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Armstrong Flight Research Center
Edwards, CA 93523-0273

UAS Integration in the NAS Project

Integrated Test and Evaluation (IT&E)

FLIGHT TEST 3

Flight Test Plan

FT3-FTP-01

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REVISION SHEET

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This Flight Test Plan is a living document that will mature as flight test planning matures.

The document will be updated and finalized prior to the FT-3 Tech Brief.

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1 Introduction

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

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

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

1.1 Purpose

The integrated Flight Test 3 (FT3) will gather data for the UAS researchers or their development and evaluation of Communication system, Sense and Avoid (referred to as Detect and Avoid in the RTCA SC 228 ToR) algorithms and pilot displays for candidate UAS systems in a relevant environment. The technical goals of FT3 are to: 1) perform end to end traffic encounter test of pilot guidance generated by Self Separation algorithms (aircraft sensor to wind, TCAS II, and latency uncertainties to Ground Control Station (GCS) display); and 2) conduct flight test of prototype Communication system as part of an integrated DAA system; 3) collect data to inform the preliminary draft of the Methods of Performance Standards (MOPS) for Detect and Avoid and C2, to include display and human performance standards in both MOPS. The completion of FT3 will provide valuable data to the Separation Assurance/Sense and Avoid Interoperability (SSI), Communication (Comm) and Human Systems Integration (HSI) research as well as reduce the risks associated with building a relevant flight test environment moving towards the final flight tests (FT4).

FT3 objectives and test infrastructure builds from previous UAS project simulations and flight tests. The basic test infrastructure has been used during the Integrated Human in the Loop (IHITL) simulation, Part Task 4, (PT4) Part Task 5 (PT5), UAS Controller Acceptability Study (UAS-CAS 1), and GRC Comm prototype CNPC system ground and flight tests. NASA Ames

(ARC), NASA Armstrong (AFRC), NASA Glenn (GRC), and NASA Langley (LaRC) Research Centers will share responsibility for conducting the tests, each providing a test lab and critical functionality. UAS-NAS project support and participation on the 2014 flight test of ACAS Xu and Self Separation (SS) significantly contributed to building up infrastructure and procedures for FT3 as well. The experiment will be divided into two distinct test configurations each focusing on different aspects of the primary technical goals. The first is a four-week study (described as Pairwise Encounters) looking at the SS algorithm alerting times to support the definition of well-clear. The second is a four-week study (described as Full Mission (FM) flights) focusing on UAS pilot response times to, and acceptability of, the same SAA alerts, resolutions, and GCS displays under real world uncertainties, including real voice comm delays.

The two test planned baseline configurations will be conducted in two phases. The Pairwise Encounters (also called Configuration 1) will be conducted out of NASA Armstrong over a four-week period beginning in June 2015. The Full Mission flights (also called Configuration 2) will start data collection in July 2015 and continue over a four-week period, run out of NASA Armstrong. NASA Glenn (along with the Communication system under test) and NASA Armstrong will provide the live aircraft. At least one aircraft from NASA Glenn will support the test as a UAS surrogate. Over the course of FT3, data will be collected from a total of 10 pilot subjects and evaluated over fifty aircraft encounters. Additional test dates are available to account for make-up data collection opportunities, if needed.

Test facilities are Government owned, managed, leased or under agreement and fall into two categories:

Development Facilities:

- Distributed System Research Laboratory (DSRL) at NASA Ames
- Flight Deck Display Research Laboratory (FDDRL) at NASA Ames
- Research Aircraft Integration Facility (RAIF) at NASA Armstrong
- UAS Sense and Avoid Research Lab at Stinger Gaffarian Technologies (SGT, outside of NASA Langley)
- GA-ASI Grey Butte Flight Test Facility
- GA-ASI System Integration Lab

Test Facilities:

- Crew Vehicle Simulation Research Facility (CVSRF) at NASA Ames
- Distributed System Research Laboratory (DSRL) at NASA Ames
- Research Aircraft Integration Facility (RAIF) at NASA Armstrong
- Gryden Aeronautical Test Range (DATR) at NASA Armstrong
- Stand Alone Facility (SAF) at NASA Armstrong
- The Radio Frequency (RF) Communications facility at NASA Armstrong
- Edwards R-2508 Complex

1.2 Stakeholders, Participants, and Responsibilities

NASA Integrated Aviation Systems Program (IASP) provides direction for the UAS in the NAS project. The project office has overall responsibility for FT3 flight test. NASA Ames, NASA Armstrong, NASA Glenn, NASA Langley, GA-ASI and Honeywell support the project and are participants in the FT3 activity. The following is a brief description of responsibilities:

- **NASA Ames Research Center (ARC):** NASA Ames is responsible for providing the HSI research requirements for subject pilot evaluation based on performance during scenario events. Subject pilots will perform scenario tests from the Research Ground Control Station (RGCS) located at NASA Armstrong. ARC will provide one of the Self Separation algorithms to be used during pairwise and full mission flight test.

- **NASA Armstrong Flight Research Center (AFRC):** NASA Armstrong is the responsible test organization for all test missions flown from AFRC. AFRC is responsible for providing the RGCS to be used for subject pilot evaluation. Further AFRC is responsible for hosting and supporting the Live Virtual Constructive (LVC) infrastructure for hosting data distribution between NASA Ames, Glenn and Langley. AFRC is also responsible for providing the live unmanned aircraft to be used during pairwise encounters. Ikhana will provide the unmanned aircraft ownship platform to support pairwise encounters within R-2515 airspace. In addition to providing the UAS ownship aircraft, AFRC will also provide intruder aircraft (T-34 / King Air) as required.

- **NASA Glenn Research Center (GRC):** NASA Glenn is the participating test organization for all test missions flown from GRC or AFRC. GRC is responsible for providing communication and control system interface, the high speed ownship during some pairwise encounters, the UAS Surrogate ownship aircraft and a manned high speed intruder aircraft to be used during Full Mission flights.

- **NASA Langley Research Center (LaRC):** NASA Langley is responsible for providing a Self Separation algorithm (Stratway +) that will be displayed and evaluated by subject pilots during flight encounters.

- **General Atomics Aeronautical Systems Inc. (GA-ASI):** Is responsible for providing hardware, software and integration support on the NASA Ikhana UAS. GA-ASI will provide pairwise encounter requirements for autonomous aircraft response maneuvers. GA-ASI’s CPDS will be used to gather data during both configurations of FT3.

- **Honeywell:** Honeywell is providing the software for the Surveillance Tracking Module (STM) prototype that contains the Honeywell Fusion Tracker. Honeywell will also provide a second Traffic Alert and Collision Avoidance System (TCAS) II equipped intruder aircraft to support pairwise flight test encounters and may support full mission flights as well. The Honeywell intruder aircraft is capable of onboard TCAS data recording.

1.3 Requirements Flow & Documentation

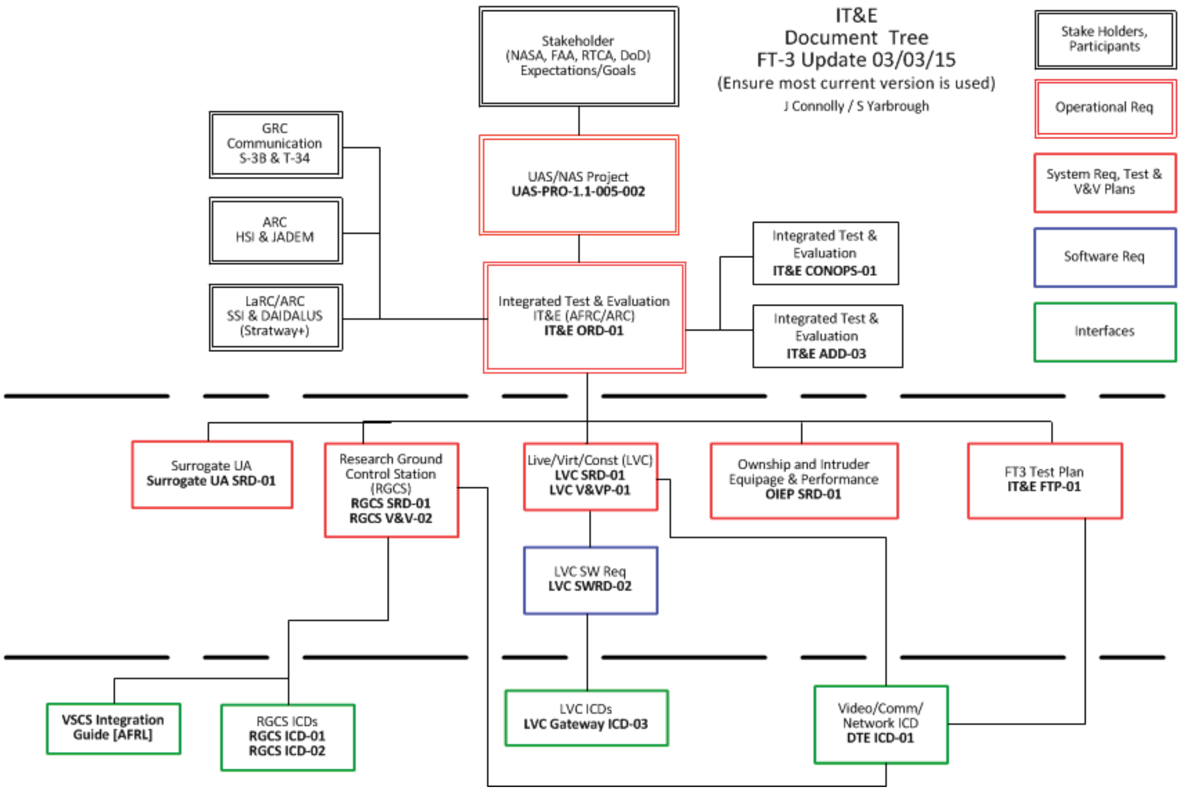
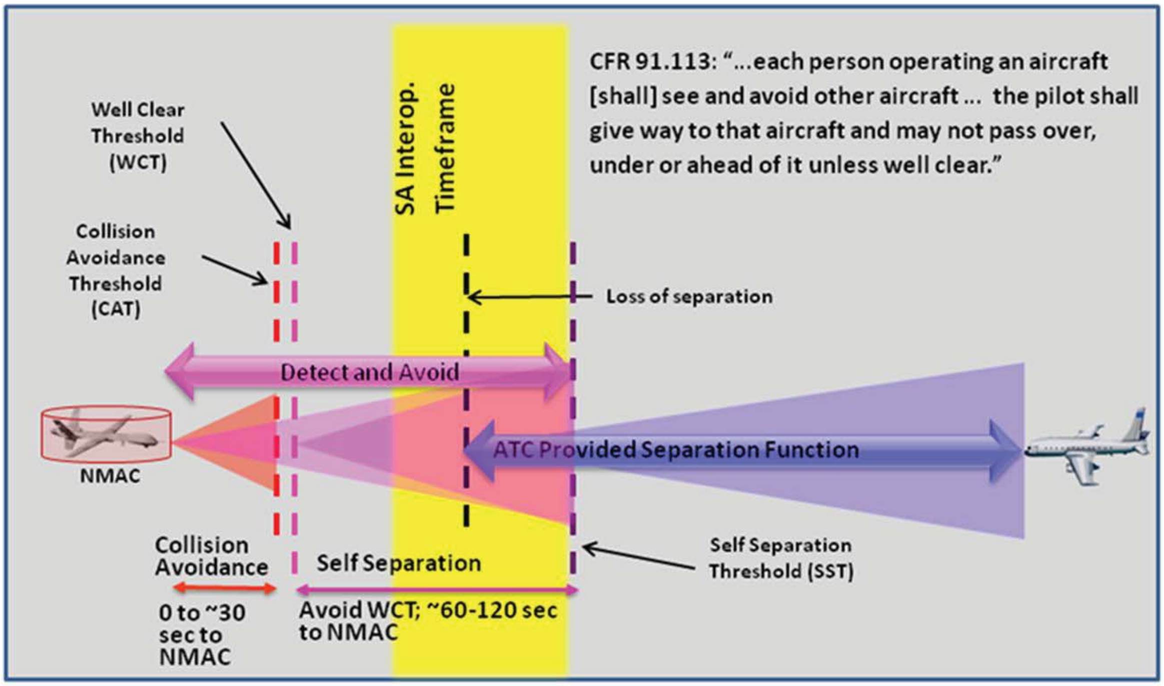


Figure 1-1. UAS-NAS IT&E Document Tree.

