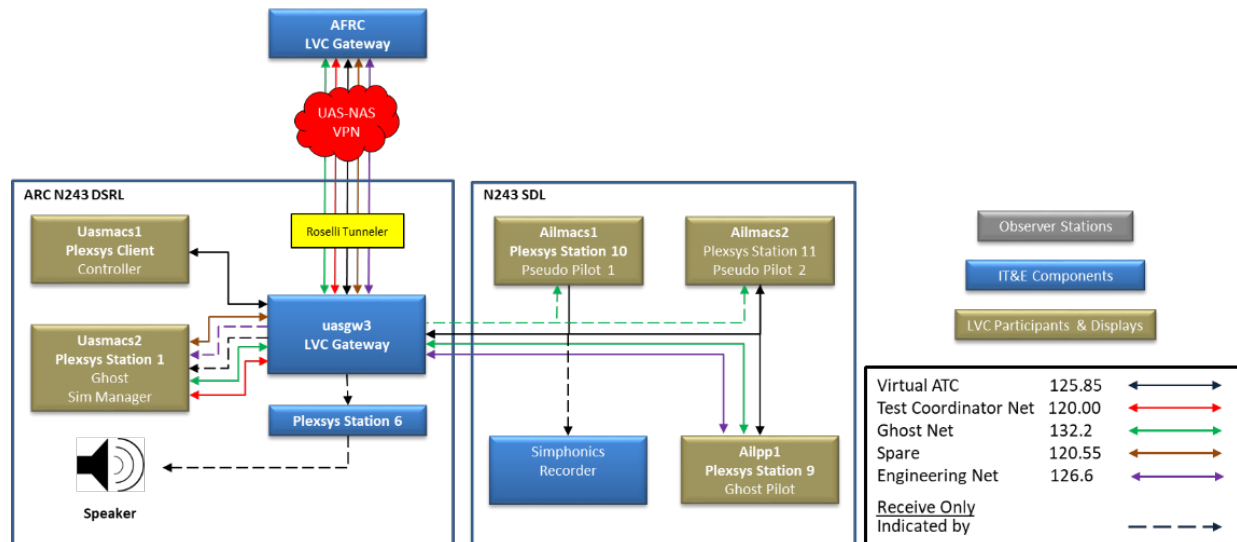


Figure 3: FT6 ARC Communication Layout

3.0 Software Application Descriptions

Listed in Tabel 1 are the various application that was used to support the system under test and as described in Figures 1 and 2.

Table 1: Software Application List

Application	Description	Version	Type	Laboratory	Location
Aeronautical Data Link and Radar Simulator (ADRS)	Central communications process that enables data transfer between all MACS stations and other external components.	ADRS-082514-042815-A	Linux	DSRL	uasgw3
LVC Gateway	Communications hub for message processing between components of the LVC/DE	v.0.1.19_20180308_R2	Linux	DSRL	uasgw3
LVC Logger	Records message data processed by the LVC Gateway and creates a log file for data collection	v.0.1.19_20180308_R2	Linux	DSRL	uasgw3
Multi Aircraft Control System (MACS)	High fidelity environment for conducting real time controller and pilot simulations	MACS-AOL-2015-TOM	Windows	DSRL/SDL	uasmacs2 uasmacs1 uaspp1 uaspp2 ailmacs1 ailmacs2 ailpp1 ailpp2
Plexsys Sonomarc	Voice over Ip system for ATC communications	v2.3.0.206 (T3 Stations) v3.5.0.31 (soft clients)	Windows	DSRL/SDL	Station 6 Station 9 Station 10 Station 11 Station 12 uasmacs1 (Entity 5)
SaaProc (JADEM/Daedalus)	Processes information of aircraft in the vicinity of the ownship for DAA threats and generates alert messages to subscribers.	v9.0.1 (with JADEM v9.0.0 & Daidalus v2E [with hotfix])	Windows	DSRL	uaspp1
Sensor Surveillance Adapter (SSA)	Translates LVC messages to/from TrackState to/from MPIFlightState	v.0.1.19_20180308_R2	Linux	DSRL	uasgw3
Flight Plan Generator (FPG)	Initiates a MPIFlightPlan for aircraft lacking a flightplan for MACS propagation.	FPG 2.0	Linux	DSRL	uasgw3
Simphonics	Voice over Ip system for recording ATC communications	v4.1.106.0	Windows	DSRL	SMPC201691(Recorder) SMPC201685(Receiver)
Voice Tunneler (AMES VPN)	Ip tunnel which connects and enables audio transmission by users of Plexsys Sonomarc and Simphonics	NickRoselli_20130830	Linux	DSRL/AFRC	uasgw4
VSCS Control Station	Virtual Ground Control Station (GCS) for the ownships	v2018.2.2.902	Windows	DSRL	uasvscs2
Video Ingest and Distribution System (VIDS)	Web based realtime video streaming and capture solution	v03.2016.06.07	Windows	DSRL	uasvsvr

4.0 Laboratory Set-up and Shutdown Sequence

Pre-start Procedures

1. Check Memory Utilization

- a. Check and report Memory and CPU usage to the Simulation Manager.