Details for this section are TBD.

2 FT3 ConOps

The UAS in the NAS Project has ongoing research efforts focusing on the investigation of the interoperability of SAA algorithms with Collision Avoidance (CA) and Separation Assurance (SA) concepts. Figure 2-1 shows the overlap of these concepts. Primary counterparts to this research are the display and interaction with the outputs of these systems by pilots and controllers, as well as additional response delays observed due to an unmanned aircraft’s distributed communication system.



*It is possible for the CAT to be greater than the WCT

Figure 2-1. Collision Avoidance, Sense and Avoid, and Separation Assurance Interoperability.

As such, the Project is conducting a series of integrated human in the loop simulations and flight tests in order to evaluate pilot performance in response to SAA alerting and guidance, as well as pilot and controller acceptance of the usability, display, and timeliness of the alerting and guidance (see Figure 2-2). FT3 will utilize the distributed Live, Virtual, Constructive (LVC) environment developed by the Project to provide the core infrastructure and supporting simulation software components, to integrate a real UAS flying under nominal (non-contingency) operations, interacting with air traffic control (ATC) and virtual and live manned aircraft during Configuration 2 full mission flights. An instance of the LVC environment will be explicitly configured to meet the requirements for each of FT3 test configurations, providing the appropriate level of functionality, fidelity and security as needed. LVC software test components include a research prototype GCS and live aircraft at NASA Armstrong, constructive aircraft target generators at NASA Ames, and virtual ATC workstations at NASA Ames.

Java Architecture for DAA Extensibility and Modeling (JADEM) provides an Application Programming Interface for modeling DAA functions in simulation and flight test environments. For this flight test, there are six DAA sub-functions: detect, track, evaluate, prioritize, declare, and determine. The detect and track function—or surveillance system— models the process to which sensors on-board UAS detect other aircraft, and provide track data for each intruder within the sensors' field of regard to be displays on the UAS pilot's traffic display. Perfect, sensor errors, and configurable range and field of regard can be modeled in JADEM. Since this flight test utilizes an operational surveillance system onboard the UAS, JADEM's surveillance model is simply a pass-through. The evaluate, prioritize, and declare functions are responsible for evaluating each intruder detected by the surveillance system and determine whether to provide an alert to the pilot and the severity of the alert. The alerting logic used for this flight test is based on alerting requirements in the draft DAA MOPS. The determine function provides guidance to the pilot to aid in the pilot executing a maneuver to remain well clear. There are two main algorithms within JADEM's guidance: (i) Autoresolver, and (ii) OmniBands. The Autoresolver provides directive guidance, i.e. a specific resolution maneuver, for the pilot to execute to remain well clear. OmniBands is an algorithm that provides suggestive guidance, i.e., ranges of heading and altitude "bands" to which the pilot could execute in order to remain well clear.

The FT3 test environment builds upon the LVC test environment used during IHITL and the ACAS Xu flight test. Prior to discussing the specific test setups, a description of the high-level system configurations is in order. Note this describes the system level requirements for FT3 in the abstract sense, specific hardware and software components that comprise the implemented system are described later in this document.

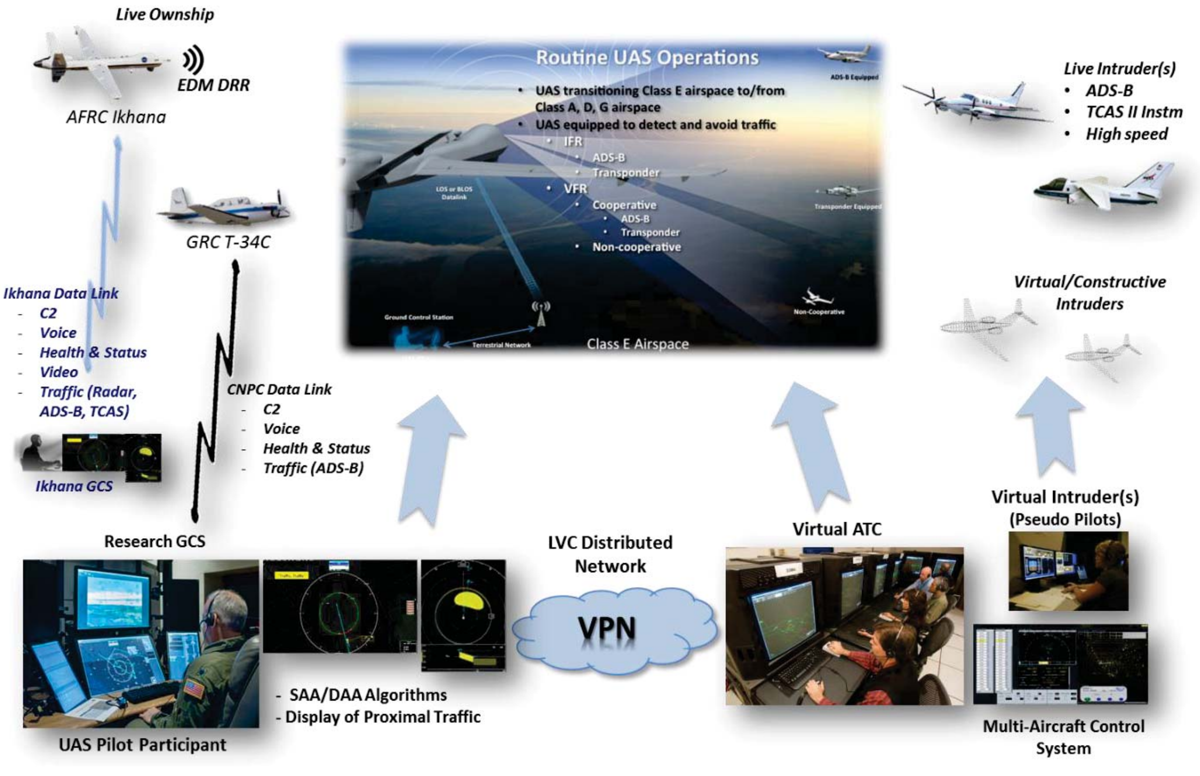


Figure 2-2. UAS in the NAS ConOps Overview.

2.1 Pairwise Encounters (Flight Test Configuration 1)

This test configuration investigates the advisories generated by the Self Separation and Collision Avoidance Algorithms fed by data from live aircraft during flight. Flight Test Configuration 1 is further defined into two distinct groups (Configuration 1A and 1B). Configuration 1A involves flight test encounters using a low-speed, unmanned ownship aircraft. Configuration 1B involves flight test encounters using a high-speed manned ownship aircraft. In these tests a UAS or high-speed manned ownship aircraft will be flown with either one or two manned intruder aircraft, under scripted flight paths to induce alerting and in some cases maneuvering based on specific geometry encounters. Three SS algorithms will be evaluated: Three SS algorithms will be evaluated: 1.) Stratway+ (now called Detect & AvoID Alerting Logic for Uncrewed Systems or DAIDALUS), originally developed to support tactical resolution advisories for manned aircraft; 2.) AutoResolver, first developed to support air traffic controllers with advisories to maneuver aircraft in the en route and Terminal airspace based on predicted Loss of Separation (LOS). This algorithm has been modified to work with pilots to receive and evaluate intruder TCAS messages, support Resolution Alerts and CA maneuvers in response to Loss of Well Clear predictions and includes a model of an airborne sensor that applies a filter to restrict the inputs to the AutoResolver; and 3.) CPDS developed by GA-ASI and TU Delft for Human Factors and user display research. This study seeks to exercise the SS concepts alerting guidance and examine the timing and utility of the alerts under real world flight conditions.

2.2 Full Mission Encounters (Flight Test Configuration 2)

The experimental goal of this study is to continue the evaluation of the display of self-separation alerts and guidance information to the UAS pilot, based on IHITL and Part Task 5 results, and lessons learned. The UAS Surrogate aircraft is flown on a visual flight rules (VFR) flight plan with scenarios containing a mix of two live and several virtual manned instrument flight rules (IFR) and VFR (squawking) aircraft. Voice Communication and data messages between the UAS Surrogate aircraft and the Ground Control station will utilize the UAS Project’s prototype UAS Communication system. In this setup, controllers act as confederates, allowing for (and ensuring) interaction between the manned and UAS aircraft. An SS algorithm provides alerts and advisories for display to the pilot on the GCS-TD. The pilot uses the display information to negotiate maneuvers to avoid the traffic with ATC. The Full Mission test configuration is designed to connect virtual air traffic control (ATC) and constructive aircraft processes running at NASA Ames with a live manned aircraft and a UAS surrogate controlled by the research GCS. The framework for the simulation environment will be supplied by the LVC via the High Level Architecture (HLA) messaging infrastructure. The research GCS will control the UAS surrogate via the Vigilant Spirit Control Station (VSCS) and also provide a traffic display (GCS-TD) used to present SS advisories to the pilot. The components send and receive data through a gateway connected to the HLA network. The constructive manned aircraft and ATC workstations communicate directly via a local gateway and communicate to the other components via that gateway and the HLA. The constructive manned aircraft generators provide the required background traffic supporting a more realistic environment. The prototype UAS Communication System will be integrated into the surrogate aircraft and used to send voice and data messages to and from the GCS.

2.3 Goals and Objectives

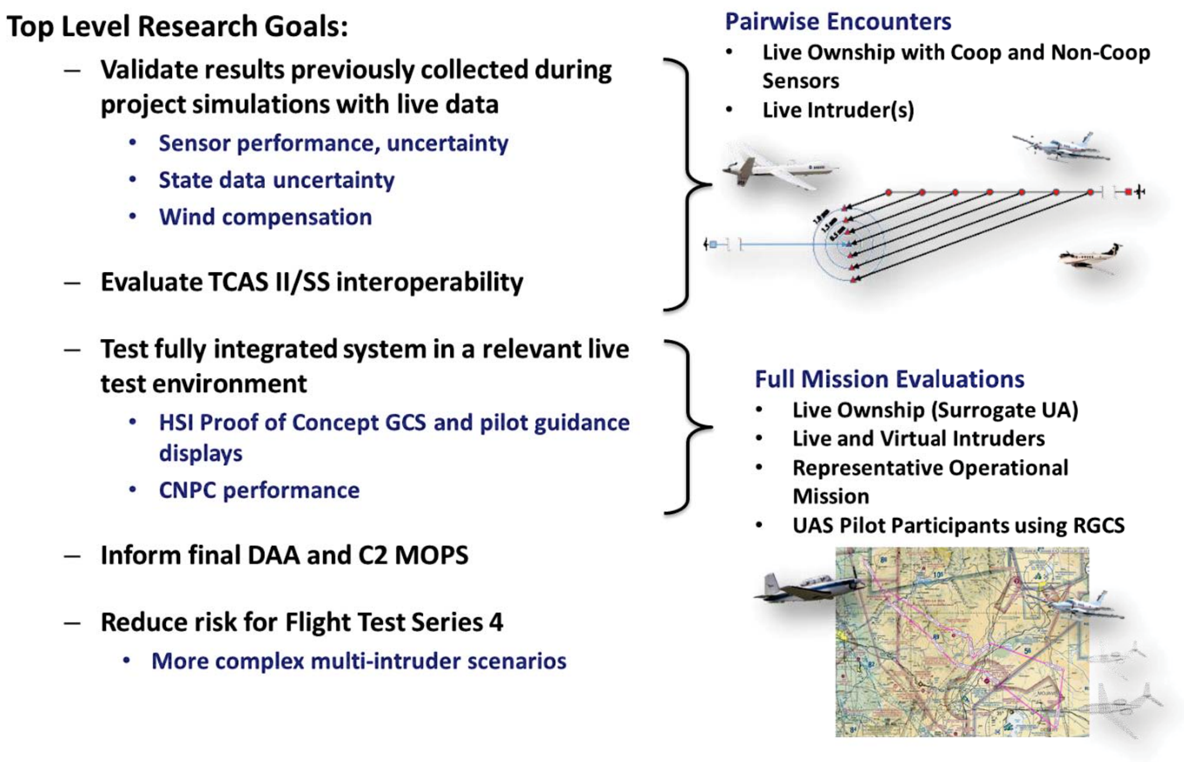


Figure 2-3. FT-3 Primary Technical Goals and Objectives

2.3.1 Flight Test 3 Goals

Flight Test 3 serves as the mechanism to test two primary technical goals and one programmatic goal:

Pairwise Encounter Goal:

- Validate results previously collected during project simulations with live data
- Evaluate TCAS II / SS interoperability

Full Mission Goal:

- Test fully integrated system in a relevant live test environment

Project Goal:

- Inform final DAA and C2 MOPS
- Reduce risk for Flight Test Series 4

2.3.2 Flight Test 3 Objectives

The Flight Test 3 Series objectives for Pairwise Encounters (Configuration 1):

1.) Validate CPA prediction accuracy and self-separation alerting logic in realistic flight conditions

2.) Validate self-separation trajectory model including maneuvers
3.) Validate sensor and tracking models
4.) Evaluate TCAS/self-separation interoperability
    - Ownship CA/SS interaction
    - Compatibility with intruder's TCAS
5.) Evaluate DAA performance in multi-threat encounters
6.) Evaluate TCAS II as installed performance on a UAS
7.) Qualitatively evaluate pilot impression of self-separation advisories
8.) Inform final MOPS

Specific Flight Test 3 requirements for Pairwise Encounters (Configuration 1):

<u>Flight Test 3 Pairwise Encounters (Configuration 1) shall:</u>

1.) Evaluate the SAA aircraft and trajectory models in flight with real world uncertainties
    - Measurements/Metrics
        - Climb rates, descent rates, turn radius, along /cross track trajectory error, altitude trajectory error, winds, CPA error
2.) Evaluate the SAA pilot models in flight with real world uncertainties
    - Measurements/Metrics
        - Pilot reaction times (evaluation time, maneuver time)
3.) Measure the Self separation alert threshold using cooperative sensors in flight with real world uncertainties
    - Measurements/Metrics
        - SS alert time, distance, CPA, resolution maneuver type, etc.
4.) Measure the Self separation alert threshold using non-cooperative sensors in flight with real world uncertainties
    - Measurements/Metrics
        - SS alert time, distance, CPA, resolution maneuver type, etc.
5.) Measure the surveillance data accuracy of non-cooperative sensor
    - Measurements/Metrics
        - Get measurement list from Honeywell
        - Data fusion evaluation, if applicable
6.) Evaluate whether the intruder pilot(s) thought that well clear was maintained throughout the encounter where the ownship maneuvered in response to a self separation alert.
    - Measurements/Metrics
        - Subjective feedback from pilot(s) on manned Intruder
7.) Evaluate alert threshold interoperability between CA (i.e., TCAS) and SS
    - Measurements/Metrics
        - Compare Intruder TCAS TA time vs. SS alert time
        - Compare Intruder TCAS RA vs. SS maneuver

- Compare Ownship TCAS TA time vs. SS alert time
- Compare Ownship TCAS RA vs. SS maneuver

The Flight Test 3 Series objectives for Full Mission Flight Encounters (Configuration 2):

1.) Evaluation of integrated Self Separation algorithms, GCS Traffic displays, and prototype CNPC systems in a realistic environment
2.) Evaluate the effect of Self Separation alerting and guidance information on pilots' ability to maintain well clear
3.) Gather objective and subjective pilot data to evaluate/validate Well-clear definition
4.) Analyze the performance of fourth generation CNPC systems

Specific Flight Test 3 requirements for Full Mission Flight Encounters (Configuration 2):

<u>Flight Test 3 Full Mission Flight Encounters (Configuration 2) shall:</u>

1.) Measure the UAS pilot response time to detect potential conflicts and maintain well clear for each DAA display
    - Measurements/Metrics
        - Response Time (RT) to detect conflict
        - RT to contact ATC
        - RT to initiate resolution maneuver
        - RT to upload maneuver
        - RT for A/C to maneuver
        - RT to clear conflict
2.) Evaluate the performance of UAS pilots to maintain well clear for each DAA display
    - Measurements/Metrics
        - Number of well clear violations
        - Number of NMACs
        - Minimum horizontal and vertical distances
3.) Evaluate UAS pilot workload while operating with each DAA display
    - Measurements/Metrics
        - NASA TLX
4.) Evaluate UAS pilot subjective assessment of each DAA display
    - Measurements/Metrics
        - Preference
        - Ease of Use/Learning
        - Usability
        - Self-ratings of ability to maintain well clear
5.) Evaluate the impact of real world atmospheric, sensor, and communication latency uncertainties on SS alerts and advisories
    - Measurements/Metrics

        - Preference
        - Ease of Use/Learning
        - Usability
        - Self-ratings of ability to maintain well clear

6.) Measure the CNPC system in real world conditions
    - Measurements/Metrics
        - Amount /Duration of voice communications Pilot/ATC
        - Latency of voice communications Pilot/ATC
        - Number of targets ADS-B & Radar
        - Latency of target information Air/Ground
        - Latency of commands to aircraft
        - Latency of telemetry from aircraft
        - Percentage of telemetry information successfully received from aircraft

3 Flight Test Systems and Architecture

NASA Armstrong will provide facilities, infrastructure and systems required to perform the baseline FT3 pairwise and full mission test encounters within the Edwards Complex. Figures 3-1, 3-2 & 3-3 (respectively) depict the architecture that comprise the flight test systems required to support the flight test activity.

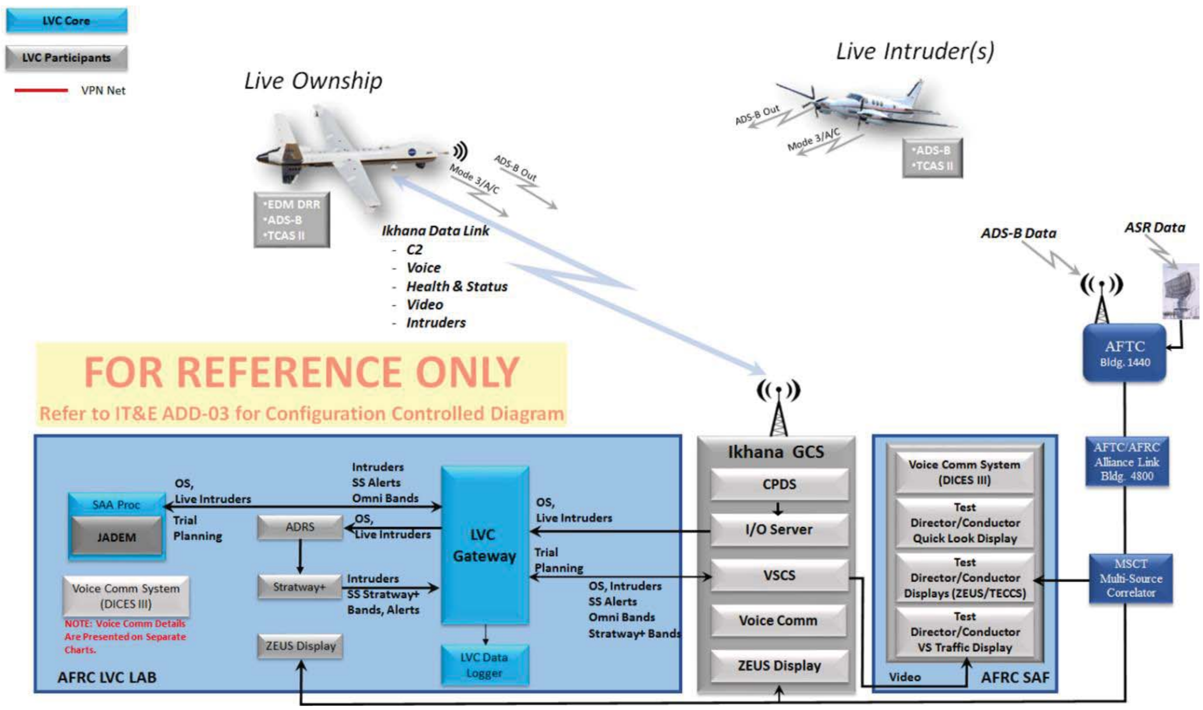


Figure 3-1. FT3 Baseline Configuration 1A (Pairwise Encounters at AFRC) UAS Ownship vs Manned Intruder.

Configuration 1A flight test encounters include pairwise encounters between a low speed ownship aircraft that will be performed by Ikhana configured with the GA-ASI prototype TCAS-Self Separation system.

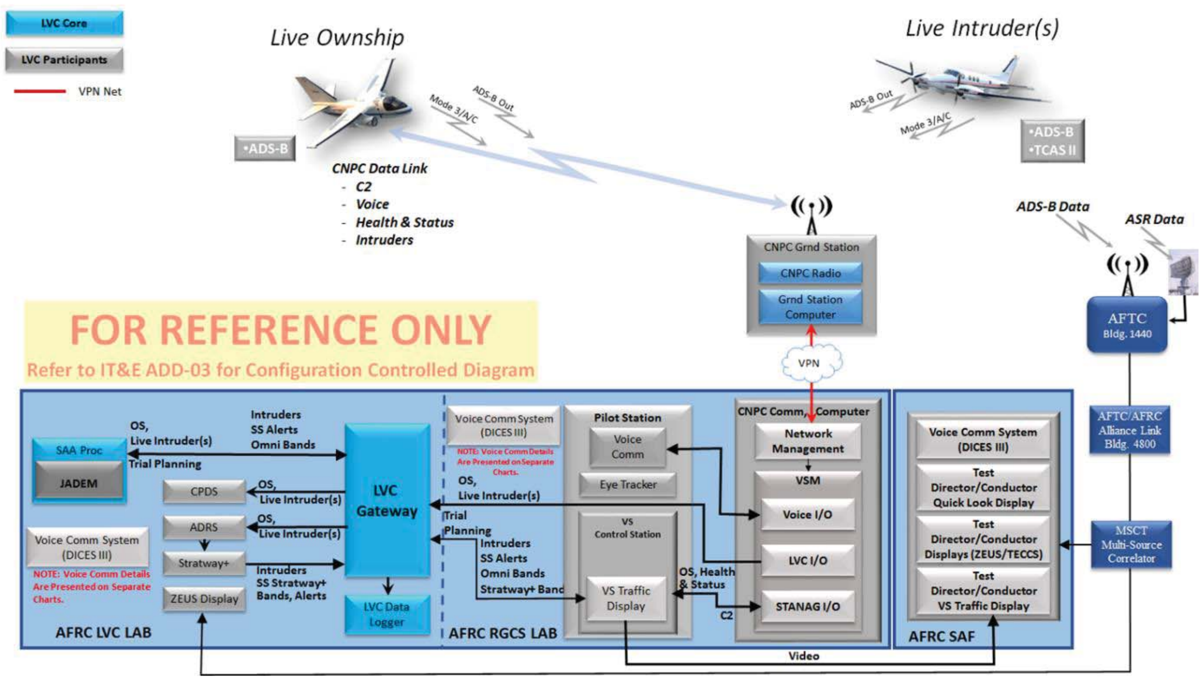


Figure 3-2. FT3 Baseline Configuration 1B (Pairwise Encounters at AFRC) High Speed Ownship vs Manned Intruder.

Configuration 1B flight test encounters include pairwise encounters between a high speed ownship aircraft that will be performed by GRC S-3B configured with CNPC and ADS-B system.