Position	Full Mission	Scripted Encounters
DSRL		
uasvscs2	X	X
uasmacs1	X	X
uasmacs2	X	X
uaspp1	X	X
uaspp2	X	X
SDL		
ailmacs1	X	
ailmacs2	X	
ailpp1	X	
ailpp2	X	

- b. Reboot any systems of concern.
- c. Continue to monitor during test and report as needed/requested.

Note: Acceptable values for operations are ± 20 milliseconds.

2. Start Voice Communication

- a. Start tunneler as client @ host: uasgw3
- b. `cd vast/users/uas/voice_tunneller/FromNickRoselli_20130830`
- c. Execute StartClient_ToDryden.bat
- d. Script contents: `java -jar routingpoint.jar -r host_IPaddress:13123 -I 234.5.6.210:3001 -o 234.5.6.210:3001 -t 5`
- e. Report: Tunneler Client Running

3. Perform communication checks

- a. Ghost/Simulation Manager check each frequency with the DSRL and the SDL.
- b. Test Conductor check each frequency with Ghost.

Table 2: FT6 Radio Frequency (Simulated MHz) Channels

Positions	Simulated Channels (MHz)
A/G ZOA 40/41 (Virtual ATC)	125.85
Engineering Net	126.6

Ghost Net	132.2
Spare	120.55
Test Conductor Net	120.0

4. Software Verification

- a. Verify the software conforms to the configuration identified in Table 1 (Software Application List).
- b. Report software verification complete

5. Perform Time Test

- a. Run Strip charts on all Windows desktops.

Position	Full Mission	Scripted Encounters
DSRL		
uasvscs2	X	X
uasmacs1	X	X
uasmacs2	X	X
uaspp1	X	X
uaspp2	X	X
SDL		
ailmacs1	X	
ailmacs2	X	
ailpp1	X	
ailpp2	X	

- b. Double click on the “strip chart” shortcut on the desktop.
- c. Run timesvr on uasgw3 (Tquery):
 - i. `cd /vast/users/uas/tquery_files/`
 - ii. `./timesvr`
 Executable: timesvr
 Report “Server Running”

Note: Acceptable values for operations are ± 20 milliseconds.

6. Configure Simphonics

- a. Check Simphonics file vne.V+ Run Time System for a “heartbeat”.
- b. At the Simphonics computer, select “Record/Playback”.
- c. Select the FT6 UAS project from the pull-down menu.
- d. Verify settings.
 - i. Station: DSRL EOS
 - ii. Device Name: DSRL EOS
 - iii. Rx: 1

- iv. Tx: 1
- v. Freq: 125.85
- vi. File: DSRL EOS 1-125.85-rxtx

7. ***Start Video Ingest and Distribution System (VIDS)***

- a. Using remote control turn on center display located on wall.
- b. Verify viewer 1 desktop is depicted on overhead display.
Note: If desktop 1 is not displayed, follow the video switch procedures (cheat sheet) to bring up the display.
- c. On a kvm station, enter “Ctrl ~” and select #14 uasvsvr.
- d. Press “Esc” to close window.
- e. Launch VIDS controller on desktop.
- f. Verify AFRC is transmitting and we are receiving 3 streams.
 - i. AFRC_VSCS_OBS
 - ii. AFRC_PICOLLO_OBS
 - iii. AFRC_ZEUS_OBS
- g. If streams are not displayed, click the reload button. If streams still do not display, call AFRC to verify streaming.
- h. Enter “Ctrl ~” and select #15 uasviewer1.
- i. Press “Esc” to close window.
- j. Right click to open new Konsole.
- k. Type “firefox” and press “Enter”.
- l. Drag the Firefox browser off the left side of the kvm desktop and center the display on the center overhead screen.
- m. Select full screen.
- n. On the kvm, “Ctrl ~” back to #14 uasvsvr.
- o. Press “Esc” to close window.
- p. Verify all 3 streams are displayed.
 - i. On the VIDS interface, select “uasveiw1”.
 - ii. Select an AFRC stream.
 - iii. Verify the stream is displayed on the center overhead screen.
 - iv. Repeat steps p.i through p.iii for the remaining streams.
- q. Select the desired stream for display.

8. ***Load forecast winds into MACS (Full Mission Only)***

- a. 5 minutes prior to the hour, double click the PfeifferWx icon at uaspp2 to open Pfeiffer Weather Conversion folder.
*Path: Z:\uas\UAS_Sandboxes\FT6_Exp\macs.dir\
PfeifferWeatherConversion.*
- b. Open the Firefox browser at uaspp2.
- c. Click on RAP bookmark.
http://www.meteo.psu.edu/bufkit/data/RAP/##/rap_edw.buf
- d. Replace the “##” in the internet address with the hour (UTC) for the required forecast and press “Enter” on the keyboard.
- e. Copy the first full data set on the page.

Note: Repeat Step 6 once each hour for the duration of the Full Mission flight.