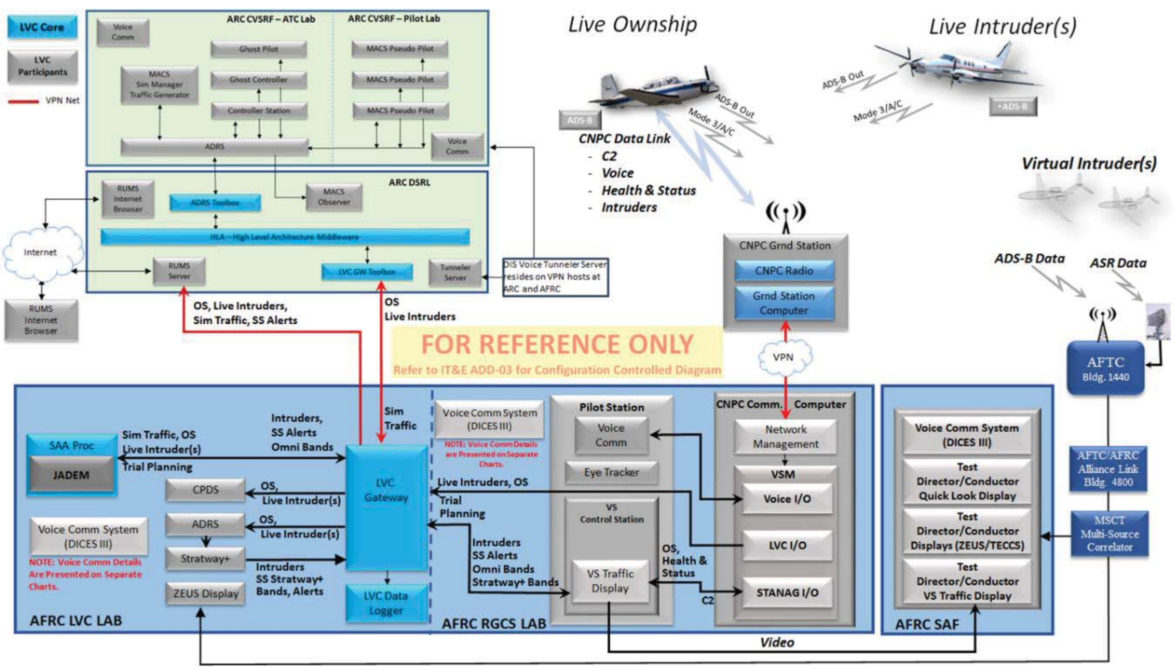


Figure 3-3. FT3 Baseline Configuration 2 (Full Mission Flights at AFRC) UAS Surrogate Ownship vs Manned Intruder.

Configuration 2 Full Mission flight test encounters include pairwise encounters between a low speed ownship UAS Surrogate aircraft that will be performed by GRC T-34C configured with the CNPC and ADS-B.

3.1 Flight Test Management

The integrated team approach to supporting FT3 operations includes personnel from NASA Armstrong, NASA Ames, NASA Glenn, NASA Langley, Honeywell, and GA-ASI. The Armstrong DPMf and the AFRC and Ames Integrated Test and Evaluation (IT&E) Co-PE's lead the test management decisions with inputs from subject matter experts within the aforementioned organizations assigned to the UAS-NAS project. SSI, HSI and Collaboration PE's lead the research decisions. A Test Conductor, as assigned from the IT&E subproject, has the responsibility to develop the flight test plan and has decision authority during actual flight test operations.

3.1.1 Success Criteria

Success criteria for pairwise and full mission flight encounters is described in section 4 of this document.

3.1.2 Vehicle Configurations

Figure 3-4 gives a high level overview of the systems involved in the flight test.

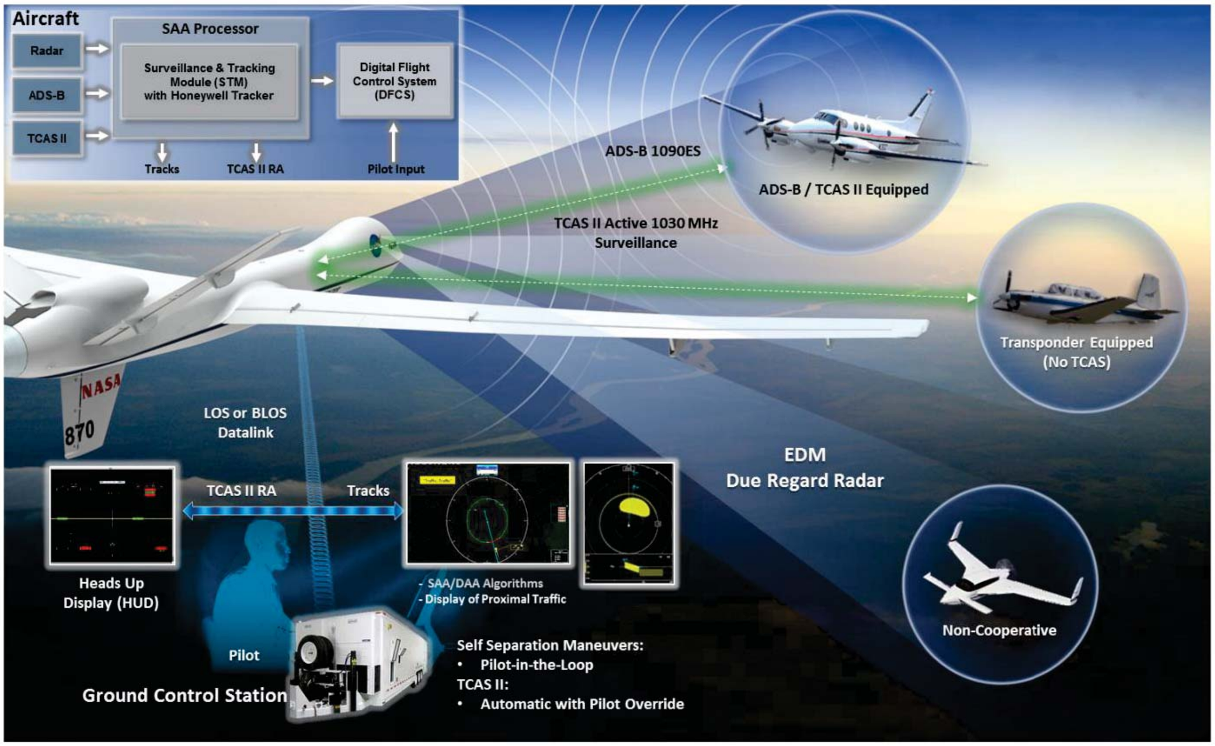


Figure 3-4. Self-Separation Flight Systems

The aircraft elements include the following required subsystems to execute the flight test and achieve all data collection objectives:

3.1.2.1 Ikhana Predator B (Ownship)

- Honeywell Tracking Software
- Non-Cooperative Sensor System (GA-ASI Air-To-Air Radar)
- Ground Control Stations (GCS) and Support crew
- GCS Displays and Architectures
- GCS Software to accommodate TCAS II
- Conflict Prediction and Display System (CPDS)
- SSI Stratway+ (Incorporated into VSCS Display)
- Vigilant Spirit Control Station (VSCS)+AutoResolver
- Avionics Packages for TCAS II, ADS-B, and Transponders
- Data recording equipment

3.1.2.2 Intruders

- Avionics Packages for TCAS II (as req), ADS-B, and Transponders

- Navigation system that use Global Positioning System (GPS) derived position

3.1.3 Flight Test Systems Roles and Responsibilities

This section describes the roles and responsibilities for test systems provided by the various participating organizations participating in Flight Test 3. Flight systems include: aircraft, aircraft support systems (i.e. GCS), communication, IT, simulation, networking, and other systems and subject matters experts to support these systems that contribute directly to executing flight operations.

3.1.3.1 NASA Armstrong

NASA Armstrong IT&E subproject will provide several of the systems required for executing the flight test within the Edwards Complex including the RGCS, LVC, SAF, DATR and Ikhana GCS. These systems will be staffed and managed by IT&E personnel assigned to support the UAS-NAS project. Each major system (RGCS, LVC, and Ikhana GCS) has a lead who is responsible for preparing these systems for the flight test. Armstrong will also provide the Ikhana MQ-9 UAS aircraft with qualified aircrew in support of the flight test pairwise encounters.

3.1.3.2 NASA Ames

NASA Ames will provide several of the systems required for executing the full mission flight test including virtual ATC, constructive air traffic, and LVC. ARC personnel will provide flight test support serving as confederate ATC controllers, ghost controllers and pseudo pilots for simulated aircraft that are required to create a realistic virtual traffic environment for the subject pilot under test, simulating mission operations within Oakland Center airspace. Ames personnel are also responsible for staffing and supporting pairwise and full mission flight activity by providing subject matter expertise for the ARC developed SSI algorithm while under test. HSI SMEs will be responsible for managing the research on human system interface between subject pilots operating the RGCS at Armstrong while performing the full mission flight profile using specific mission display interfaces.

3.1.3.3 NASA Glenn

NASA Glenn personnel are responsible for staffing and supporting flight test missions with subject matter expertise for the GRC developed CNPC radio system. GRC is responsible for providing a UAS Surrogate aircraft (T-34C) and high speed ownship/intruder aircraft (S-3B) in support of the flight test.

3.1.3.4 NASA Langley

NASA Langley personnel are responsible for staffing and supporting flight test missions with subject matter expertise for the LaRC developed SSI algorithm while under test.

3.1.3.5 Honeywell

Honeywell is responsible for providing subject matter expertise for the company-developed fusion software used on Ikhana during flight test. Honeywell is also responsible for flight test support providing their instrumented C90 aircraft as a TCAS equipped intruder aircraft along with qualified aircrew.

3.1.3.6 GA-ASI

General Atomics (GA-ASI) is responsible for providing subject matter and technical expertise for the company-developed hardware and software installed on Ikhana during flight test. GA-ASI is responsible for providing recommended Engineering Development Module (EDM) radar test objectives and test encounter scenarios for testing the radar in a relevant environment. GA-ASI will contribute technical expertise related to SAA, including with CPDS.

3.1.4 Flight Test Planning

AFRC is responsible for developing the flight test plan for FT3. Support from ARC, GRC, LaRC, HW and GA-ASI is required in order to develop a comprehensive test plan. The baseline for the plan is pairwise and full mission flight encounters conducted within the R-2508/2515 airspace complex located at Edwards AFB, CA. Indianapolis Center airspace located in southern Ohio has been identified as an alternate location for performing the high speed pairwise and full mission encounters.

3.2 Flight Test Resources

Resources from all organizations involved with the flight test are described and identified in the following sections.

3.2.1 Live Resources

The flight test will require various mixtures of manned and unmanned aircraft types with different subsystem requirements. The following aircraft are planned to be available for use in the flight test:

Aircraft	Provider	Role
Predator B "Ikhana"	NASA AFRC	UAS/Ownship
T-34C	NASA GRC	UAS Surrogate/Ownship
S-3B	NASA GRC	High Speed Ownship/Intruder
King Air (N3GC)	Honeywell	TCAS Threat/Intruder
T-34C	NASA AFRC	Second/Backup Low Speed Intruder
King Air	NASA AFRC	Second/Backup Low Speed Intruder

3.2.1.1 Unmanned Aircraft (Ownship)

An 'ownship' is the aircraft that hosts the systems (hardware and software) under test. Reference Ownship and Intruder Equipage and Performance SRD (OIEP SRD-01) for detailed information.

3.2.1.1.1 Predator B (Ikhana)

AFRC will provide the Ikhana Predator B unmanned aircraft (Figure 3-5) to support FT3 as the ownship for all pairwise encounters except encounters that require operations by the ownship that exceeds 180 KGS.

Figure 3-5. NASA AFRC, MQ-9 Predator B (Ikhana), T/N 870, Ownship Aircraft

The NASA AFRC Predator B (Ikhana) is a turbo-prop single engine unmanned aircraft built by GA-ASI. Ikhana has been configured with the GA-ASI prototype Sense and Avoid (SSA) system that includes integrated hardware and software components enabling the aircraft to perform pilot enabled and autonomous response to collision conflict resolution. The system is dependent upon SAA sensors. The SAA cooperative sensors in the aircraft include an Automatic Dependent Surveillance-Broadcast (ADS-B) In/Out compatible Identification Friend-or-Foe (IFF), and a Traffic Alert and Collision Avoidance System (TCAS). An Active Electronically Scanned Array (AESA) Air-To-Air Radar (ATAR) is installed to detect all airborne targets. The Ikhana will support the test mission as the UAS ownship during most of the pairwise encounters flown at Edwards AFB.

General Performance Characteristics

Weight:	10,500 lb
Speed:	200 kt
Ceiling:	40,000 ft
Endurance:	24 hr

3.2.1.2 Manned Aircraft (Ownship or Intruder)

An ‘ownship’ is the aircraft that hosts the systems (hardware and software) under test. An ‘intruder’ is an aircraft that supports the flight test to permit the live data collection requirements to be met. Intruder aircraft must be properly equipped to support the flight test. Reference Ownship and Intruder Equipage and Performance SRD (OIEP SRD-01) for detailed information.

3.2.1.1.2 T-34C Mentor

Figure 3-6. NASA GRC, T-34C Mentor, T/N N608NA, UAS Surrogate Aircraft

The NASA GRC T-34C Mentor (Figure 3-6) is a turbo-prop single engine aircraft that seats two pilots in tandem. The T-34C will support the test mission as an ADS-B equipped UAS surrogate aircraft during full mission encounters. The aircraft is configured as a UAS surrogate using a 2-axis S-TEC autopilot that when coupled to the onboard flight navigation computer provides automatic maneuvering for heading and a cueing system to the front seat pilot for speed and vertical control. The surrogate is equipped with a CNPC radio that is a system under test for the Comm subproject. The T-34C can also support test missions as a non-cooperative intruder aircraft.

General Performance Characteristics

Weight:	4,300 lb
Speed:	214 kt
Ceiling:	30,000 ft
Endurance:	4 hr

3.2.1.1.3 S-3B Viking

Figure 3-7. NASA GRC, S-3, Viking, T/N N601NA, High Speed Ownship/Intruder Aircraft

The NASA GRC S-3B Viking (Figure 3-7) is a four-seat, twin engine turbofan-powered high performance jet aircraft. The aircraft is ADS-B equipped and will support test missions as a high speed ownship/intruder aircraft for pairwise and can serve as an intruder for full mission encounters. During FT4, the S-3B will be capable of operating as an ADS-B and ATAR equipped UAS surrogate aircraft that will have 2-axis autopilot control for UAS autonomous operations.

General Performance Characteristics

Weight:	32,000 lb
Speed:	429 kt
Ceiling:	40,000 ft
Endurance:	10 hr

3.2.1.1.4 Beech C90

Figure 3-8. Honeywell, Beech C90, T/N N3GC, Intruder Aircraft

The Honeywell Beech C90 (Figure 3-8) is a twin engine turbo-prop, eight seat aircraft modified with an onboard TCAS system recording. The C90 supports test missions as an ADS-B and TCAS II equipped intruder aircraft primarily for pairwise encounters but can also support full mission operations as required.

General Performance Characteristics

Weight:	10,100 lb
Speed:	247 kt
Ceiling:	30,000 ft
Endurance:	4.5 hr

3.2.2 Virtual Resources

3.2.2.1 Multi-Aircraft Control System (MACS)

The Multi-Aircraft Control System (MACS) program provides a virtual ATC display functionality and generates the constructive air traffic that provides a realistic environment for the subject under test during full mission flights. A separate instance of MACS will be used for each function supporting flight test, including an ATC sector position a Ghost Controller, Ghost Pilot, two Pseudo Pilots, and a Pseudo Pilot Manager. An emulation of the En Route Automation Modernization (ERAM) environment replicating Oakland Center's ZOA 40/41 sectors will be used for the full mission test. Figure 3-9 shows MACS configured as an ERAM sector display.

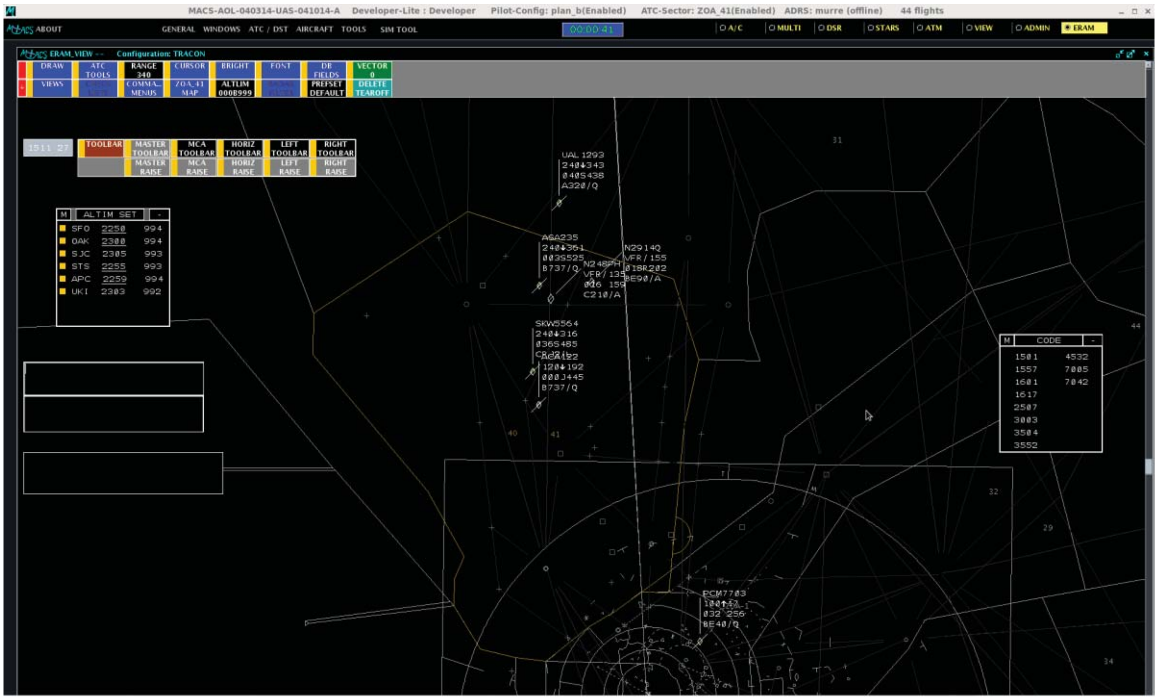


Figure 3-9. Multi-Aircraft Control System (MACS) Air Traffic Control displays

MACS also runs as a standalone Pilot Station with built-in UAS characteristics providing a virtual GCS, called the MACS GCS (Figure 3-10). This version of MACS hase the NASA Langley Stratway+ SAA system integrated into its software. The RGCS will be used for Test Setup 3 and will provide the position updates for the primary UAS aircraft of interest in each scenario. The MACS GCS will be used at NASA Langley during Test Setup 3.

Figure 3-10. MACS Ground Control Station displays.

3.2.2.2 Vigilant Spirit Control Station (VSCS)

AFRL's Vigilant Spirit Control Station (VSCS) UAS simulator provides the ground control station capability as well as modeling of a UAS aircraft in simulation mode (Figure 3-11). It connects to the LVC and the rest of the simulation environment via the HLA, providing position updates based on flight plan and state data provided by the Vigilant Spirit Simulator or a live aircraft. The Traffic Display shows Self-Separation conflict advisories and alerts in addition to intruder information such as call sign (if available), relative altitude, vertical velocity, and ground speed. The VSCS Traffic display can also show resolution maneuvers and support “vector-planning”. Vector-planning allows the pilot to test various horizontal or vertical vectors to help determine appropriate trajectories to avoid potential conflicts. Maneuver resolutions and vector-planning are facilitated by the SAA system, which is derived from the AutoResolver technologies developed by NASA Ames to support resolution advisories for manned aircraft. It will connect via the LVC Gateway, receiving data from VSCS and MACS SimMgr, and sending advisories back to the LVC, which are then sent to the VSCS and presented on the Traffic Display.

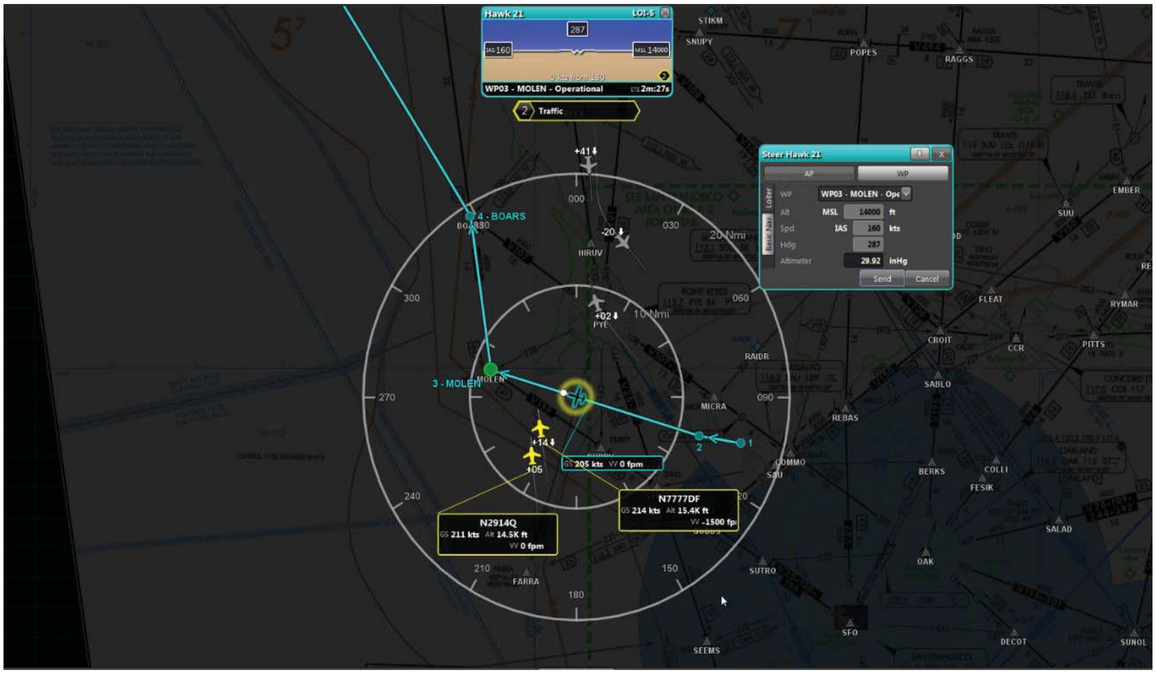


Figure 3-11. Vigilant Spirit Control System (VSCS) Integrated Traffic and Tactical Situation Display.

3.2.2.3 Conflict Prediction and Display System (CPDS)

Figure 3-12 shows a screen shot of the Conflict Prediction and Display System (CPDS) developed by General Atomics, which provides GCS-TD functionality. It shows the ownship aircraft with proximal surrounding traffic. During the FT3 the CPDS will provide the UAS pilot with situation awareness and SS advisories.

A key feature of the CPDS is to keep the pilot involved in conflict resolution before collision avoidance is necessary. The CPDS is a display that helps the pilot obtain sufficient situational awareness to anticipate and resolve potential conflicts before they become time-critical through the implementation of Conflict Probes [6].

Figure 3-12. GA-ASI Conflict Prediction and Display System (CPSD)

3.2.2.4 Research Ground Control Station (RGCS)

The UAS Ground Control Station (GCS) capability will be provided by the RGCS at NASA Armstrong for Configuration 2 (Full Mission). The RGCS is a hardware test-bed for UAS GCS information display and human factors concepts. It contains the monitors and computer systems that run the display systems under test. A graphical representation of the RGCS is depicted in Figure 3-13.

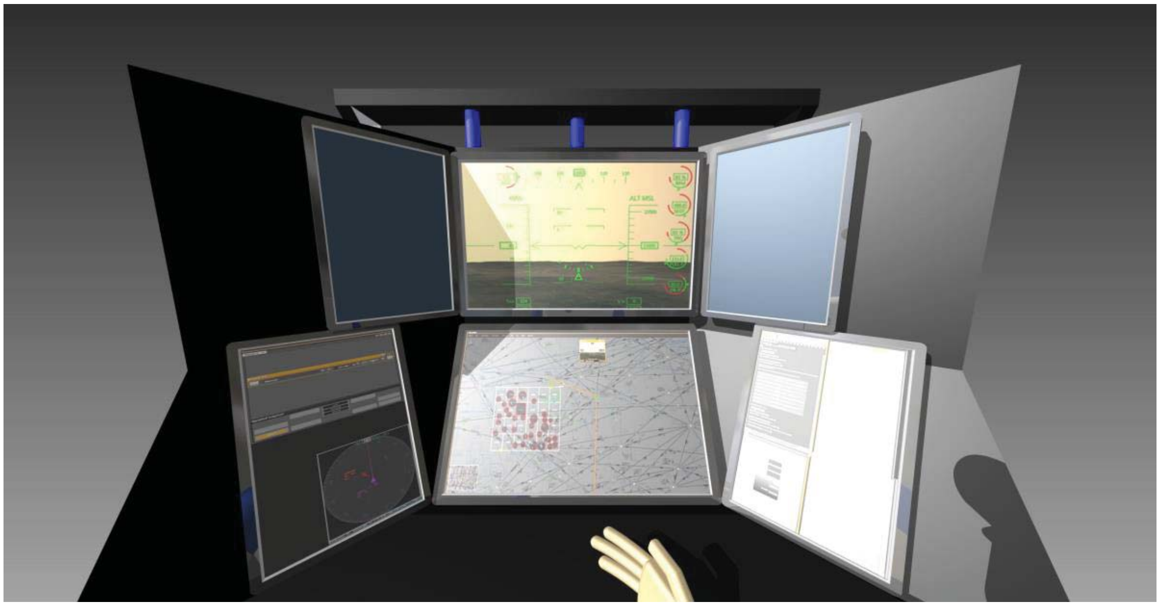


Figure 3-13. Research Ground Control Station layout.