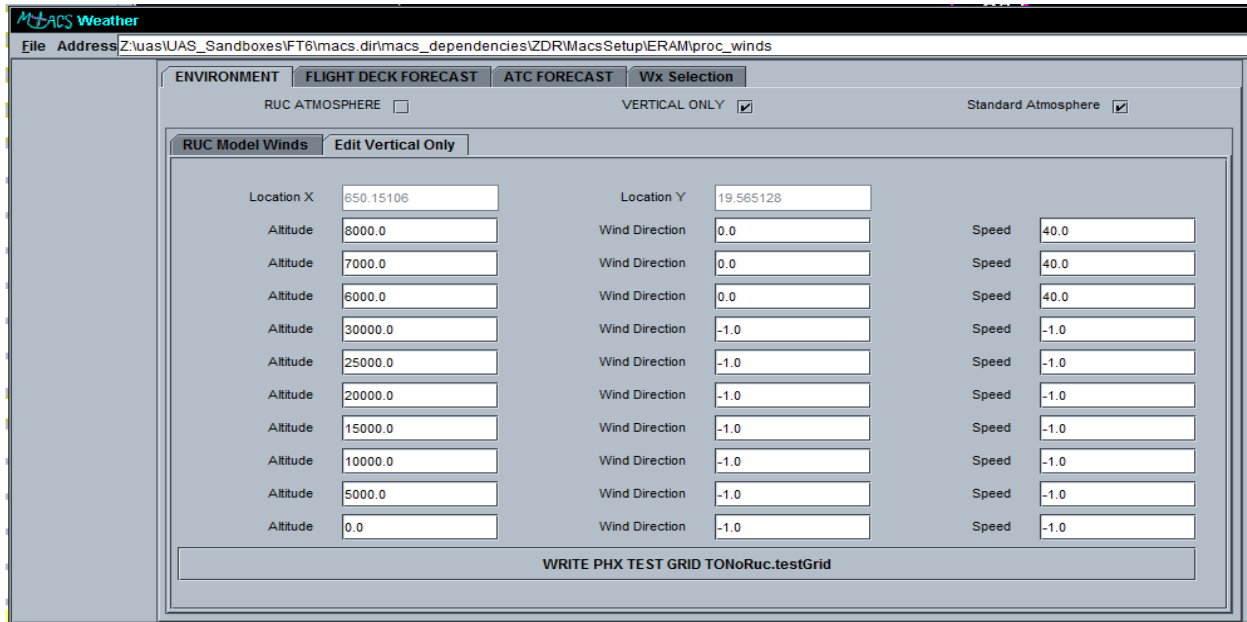


Figure 5: MACS Weather Panel

5.0 FT6 Startup Procedures

Flight Test 6 Configurations:

Configuration 1: Scripted Encounters (SE)

Configuration 2: Full Mission (FM)

1. ***Ping test uasgw3 to gateway4 @ uasgw3***
 - a. Type “ping [gateway4 ip address]”
 - b. Observe return messages.
 - c. CTRL-C
 - d. Verify 0% loss.

2. ***LVC Gateway @ uasgw3***
 - a. `cd \vast\users\uas\UAS_Sandboxes\FT6_Exp\lvc\lvc_gw\uasnas_gateway\scripts`
 - b. (*Scripted Encounters*) `./run_uasnas_gateway.bash -f FT6_AFRC_GW4_TO_GW3_CLIENT_TRACK.xml -v 1`
 - c. (*Full Mission*) `./run_uasnas_gateway.bash -f FT6_AFRC_GW4_TO_GW3_CLIENT_ALL.xml -v 1`

3. ***Launch LVC Gateway Data Logger @ uasgw3***
 - a. `cd \vast\users\uas\UAS_Sandboxes\FT6_Exp\lvc\lvc_gw\LvcPlayer\scripts\`
 - b. `./run_lvc_gwLogger.bash -f gwlogger_v19_R2_config@LOCALHOST.xml -v 1`
 - c. Verify Logger connection to the LVC Gateway @ uasgw3.

4. ***Launch ADRS from host: uasst6***
 - a. `cd \vast\users\uas\UAS_Sandboxes\FT6_Exp\macs.dir\ctas\software\realtime_procs\ aero_dlnk_radar_str`
 - b. `./adrs -data ZOA_NASA`

5. ***Launch MACS Stations***
 - a. Shortcut method
 1. On the station desktop, double click on the shortcut icon.
 - b. Manual method
 1. Open MacsStart folder. (See Table 3)
`\vast\users\uas\UAS_Sandboxes\FT6_Exp\ macs.dir\macsdependencies\ZDR\MacsStart\`
 - c. Double click on the desired bat file.
 - d. Verify “Connected” is displayed on the title bar of the window.

Table 3: MACS Stations

<u>Station</u>	<u>Shortcut</u>	<u>.bat File</u>	<u>Scripted Encounters</u>	<u>Full Mission</u>
DSRL				
uasmacs1	Controller	controller.bat		X
uasmacs2	Ghost	ghost.bat	X	X
uaspp1	Sim Manager	simman.bat		X
uaspp2	Observer	observer.bat	X	X
SDL				
ailmacs1	Pilot 1	pilot.bat		X
ailpp1	Pilot 2	pilot2.bat		X
ailpp2	Ghost Pilot	gpilot.bat		X
ailmacs2	Observer	observer.bat		X

6. Load the MACS scenario in Sim Manager. (Full Mission Only)

7. Launch SaaProc @ uaspp1

- a. Shortcut method
 - i. On the station desktop, double click on the “FT6 SaaProc” icon.
- b. Manual method
 - i. Open Z:\sers\uas\UAS_Sandboxes\FT6_Exp\SaaProc\SaaProc v9.0.1
 - ii. Double click “runSaaProc.bat”
 - iii. Click “Start” button on the SaaProc.
- c. Configure the SaaProc GUI.
 - i. Set Subject Number.
 - ii. Set Trial Number to “1”
 - iii. Select Algorithm Configuration as specified by Flight Card.
 - a. FT6_ADSB_3.5.xml
 - b. FT6_ADSB_3.0.xml
 - c. FT6_ADSB_2.5.xml
 - d. FT6_ADSB_2.0.xml
 - iv. Verify Processor Configuration
 - a. FT6_ADSB_GW3_noise.cfg
 - v. Set Jadem Co-Altitude Parameters (Full Mission Only)

Intruder Callsign	Vertical Offset (ft)
NON-COOP	-500
<ADS-B Intruder Callsign>	-500

- vi. Verify Cooperative Toggles for the intruder aircraft is unchecked. (Full Mission Only)
Note: If the intruder encounter is cooperative check the aircraft's toggle and click the update button.
- vii. Verify Gateway ip address = [host_IPaddress]
- viii. Verify the Ownship Callsign is "TIGER50"
- d. Verify connections on Gateway at uasgw3.
- e. Verify ownship check-in.

8. Launch Sensor Surveillance Adapter (SSA) @ uasgw3 (Scripted Encounters Only)

- a. cd
`\vast\users\uas\UAS_Sandboxes\FT6_Exp\lvc\lvc_gw\SensorSurveillanceAdapter\scripts`
- b. `./run_SensorSurveillanceAdapter.bash -f SSA_FT6_TIGER50@LOCALHOST.xml -v 0`
- c. Verify SSA connection to the LVC Gateway @ uasgw3.

9. Launch Flight Plan Generator (FPG) @ uasgw3 (Scripted Encounters Only)

- a. cd `\vast\users\uas\UAS_Sandboxes\FT6_Exp\lvc\lvc_gw\FPG.2.0`
- b. `./FPG -p 7877 -h uasgw3 -o TIGER50`
- c. Verify FPG connection to the LVC Gateway @ uasgw3.

10. Launch VSCS Control Station @ uasvscs2

- a. Double click the "VS Ground Station" icon.
- b. Verify Network File = NASA Ames – FT6_TIGER50_external.vsxml.
- c. Set CS ID to "UASGS1".
- d. Verify "Restore Settings from Cloud" is unchecked.
- e. Verify Role = Core:\Projects\NASA\FT6\RoleIndependentGS1\Role1
- f. Verify Layout = 1 Monitor, TSD Only
- g. Click Launch
- h. Verify connections on the gateway at uasgw3.

11. Start the scenario. (Full Mission Only)

- a. When directed by the Test Conductor, Ghost controller shall:
 - i. Advise "All stations, scenario start in 3, 2, 1, start." Start scenario at "Start".
 - ii. Verify MACS traffic displayed at all MACS stations and advise "Traffic displayed".
 - iii. Verify ownship is displayed at the Controller scope and advise "Ownship displayed".

12. Start Simphonics recorder. (Full Mission Only)

- a. AFRC LVC request Ghost Controller to “Advise ready to record”.
- b. Ghost Controller:
 - i. On the Simphonics Record/Playback page
 - 1. Enter the Session: YYYYMMDD.
 - 2. Click “Continue”.
 - 3. Click “Disable Host Control”.
 - ii. Advise “Ready to record”.
- c. AFRC LVC advise all stations, “Start recorders in 5, 4, 3, 2, 1 Start”.
- d. Ghost Controller start Simphonics recorder and advise “Simphonics recorder started”.

13. *Cycle LVC Data Logger.*

- a. AFRC LVC advise all stations “Cycles Loggers”.
- b. Ghost Controller stop the LVC Data Logger and initiate an immediate restart using step 2 above.
- c. Ghost controller advise “Logger cycled”.

6.0 Shut Down Procedures

- 1. Stop the MACS simulations.*
- 2. Shutdown recorders*
- 3. Shutdown the Vigilant Spirit GCS.*
- 4. Shutdown SaaProc by pressing the shutdown buttons.*
- 5. Shutdown the SSA using CTRL C.*
- 6. Shutdown the FPG using CTRL C.*
- 7. Shutdown ADRS at uasst6 and atc-proxy using CTRL C.*
- 8. Shutdown the Data Logger using CTRL C.*
- 9. Shutdown the LVC Gateway using CNTL C.*
- 10. Shutdown MACS in the DSRL and ATC Lab by clicking the “X” on the MACS window.
(@ end of day only)*
- 11. Shutdown VIDS.*
 - a. CTRL C Konsole on uasveiw1.*
 - b. Ensure AFRC is no longer sending streams.*
 - c. Close VIDS controller window.*

7.0 Data Transfer Procedures

1. Copy LVC data to a portable device or single location on vastasvr1

- a. Locate the LVC Gateway logs under
`\vast\users\uas\UAS_Sandboxes\FT6_Exp\lvc\lvc_gw\uasnas_gateway\logs`
- b. Locate the LVC Logger logs under
`\vast\users\uas\UAS_Sandboxes\FT6_Exp\lvc\lvc_gw\LvcPlayer\logs`
- c. Locate the LVC Logger output under
`\vast\users\uas\UAS_Sandboxes\FT6_Exp\lvc\lvc_gw\LvcPlayer\output`
- d. Locate the LVC SSA logs under
`\vast\users\uas\UAS_Sandboxes\FT6_Exp\lvc\lvc_gw\
SensorSurveillanceAdapter\logs`