3.2.2.5 Multi-Aircraft Control System Programs

The MACS SimMgr and MACS Pseudo Pilot programs provide constructive aircraft targets during testing (Figure 3-14). For the purposes of the IHITL, PT5 and FT3, constructive aircraft are defined as background traffic that fly a prescribed flight path. A subset of the constructive traffic are designated as encounters which interact with the subject aircraft. Other MACS traffic are not the primary aircraft of interest in the scenario, but lend fidelity to the ATC environment. The MACS SimMgr reads the initial conditions and flight path from an input scenario file. Aircraft are then assigned to the MACS Pseudo Pilot stations where the aircraft position updates are generated and sent into the LVC system based on the flight paths and aircraft model data. MACS uses a four degree of freedom trajectory engine to update the location of the aircraft on a one second frequency (emulating ADS-B). The constructive targets can emulate IFR or VFR aircraft.

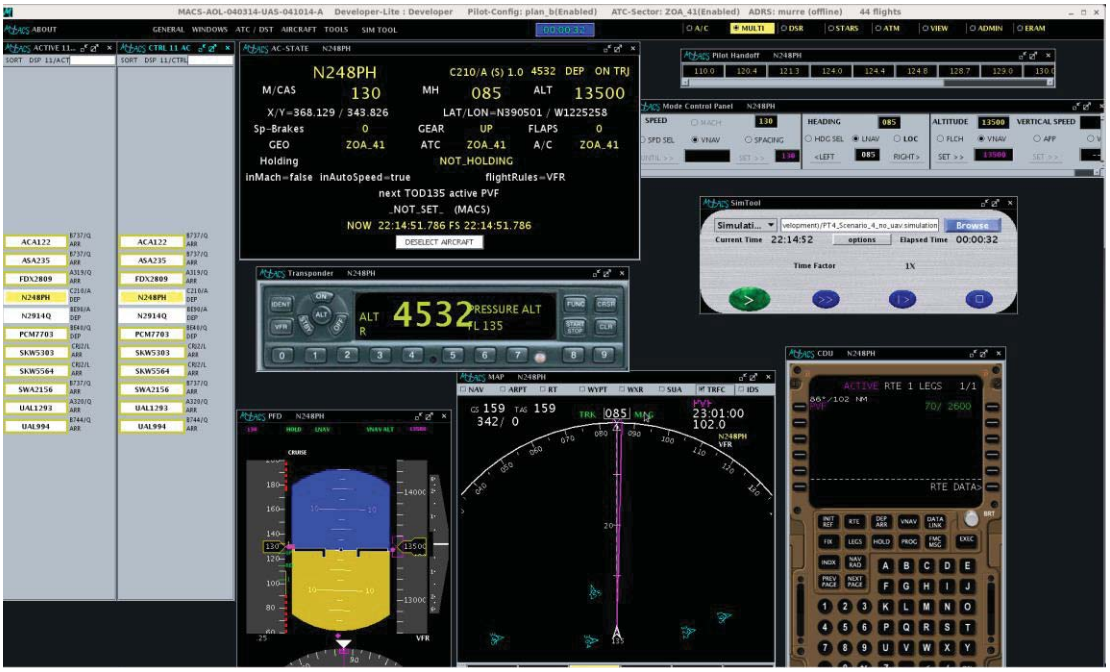


Figure 3-14. Multi-Aircraft Control System (MACS) pseudo pilot displays.

Two instances of MACS ERAM will be used to automate the Air Traffic Control environment. The "Controller" display will emulate ZOA sector 40/41 airspace shown in Figure 3-14. The Ghost position will duplicate the controller's ERAM display and act as the surrounding the ATC positions. The Controller and Ghost will perform ATC duties compliant with FAA orders and procedures specific to ZOA sector 40/41.

3.2.3 Test Facilities

Table 1 presents a list of the test facilities to be used for FT3 and their purpose. Testing will be conducted at three primary facilities: the DSRL and CVSRF labs at NASA Ames and the RAIF lab at NASA Armstrong. The DSRL lab at NASA Ames will be the virtual control center for the as well as contain the core LVC interface components, including HLA, HLA Toolboxes and the LVC Gateways. CVSRF is also located at NASA Ames and will run the instances of MACS ERAM and MACS SimMgr. The RAIF at NASA Armstrong contains two work areas, the RGCS/UAV Simulation Development Lab and the LVC Distributed Environment Lab. The first contains the RGCS, which connects to the HLA via an LVC Gateway. The second contains the LVC Gateway and simulation monitoring displays. The LVC lab also serves as a viewing area for project VIPs.

Table 1. List of FT3 Facilities.

Facility	Location	LVC Component
Crew Vehicle Simulation Research Facility (CVSRF)	NASA Ames	MACS ERAM, MACS SimMgr
Distributed System Research Laboratory (DSRL)	NASA Ames	HLA
Research Aircraft Integration Facility (RAIF) UAV SIM Development Lab	NASA Armstrong	RGCS, LVC Test Support

3.2.4 Test Area

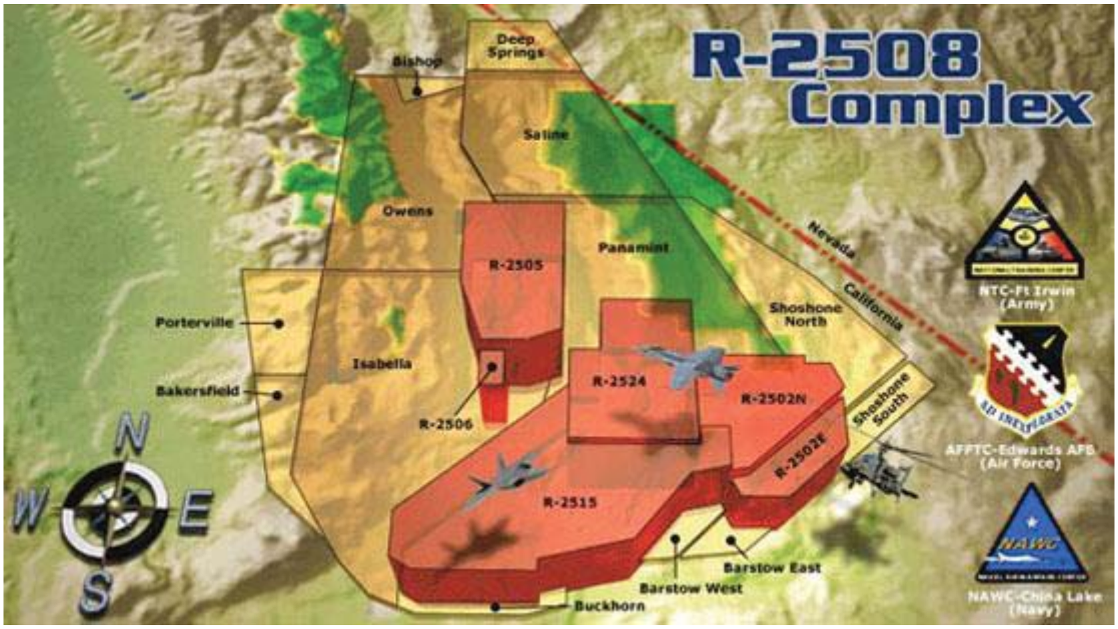


Figure 3-15. Southern California R-2508 Range Complex.

The baseline IT&E CONOPS describes pairwise and full mission encounters being flown at Edwards AFB within the R-2508/2515 airspace complex (Figure 3-15). NASA Armstrong is properly equipped to fully support the planned flight test missions using the DATR with some support provided by the Air Force. The HW C90 will operate out of the Van Nays Airport.

3.2.5 Spectrum Management

Spectrum requirements for new RF systems (CNPC and EDM radar) must be vetted through the NASA AFRC SMO for operations that occur within the R-2508/2515 airspace complex.

3.2.6 Communication Resources

Both pairwise and full mission encounters requires voice communications to meet mission effectiveness and ATC requirements (Figure 3-16). All voice communications are planned for using VHF two-way aviation radio frequencies. A minimum of 2 VHF radios are required as mission discreet channels to meet minimum test objectives. One VHF radio will be used to perform actual test mission tasks (TC/SPORT Net) and one VHF radio will be used for performing the mission under test (Virtual ATC Net). As depicted in the baseline Voice Communication Architecture Figures 2-23/24, the Control and Non-Payload Communications (CNPC) radio will support the voice comm requirements for the UAS Surrogate aircraft. The test conductor will primarily use TC/SPORT net to conduct the actual flight test mission communicating mission-related information to all airborne test aircraft on that channel. For missions flown within the Edwards complex, an assigned, dedicated SPORT controller will monitor TC/SPORT net and provide real-time traffic and airspace calls as required. The Virtual

ATC net is used by the pilot under test who is positioned at the RGCS pilot station. Virtual ATC provides a representative virtual ATC environment within Class E airspace in Oakland ARTCC airspace (ZOA).

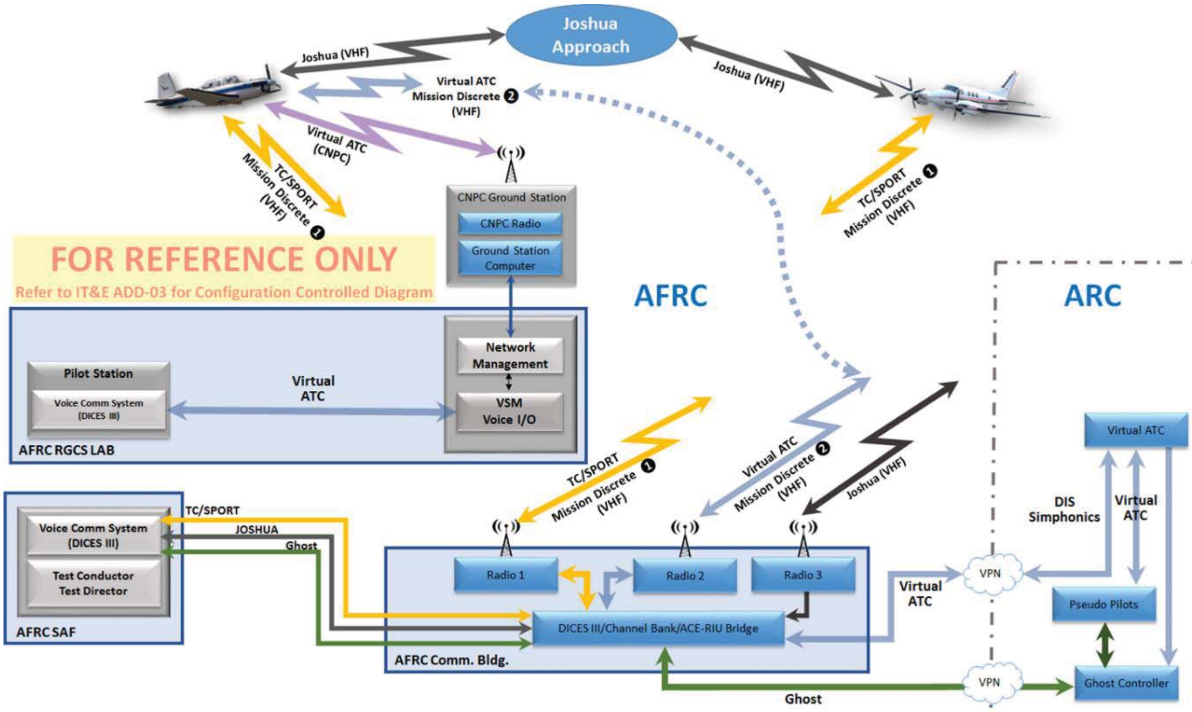


Figure 3-16. Full Mission Voice Comm Architecture at AFRC.