2. Process and copy Voice data to a portable device or single location on vastasvr1

- a. Open windows explorer and go to E:\WAVEFILERECDPLAYBACK.
- b. Locate the desired folders(s) to be processed and move (do NOT copy) the folders to C:\Audio_Processing
- c. At the Start menu, select run, then type "cmd".
- d. Press "Enter".
- e. Use the command "rename_and_parse.bat staging".
- f. Move the folders from C:\Audio_Processing and return them to E:\WAVEFILERECDPLAYBACK.
- g. Copy the data to the portable device or vastasvr1 location used in step 1

3. Transfer the data to Armstrong

- a. Take the portable media used in the previous steps to a computer with internet access, or locate a computer with internet access and vastasvr1 mapped.
- b. Compress the consolidated data via preferred means.
- c. Use NASA Large File Transfer
<https://transfer.ndc.nasa.gov/courier/web/1000@/wmLogin.html> to send the compressed file to Victor Loera at Armstrong.

Appendix B: Air Traffic Control Clearances

This section gives a description of the Air Traffic Control phraseology used during the flight test conditions.

FT6 Air Traffic Control Ownship Clearances

The phraseology below was designed to promote clear understand between Air Traffic Control and the Subject Pilot under Test (SPUT) during Flight Test 6 Full Mission Flights. The clearances are based on standardized phraseology established by FAA JO 7110.65, Air Traffic Control. The clearances communicate ATC directions for Mission Start, contingency routes, the Four Corners Extension, and holding. SPUT transmissions are in depicted in *italicized RED text*; Controller transmissions are in **bold BLUE text**.

Mission Start Procedure/Clearance to Full Mission Route

“Oakland Center, TIGER five-zero, holding at ALPHA, level eight thousand, request clearance via Full Mission Route.”

TIGER five-zero, Oakland Center, cleared direct waypoint 1, Full Mission Route, maintain eight thousand.”

TIGER five-zero, cleared direct waypoint 1, Full Mission Route, maintain eight thousand.”

Clearance via Four Corners Extension

TIGER five-zero, after waypoint 4, cleared via Four Corners Extension then continue via Full Mission route, maintain eight thousand.”

TIGER five-zero, after waypoint 4, cleared via Four Corners Extension then continue via Full Mission route, maintain eight thousand.”

Clearance via Four Corners Route

TIGER five-zero, cleared direct waypoint <waypoint #>, Four Corners Route, maintain eight thousand.”

TIGER five-zero, cleared direct waypoint <waypoint #>, Four Corners Route, maintain eight thousand.”

Clearance via Mercury Spin Route

TIGER five-zero, cleared direct waypoint <waypoint #>, Mercury Spin Route, maintain eight thousand.”

TIGER five-zero, cleared direct waypoint <waypoint #>, Mercury Spin Route, maintain eight thousand.”

Holding

Note: Holding patterns at the loiter points are not published. It is assumed that the holding procedure for the loiter points was part of the mission brief for the SPUT and is programed into the UAS. Proper phraseology for loiter point holding is “hold as briefed” rather than “hold as published” and eliminates the need for the controller to issue detailed holding instructions.

Clearance to Loiter Point for Constraints

TIGER five-zero, cleared direct <loiter point>, hold as briefed, maintain eight thousand, expect further clearance <time+<# of minutes>>, <nature of the constraint>.”

TIGER five-zero, cleared direct <loiter point>, hold as briefed, maintain eight thousand, expect further clearance <time+<# of minutes>>.”

Clearance to Loiter Point for Encounter Debrief

TIGER five-zero, cleared direct <loiter point>, hold as briefed, maintain eight thousand, advise when ready for further clearance.”

TIGER five-zero, cleared direct <loiter point>, hold as briefed, maintain eight thousand, will advise.”

Appendix C: Lessons Learned

Gathered in this sections are the lessons learn from the Ames’ IT&E team, at the conclusion of the Flight Test Series 6 activities. The Armstrong FT6 Flight Test report contain a more comprehensive lessons learned list that includes both the Ames and Armstrong specific information, like the test range, fight vehicle, and their facilities.⁴

The key to deciphering the table below is as follows:

Table C1: Lessons Learned Nomenclature Description

<u>Heading Name</u>	<u>Heading Descriptor</u>
Description	Describe the discrepancy, problem, or condition in detail.
Issue Rating / Impacted Facility	Is the rating a nice to have (desired) or a must have (required)? And identifies the laboratory which will be impacted by this issue.
Impacted System or Process	Describe the applicable system or process that may be impacted by this issue.
Lesson Type / Lessons Learned	
<u>Lessons Learned Descriptor</u>	
Mitigation / Recommendation	What is the remedy?
Experience	Practicle knowledge, skill, or practice derived by direct observation of or participation in events or a particular activity.
Process Improvement	Proactive task of identifying, analyzing, and requiring change to an existing practice.
Training	A process by which someone is taught skills that are needed to complete a task.