Virtual ATC net is used to support the comm requirements for performing the mission under test during full mission encounters. Subject pilots positioned at the RGCS will communicate to ATC on the Virtual ATC net. From the subject pilot’s perspective, he/she is flying their UAS within Oakland ARTCC airspace and they are communicating with Oakland Center controllers. Since the UAS Surrogate aircraft is a required participant of the virtual element during full mission encounters, the surrogate must also have a dedicated radio assigned to Virtual ATC. Figure 3-17 depicts a basic communication plan for Configuration 1 and 2 missions.

All actual (live) aircraft participating in the test must be able to communicate with real ATC responsible for the airspace where the test is being conducted hence there may be periods of time where a VHF radio must be available and channelized to local ATC. For the Edwards complex, Joshua is the local airspace controlling agency when SPORT is not operational.

Ghost net is an IP link between the Test Conductor and Ghost Controller used to coordinate test encounters during full mission sorties. Variations to the planned virtual and actual test encounters are expected and the Test Conductor and Ghost Controller will need to communicate real-time in order to ensure mission success.

Test Setup 1

Net / Position	Test Conductor	GCS Pilot	Virtual ATC	Pseudo Pilot	Ghost/ Observer	Sim Engineers	H S I	SSI
Virtual ATC (125.85)	R	T/R	T/R	T/R	R	R	R	R
Test Conductor Net (120.00)	T/R				T/R	T/R	T/R	T/R
Engineering Net (126.6)	T/R					T/R		
Ghost Coordination (132.2)	T/R	T/R			T/R		T/R	T/R

Test Setup 2

Net / Position	Test Conductor	GCS Pilot	Virtual ATC	Pseudo Pilot	Ghost/ Observer	Sim Engineers	H S I	SSI
Virtual ATC (125.85)	R	T/R	T/R	T/R	R	R	R	R
Test Conductor Net (120.00)	T/R				T/R	T/R	T/R	T/R
Engineering Net (126.6)	T/R					T/R		
Ghost Coordination (132.2)	T/R				T/R		T/R	T/R

- Virtual ATC – standard controller/pilot communications
- Test Conductor Net – communications between test team – includes researchers and UAS pilot when not test subject
- Engineering Net – test team coordination – shared between simulation engineers and researchers

Figure 3-17. FT3 Configuration 1 & 2 Communications Matrices
(Note: Net Users & Frequencies are notional in this diagram—need to update)

3.2.7 Test Support Resources

In order to conduct actual and virtual flight test encounters in a geographically diverse physical and virtual test environment, dedicated test support resources are required. Additional details for this section are TBD.

3.2.8 Instrumentation and Data Collection Resources

Details for this section are TBD.

3.2.9 LVC Test Setup Architecture

3.2.9.1 Pairwise Encounters of Live Aircraft (Test Configuration 1)

The experimental goal of this study is to gather data to help determine the effectiveness of the self-separation maneuver to remain well clear without violating the intruders Collision Avoidance threshold volume. Metrics to determine the impact of coordinating (or not) well clear maneuvers will include whether maneuver within and outside encounter was noted and its type, gross workload measured post-scenario, the amount of time spent performing the avoidance maneuvers, and acceptability assessment questionnaire administered at the end of each collection run.

Figure 3-18 shows the LVC design for the Pairwise Encounters of Live Aircraft test configuration. In this simplified data collection effort, there are no subjects, only engineering and pilot participants running preplanned flight plans for the unmanned and intruder aircraft. For the tests the unmanned aircraft will be provided by the Ikhana MQ-9. The GRC S-3B will provide high speed ownship encounter support. Ikhana will be outfitted with an air surveillance radar system, TCAS II and ADS-B. The intruder aircraft will be equipped with ADS-B and TCAS. The sensor onboard the unmanned aircraft will receive data from the intruder aircraft and feed that data to the onboard data fusion algorithm. This data will be sent do to the GCS where it will be sent to the LVC via the LVC Gateway and then on to the Self Separation algorithms.

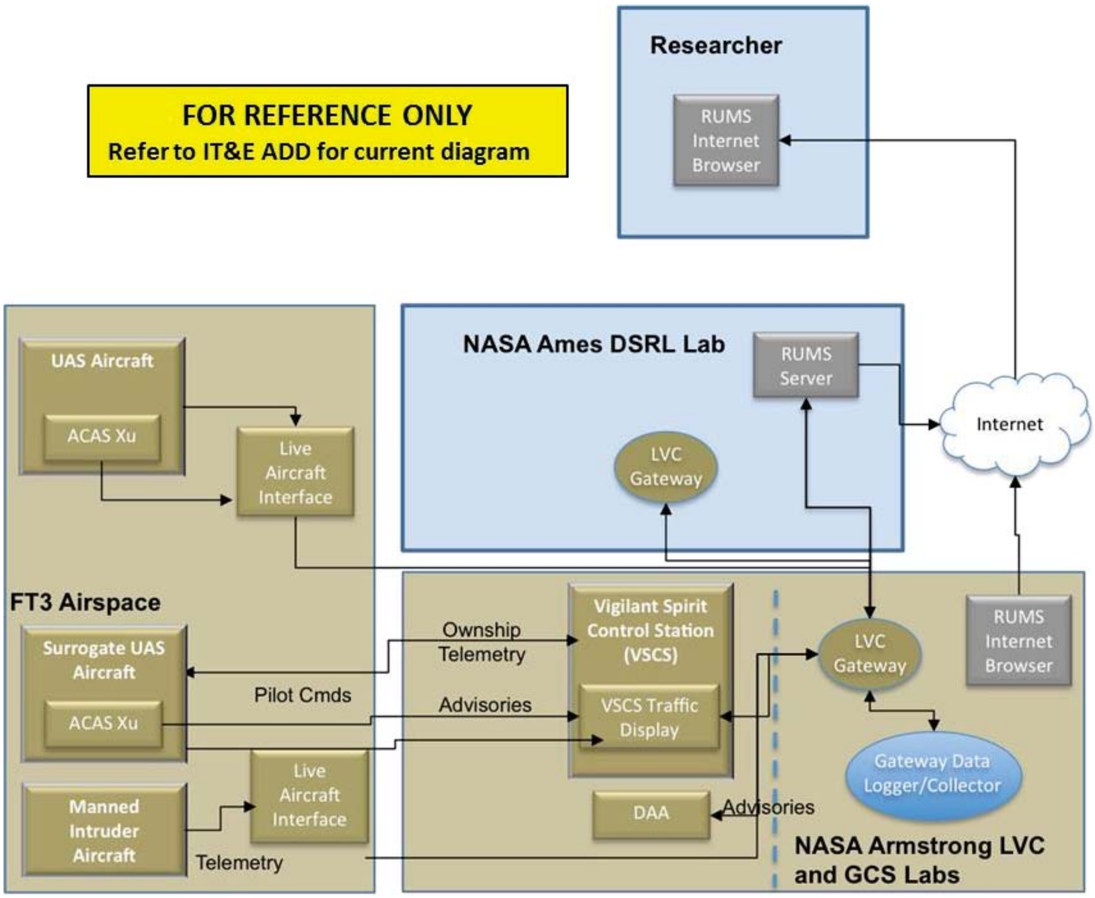


Figure 3-18. FT3 LVC system with components for the Pairwise Encounters of Live Aircraft Test Configuration (including observer positions)

Note: Need to update diagram to remove reference to ACAS Xu and add CPDS.

3.2.9.2 Full Mission of Live Aircraft Encounters (Test Configuration 2)

The experimental goal of this study is to continue the evaluation of candidate SAA information displays and systems with respect to self-separation, based on previous simulation results and lessons learned. Focus is on the effect of:

- Advanced traffic display elements and tools on pilots' ability to remain well clear
- Different sensor ranges for intruder aircraft on pilots' ability to remain well clear?

Figure 3-19 shows the LVC design for the Full Mission test configuration. The core LVC infrastructure will be provided by the HLA messaging system running at the DSRL lab at NASA Ames. The UAS pilot subject will utilize the RGCS functionality at NASA Armstrong's RGCS lab. The UAS Surrogate control will be provided by the VSCS instantiated in the RGCS. The integrated SAA display provides situation awareness of the surrounding air traffic and SAA advisories, alerts, and guidance information to the pilot. The SAA system is derived from the AutoResolver and Stratway+ technologies for Self-Separation resolution advisories, which are connected to the RGCS via a Gateway. The MACS SimMgr Pseudo Pilots running out of the CVSRF provides virtual and constructive manned background aircraft. Two live manned intruder aircraft will be used to evaluate the SSA system under real world conditions. MACS ATC provides the virtual ATC environment and will also be run out of the CVSRF at NASA Ames. Note for this test setup, the controllers and pseudo pilots are co-located in order to allow for easier collaboration against the UAS pilot subject. The MACS processes communicate to each other and the rest of the LVC processes via the ADRS, which in turn connects to HLA.

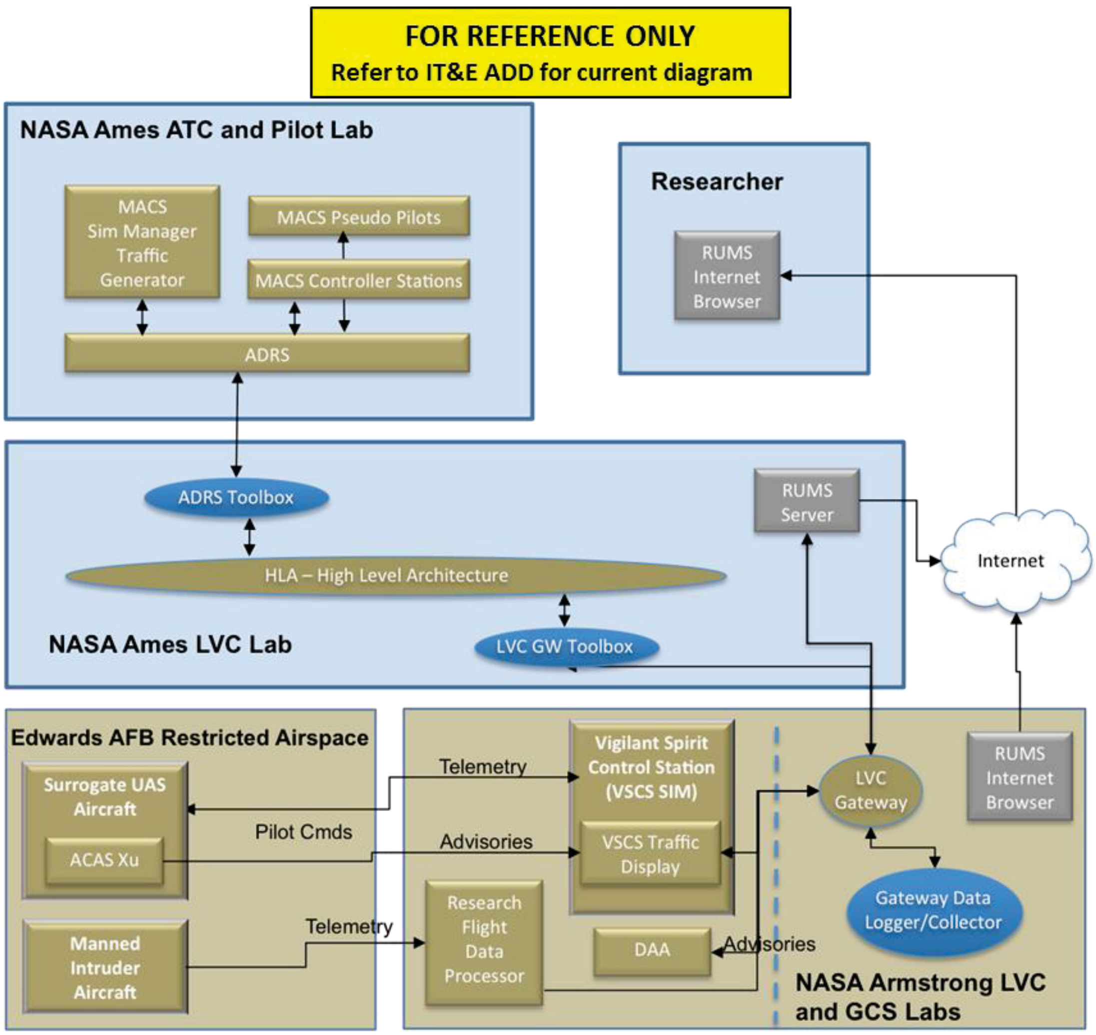


Figure 3-19. FT3 LVC system with components for the Pilot Acceptability of SAA Maneuvers Full Mission Flight test setup (including observer positions)

Note: Need to update diagram to remove reference to ACAS Xu and add CPDS.