⁴ AFRC Flight Test Series 6 Test Report, ITE-FT6-FTR-001, February 2020

Table C2: Lessons Learned from Supporting the FT6 Activities

<u>Title</u>	<u>Issue Description</u>	<u>Issue Rating / Impacted Facility</u>	<u>Impacted System or Process</u>	<u>Lesson Type: Lessons Learned</u>
Subject Pilot Recruitment	Requirements for SPUT were incomplete. Pilot Office SPUT requirements for RCGS flight of Tiger Shark aircraft were not forwarded.	Required; N/A	Recruitment	Process Improvement; Verify/review recruiting requirements with the customer to include the possibility of live flight.
Software Assurance Process Violation	Software integrity assurance was compromised when established testing and release procedures IAW the UAS-in-the-NAS SDMP were not followed. SaaProc software sent directly from ARC to AFRC without completing the V&V process. Installed software resulted in incomplete data output.	Required; N/A	V&V, Software Integration	Process Improvement; Sign off by the technical leads to facilitate software delivery and acceptance. Ensure that the CCB process is completed for any change to software prior to installation. Ensure that software at both centers remain in sync throughout testing.
Evacuation Procedures	A fire alarm at ARC required evacuation of both the DSRL and the SDL during a Full Mission flight. A quick determination was required to route the ownship to a holding point until ARC could reenter the building and get the simulation up to date for further testing.	Recommend; DSRL, SDL	Safety, Mission Execution	Experience; The evacuation of facilities should be anticipated as a possibility and procedures for determining the disposition of the ownship planned in advance.

<u>Title</u>	<u>Issue Description</u>	<u>Issue Rating / Impacted Facility</u>	<u>Impacted System or Process</u>	<u>Lesson Type; Lessons Learned</u>
Adverse Impacts on VSCS Display Requirements	Airspace availability and the SPUT's range adjustments on the VSCS display presented a challenge to fulfill researcher requirements. Reroutes in response to changes in available airspace and reduced range setting often had an adverse impact on the amount of simulated aircraft being displayed.	Recommend; DSRL	Mission Execution	Experience; Design the MACS scenario so that the researcher required traffic populates at the start of the mission in the vicinity of the ownship, and maneuver the required traffic in real time around the ownship. The assigned route of the ownship would change throughout the mission due to airspace constraints. Maneuvering the required traffic in real time around the ownship allowed the required traffic to be displayed regardless of the assigned route, the SPUT's VSCS display, and position of the ownship.
Systems Plotting Variances	During Flight Plan and airspace development, several methods and calculators were used for determining latitude and longitude for waypoints and fixes for Full mission primary and contingency routes. Additionally, software programs (VSCS, MACS, PiccoloFalcon View, Zeus, Flight Cards) had one or more acceptable formats for latitude/longitude data used to plot fixes and waypoints. As flight planning progressed, lat/long formats varies often with each update and revision to the locations of fixes and waypoints supporting the routes flown. Slight variance in the original locations of these fixes or waypoint resulted as lat/long information was converted to a differing format for systems under test.	Recommend; N/A	Planning	Process Improvement; A standardized latitude/longitude format, common to all software platforms, should be identified at the onset of a project. The use of this format then should be made mandatory for those developing airspace and flight plans.

<u>Title</u>	<u>Issue Description</u>	<u>Issue Rating / Impacted Facility</u>	<u>Impacted System or Process</u>	<u>Lesson Type; Lessons Learned</u>
Division of Ghost Responsibilities	The original architecture at ARC planned for a single ghost to handle coordination with AFRC and support the controller during the Full Mission flight. Research requirements also required the ghost to ensure traffic around the ownship. These functions overtasked the ghost resulting in missed coordination.	Recommend; DSRL	Full Mission Operations	Experience; The Ghost position was split creating the Ghost Support position. The ghost focused on coordinating with AFRC and ensuring that weather and system health were up to date and adequate. The Ghost Support provided assistance to the controller and ensured traffic was available to the ownship during Full Mission.
Secure Laboratory Access Breaches	Unauthorized personnel were able to access the DSRL and SDL while Ft6 flight operations were in progress without receiving the pre-requisite briefing required by the FT6 Mishap Plan. Signage indicating the labs were a controlled environment were clearly posted at all entries to the labs, but were not complied with. The individuals were immediately escorted from the laboratories. The SDL was equipped with a cypher lock, but the code was known to software developers that commonly used the SDL, which allowed for the breach.	Recommend; DSRL, SDL	Facility Operations	Process Improvement; Add cypher lock to DSRL access doors and temporarily change door codes to existing SDL cypher lock to prevent unauthorized access.
Subject Pilot Debrief Coordination	Ghost and Ghost support were occasionally unsure of when the SPUT debrief following encounters started or completed. This impacted how VFR traffic surrounding the ownship were maneuvered. This was especially true for those aircraft designated for preventative alerts.	Recommend; DSRL	Full Mission Operations	Experience; Research team should advise the TD when each briefing started and finished. The ghost should then advise Ghost support.

<u>Title</u>	<u>Issue Description</u>	<u>Issue Rating / Impacted Facility</u>	<u>Impacted System or Process</u>	<u>Lesson Type; Lessons Learned</u>
Comm. Realignment	Demands on the communications networks required realigning communications to specific frequencies. ARC used 132.2 to facilitate communications between the Ghost and Ghost Support positions and the pseudo-pilot and Ghost Pilot positions in the SDL. 120.55 was dedicated to managing the LVC environment, and 126.6 provided a common point of contact for communication with the TD.	Recommend; DSRL, SDL	Comm Plan	Experience; Consideration and discussion should be used to examine possible demands on the communications system with a focus on the possible demands for each circuit.
Training Impact due To Diverse VSCS System Control Capabilities	The training VSCS and RCGS VSCS stations at AFRC and the ITE VSCS at ARC demonstrated different command and control capabilities, largely due to the RCGS system setup for Piccolo. This required changes to training prepared at ARC once the System under Test was viewed at AFRC.	Required; N/A	Training	Training; Advance training for instructors and for individual developing training for the system under test including the VSCS and Piccolo should be provided. Earlier delivery of Piccolo and the VSCS version used in the RCGS.
Real Time MACS Weather Entries	Procedure for entering real time PIREP into MACS needed to be simplified. Individual entries by each position was not required	Desired; DSRL, SDL	Full Mission Operations	Experience; Earlier use of the weather program during SCO flights would have identified this issue and allowed for simplified procedures. Comparison of the forecast winds and actual winds would show issue
PIREP Requirements	Actual winds aloft sometimes varied significantly from forecasted wind conditions causing the ownship to adjust it heading to fly the assigned route of flight. This impacted radar data collection as the radar parameters shifted with the actual heading of the aircraft. MACS weather	Required; DSRL, SDL	Full Mission/SE/SC O Operations	Experience; Require regular PIREPS from the intruder aircraft. Information received should be forwarded to ARC for updates to the MACS. The information should also be logged to provided research teams information on the impact of winds on flight data.

<u>Title</u>	<u>Issue Description</u>	<u>Issue Rating / Impacted Facility</u>	<u>Impacted System or Process</u>	<u>Lesson Type; Lessons Learned</u>
	information also required updating to ensure that MACS traffic performed in a manner consistent with the ownship.			
Loss of Target Data	During development of the LVC environments at ARC and AFRC, loss of target data was experienced at both centers on sub-components of the systems. Changes to some of the components in the system impacted data flow. On occasion confusions about how the data feeds were flowing created the problem. These issues resulted in several changes to the configuration of the LVC Client	Required; DSRL, SDL	LVC Integration	Experience; Early communication between ARC and AFRC about the expected data flow took place. Subsequent development, which impacts the planned data flow, should take place as it occurs. Changes to the LVC Client should be made and tested in real time. Requirements for specific testing, such as Scripted Encounters vs. Full Mission, should be addressed separately.
Loss of Target Display on MACS	During Full Mission flights, the MACS intruder target often disappeared from the MACS presentation. The same issue occurred with the ownship but much less frequently. A review of the LVC logger files indicated that ACDelete messages were transmitted for the aircraft during the flight. This problem was unable to be corrected without a restart of the MACS and ADRS subsystems.	Required; DSRL, SDL	Full Mission LVC integration	Experience; Identify the source of the ACDelete messages and prevent transmission. Workaround using alternate presentation (AFRC VSCS display) allowed for continuous testing without a system restart.

<u>Title</u>	<u>Issue Description</u>	<u>Issue Rating / Impacted Facility</u>	<u>Impacted System or Process</u>	<u>Lesson Type; Lessons Learned</u>
Lat/Long Error during Transformation Process	An output case was missed in early development of replacement airspace translation software for MACS. Output in the format Degrees Minutes Seconds did not account for Minutes or seconds less than 10. Testing was performed early in software development to check for output errors, however this possibility was not considered and test cases were random and did not highlight the error. It remained unaccounted for until software was ready to be used and remained undiagnosed until after the original translation program was revised for FT6 needs and used instead.	Recommend; N/A	Airspace development	Process Improvement; Better planned test cases for early development could have caught the error before further development occurred.
Variance between VSCS and Piccolo Fix Numbering Systems	The differences between the Piccolo and VSCS numbering systems created confusion for the PUT during SCO flights testing the Full Mission flight plan. Controllers during testing had a different display of waypoints based on VSCS waypoints developed at ARC. This resulted in an unexpected maneuver by the ownship when the controller cleared the PUT to a specific waypoint and the aircraft proceeded to a waypoint with the same number assignment in Piccolo.	Required; N/A	System Checkout	Experience; Specific flight plans were developed in Piccolo for each type of flight plan for FT6. The VSCS fixes used for the Full Mission were then correlate with the Piccolo fixes for the flight. The VSCS fixes were then used for the flight.

<u>Title</u>	<u>Issue Description</u>	<u>Issue Rating / Impacted Facility</u>	<u>Impacted System or Process</u>	<u>Lesson Type; Lessons Learned</u>
Four Corners Route Extension	During the SCO flights, the Four Corners contingency route was shown to be too short to accommodate encounters and allow for adequate debriefing time for the research team. This track was further impacted by the intermittent loss of command and control signal in the vicinity of WPT7.	Required; N/A	Full Mission	Experience; The Four Corners Extension was created to extend the length of the Four Corners route allowing sufficient time to complete encounters. This extension also benefited the Full Mission route when UA or intruder maneuvers caused encounter near WPT4.
Requirements Gathering Processes	Requirements gathering has always been challenging across technical teams and throughout various activities. A universal template, process, or procedure has not been implemented to maintain consistency of how requirements are gathered, transmitted, and documented for verification and validation. Requirements are relayed in many forms and are sometimes assumed to be delivered. Traceability of requirements, from source to V&V procedure can be much improved. Requirements by PowerPoint or delivered verbally are not appropriate and suitable, requirements are delivered to too many points of contact (POC are not identified or requirements are not going through POC).	Required; N/A	All Development Processes	Process Improvement; Recommend Project Office develop a Requirements Gathering framework and set the tone for all subproject to follow. Developed a standardize form (i.e. source of requirements, requirements description, receiver of task, related activities, V&V/test procedure, success criteria, priority, completion date). The requirements format shall be applicable across Centers, project, and sub-team. (The concept is to have a consistent format throughout the teams.) Identify and broadcast the requirements POC to all team. Train everyone on how to initiate, write a 'good' requirement, and submit a requirements ticket for any activities, to the appropriate POC at any team and Centers. Provide a system for all team members to search and obtain the status of any relevant requirements.
Back-up System Testing	The ISA between AFRC and ARC established the primary and backup servers that established the LVC environment between the DSRL at ARC and the LVC	Required; DSRL	LVC Integration	Process Improvement; Incorporate testing of the backup systems into the test schedules for the LVC environments and SCO flights to ensure connectivity and proper configuration of the

<u>Title</u>	<u>Issue Description</u>	<u>Issue Rating / Impacted Facility</u>	<u>Impacted System or Process</u>	<u>Lesson Type; Lessons Learned</u>
	laboratory at AFRC. uasgw4 replaced uasgw3 in a single session during integration testing of the full LVC environment with ARC and AFRC. However, due to the robustness of the primary system, a complete test of possible combinations of the primary and backup hardware was not initiated.			backup systems. Develop procedures for switching to back up system(s) during flight.
TFR Design	Testing of the background traffic revealed that VFR traffic circumnavigating the TFR of transitioning above from the south were not able to provide effective returns to the ownship on the Full Mission route. Additionally, the types of maneuvers were placing a high workload on the Pseudo-pilots.	Recommend; DSRL	Full Mission	Experience; The altitude of the TFR was reduced from 14,000 feet to 10,000 feet, which reduced the overall volume of the TFR. This change allowed a greater amount of traffic to transition over the TFR and bring the aircraft within view of the ownship.
Inadvertent Corrective Alert	Pseudo pilot climbed a MACS target, N182AR, from 6500 feet to 7500 feet IAW script. The climb caused an inadvertent corrective alert with guidance, which progressed to a warning alert with guidance. The test subject responded to the alert as indicated.	Recommend; DSRL	Rehearsal / Virtual ATC Procedures	Experience; The climb for N182AR was removed from the script. The Ghost Support position issued control instructions to the Pseudo-Pilots for subsequent Preventive encounters. Ghost Support ensured that these aircraft were in level flight prior to entering the range parameters for the alerts.
Speaker Placement	A speaker was set up to allow researchers in DSRL to monitor communications between the Test Director, the research team, Payload, and Ghost. This speaker was mounted adjacent to the Controller position and created q	Required; DSRL, SDL	Rehearsal	Experience; The speaker was removed from its location near the controller position to a location near the Ghost. Volume level was set to allow reception by the researcher in DSRL without causing a distraction to the controller.

<u>Title</u>	<u>Issue Description</u>	<u>Issue Rating / Impacted Facility</u>	<u>Impacted System or Process</u>	<u>Lesson Type; Lessons Learned</u>
	significant distraction to the air traffic controller.			
Altitude Violation - Virtual Traffic	Virtual Aircraft planned for altitudes above FL230 climbed through FL230 without a clearance from Ghost Support.	Required; DSRL, SDL	Rehearsal	Experience; Instructed Pseudo-pilots to FLCH all aircraft planning to climb to high altitude at FL230, until advised by the Ghost Support position.
Anomalous Flight Plans	Virtual aircraft flight plans were replaced by a generic SFO round robin flight plan generated by the ARC FPG.	Required; DSRL, SDL	Rehearsal	Experience; The ARC FPG was removed from the architecture.
SaaProc Altitude Offset Failure	ARC SaaProc failed to process the altitude offset for the intruder aircraft which prevented corrective and warning alerts on the ARC VSCS display.	Required; DSRL	Rehearsal	Experience; The SaaProc configuration was set to recognize NASA865 when processing the altitude offset. The data being received from AFRC for the intruder used N865NA for the call sign. Corrected the issue by adding N865NA to the SaaProc configuration file.
Internet Proxy Failure	The internet proxy server was removed from service by maintenance during the Full Mission rehearsal flight. This prevented the Ghost from obtaining NOAA RAP winds for MACS processing. Maintenance restored the proxy when notified of the requirement for NOAA weather.	Recommend; DSRL	Rehearsal	Experience; Investigation discovered that maintenance was unaware that the proxy was being used to support the flight. A copy of the Full Mission schedule was forwarded to maintenance to prevent an inadvertent loss of the proxy.