3.2.10 Simulation Resources

Details for this section are TBD.

3.2.10.1 High Level Architecture (HLA) and LVC Gateway

As stated previously, the framework for the simulation environment will be supplied by the LVC via the High Level Architecture (HLA) messaging infrastructure. The LVC uses a version of the IEEE 1516 standard Pitch portable Real Time Infrastructure HLA and Federation Object Model (FOM) middleware, modified at NASA Ames, to exchange information about the air traffic environment (aircraft state, flight plans, digital messaging) among the participants operating from distributed facilities. The HLA utilizes Toolboxes to convert data from simulation components (e.g. flight simulator, or air traffic control display) into its expected format. The LVC Gateway was developed to enable passing of messages within a facility (without the need to distribute them to HLA), for those messages that are then required to be sent to a distributed facility, the gateway connects to HLA via a toolbox.

3.2.10.2 Remote User Monitoring System (RUMS)

In order to facilitate the monitoring of the data collection, the Remote User Monitoring System (RUMS) software processes connects to the LVC Gateway process and provides an ability to access and display data being collected via a web browser. The RUMS server connects to the LVC Gateway and handles the web browser data requests.

3.2.10.3 Flight Test Environment

The test environment for performing pairwise encounters requires sterile airspace to perform the encounters with 1,000 ft vertical buffers below the lowest participating aircraft and 1,000 ft above the highest participating aircraft. Ideally these encounters will be flown within the R-2515 in scheduled airspace that omits other users during the period scheduled. Due to limitations to the size of the scheduled airspace, at times intruder aircraft may maneuver outside of the schedule with concurrence by the assigned SPORT controller.

Full mission flight encounters are also planned for the R-2508 Complex which includes the use of Military Operating Areas (MOAs) adjacent to R-2515 airspace. These missions will not have vertical buffers since all participating live aircraft will be manned and see and avoid applies to all airspace users.

3.3 Flight Test Equipment

3.3.1 Aircraft Required Systems

All participating aircraft require the following minimum equipment:

- ADS-B Out
- Mode 3/C Transponder
- GPS
- VHF Voice Comm Radio (2)
- CNPC (UAS Surrogate aircraft only)

In addition to the minimum equipment some participating aircraft require to be properly equipped for flight test as described in 3.3.1.1-3.3.1.4:

3.3.1.1 Navigation Systems

Aircraft in this flight test are equipped with navigation systems that use Global Positioning System (GPS) derived position. Due to strict timing and position requirements for safety, aircraft shall not use any mode of navigation that does not use GPS as the primary source for navigation. In addition, if aircraft have a Wide Area Augmentation System (WAAS), this will be disabled so that all participating aircraft are functioning with the same atmospheric and ephemeris errors.

3.3.1.2 Certified Systems

A manned intruder aircraft equipped with TCAS II version 7.1, for the purpose of demonstrating legacy TCAS interoperability, the reception of and compliance with 1030 MHz. The TCAS traffic display on manned intruder aircraft will be the primary means by which those aircrews maintain situational awareness for safety during the Configuration 1 flight test. The Honeywell C90 (N3GC) is planned to support this requirement.

For the purpose of situational awareness on the ground, interoperability demonstration, and data collection, all aircraft will be equipped with ADS-B.

3.3.1.3 Prototype Systems

Engineering Development Model Due Regard Radar (Air-to-Air Radar):
EDM is a radar system which supports an airborne SAA architecture for the Predator B UAS. The EDM ATAR is an advanced prototype developmental radar system that has increased surveillance volume and is intended to be installed in the NASA AFRC Ikhana as part of a SAA system that senses both cooperative and non-cooperative aircraft, fuses the sensor data, generates alarms.

Honeywell Tracker:
The Honeywell Tracker fuses all sensor data that is available for a given target. For cooperative targets, ADS-B, TCAS, and EDM measurements (when available) may be fused. For non-cooperative targets, only EDM measurements are available.

3.3.1.4 Software Systems

Details for this section are TBD.

3.3.1.5 Ground Required Data Systems

All flight test operations require the following test support ground systems to be operational for mission success:

Live Virtual Constructive (LVC) Distributed Environment (DE) – The LVC-DE will provide the capability to emulate the Air Traffic Control (ATC) environment, simulate constructive background traffic and incorporate virtual Unmanned Aircraft (UA) simulations, live UA, and live surrogate UA test vehicles as well as live background air traffic. The LVC-DE will need to support currently envisioned UAS-NAS IT&E efforts as well as provide the flexibility to support future activity and expand the LVC-DE to include nodes at other Centers or Facilities.

Dryden Aeronautical Test Range (DATR) – The DATR supports the actual flight test environment with telemetry, communication and data processing systems.

- DATR telemetry tracking systems consist of multiple fixed antennas at Armstrong and a fleet of mobile systems for deployment to specified locations. The antennas are capable of supporting down-linked telemetry and video signals in C-, L-, and S-bands while sending up-linked commands in either L- or S-bands. The antennas track targets from horizon to horizon and are certified as having full on-orbit capability for low earth orbiting spacecraft. Down-linked telemetry may be received in either analog or digital format. Mobile operations can provide telemetry tracking for test missions operating outside local airspace boundaries.

- The Radio Frequency (RF) Communications facility provides more than 40 ultra-high frequency (UHF), very high frequency (VHF), and high frequency (HF) transmitter receivers, and a UHF flight termination system (FTS). An extensive range intercommunication system consists of trunk lines, communication panels, public address systems, commercial telephone systems, and military ground communication networks. An integrated network of communication, fiber optic, and satellite systems is also used to relay telemetry, radar, audio, and video data between Armstrong facilities, NASA centers, other government agencies, and industry partners

- Data processing systems acquire and merge data from multiple sources in various formats to a single, time-correlated, composite stream for processing, distribution, real-time display, and storage archival. Segments of post-mission data is available on portable media immediately following the test mission.

ADS-B Receiver Data Source – Details for this section are TBD.

3.3.1.6 Control Room Required Systems

Stand Alone Facility (SAF) – The SAF, located at NASA AFRC in building 4800, will be used by the test conductor and test director to coordinate, manage, and execute the flight test. The room has three workstations, one dedicated to UAS-NAS operations, each configured with DICES III voice comm systems and several display monitors (including ZEUS, Quick Look, TECCS, Ikhana video camera sources, and VS traffic displays) providing situational awareness and two-way voice capability for test execution.

3.3.1.7 Support Systems

Details for this section are TBD.

3.4 Security Requirements

Details for this section are TBD.

3.4.1 General Security

No General Security issues. The tests will involve and be conducted by NASA civil servants and contractors; specific partner agreements for external partners for these tests are in place and on file.

3.4.2 Operations Security

There is no sensitivity to the data collected during the tests. All participants are diligent to potential comm radio spoofing/interference that sometimes occur on VHF nets.

3.4.3 Communications Security

Voice communications will be conducted via actual RF radios transmitting in free space or with comm links over an encrypted VPN. The specific IT security plans are on file and under access control.

3.4.4 IT Security

All transmissions between distributed facilities are encrypted. The specific IT security plans are on file and under access control.

3.4.5 Data Security

There is no sensitivity to the data collected during the tests. The Data Analysis Plan contains the details regarding handling and storage of the data.

3.5 Flight Test Limitations

The following limitations apply to this flight test:

● FT3 will use various simulators to emulate a realistic test environment. These simulators have varying degrees of fidelity (i.e. ability to match their real counterparts). MACS uses a set of aircraft models in order to generate aircraft position updates. Similarly, the MACS ERAM emulates an ATC en route environment, though not all ERAM functionalities will be available for the IHITL. Though the MACS aircraft and ATC emulation are not perfect reproductions, they have been used to model aircraft flight and air traffic control display capabilities for many simulations.

● The Engineering Development Model (EDM) Due Regard Radar has a field of regard of ±110° in the horizontal direction and ±15° in the vertical direction. EDM range is expected to exceed 10nm. Additionally, the Prototype DRR has a field of regard of ±45° in the horizontal direction and ±15° in the vertical direction. DRR has a range to detect targets between 5-15 miles depending on aircraft size and could detect larger aircraft out to 30 miles.

● During FT3 scenarios that coordinate with TCAS, the intruder aircraft may be expected to maneuver when an alert is given during certain encounters. At other times, the intruder will not respond to TCAS alerts which will ensure that the ownship aircraft receives an alert and has an opportunity to act on it. This, however, does not preclude the TCAS equipped intruder aircraft from responding to TCAS alerts for non-participatory aircraft since these alerts would be unplanned and are to be considered a real-world safety of flight threats.

● Pairwise encounters are planned to occur in R-2515 within scheduled work areas that includes Mercury Spin, East/West Range, Four Corners and Buckhorn MOA. ATC expects all participating aircraft to remain within the scheduled/assigned airspace boundaries at all times unless prior coordination/permission is provided by ATC.

● ATC expects all participating aircraft to remain within the scheduled/assigned airspace boundaries at all times unless prior coordination/permission is provided by ATC for Full Mission Flight test encounters that are planned to occur within the R-2508 Complex.

4 Flight Test Execution

Execution of all flight test encounters will follow a buildup approach and employ best practices used by the flight test communities located at Edwards AFB, CA. The NASA Armstrong airworthiness and flight safety review process will apply to all encounters flown out of AFRC. This section identifies general and specific operational processes and procedures that will be used to execute the flight test. Flight test is divided between Pairwise (or Configuration 1) encounters and Full Mission Flight (or Configuration 2) test encounters. Flight safety is essential to all test encounters and aircrew are expected to use good judgment at all times. Pairwise flight test encounters will be performed using a safety buildup approach which means that test cards with encounters that have the greatest vertical separation will normally start first followed by encounters where the vertical separation is decreased. Once a particular test encounter geometry has been cleared at a specific vertical separation, same encounters performed on subsequent test days do not require a repeat of the test buildup task.

All flight test encounters that have <500 ft vertical separation require an altimeter calibration prior to performing these encounters. Further, the intruder pilot performing test encounters of <500 ft vertical separation require visual identification (VID) of the ownship aircraft at least 1 nm prior to intruder aircraft based on TCAS display. The intruder pilot is expected to establish and maintain the visual throughout every encounter (regardless of vertical separation) from 1 nmi prior to ownship aircraft (based on TCAS display) through the CPA unless the test is concluded prior to the CPA due to alert maneuvering or situations where VID is expected to be lost during the encounter. Once VID is established on the ownship aircraft, the intruder pilot will callout the visual on the TC/SPORT net. When encounters are flown with manned aircraft (Configuration 1B and 2), the visual requirement applies to both ownship and intruder aircraft.

Sections 4.1 through 4.5 cover procedures and tasks required for every test day unless otherwise noted (altimeter calibration procedures). Sections 4.5 and 4.6 cover specific requirements, procedures, and tasks for pairwise (Configuration 1) and full mission flight (Configuration 2) encounters (respectively).

4.1 Mission Briefings

Flight test operations will typically be preceded by two briefings using the NASA Armstrong standard processes.

4.1.1 Preflight Brief

The first prebrief is called a T-1 briefing which is normally performed the day prior to a mission. All flight test participants are required to participate in the T-1 briefing. The T-1 briefing covers numerous topics that include the following: Roll Call, Time Hack, Mission Summary (Overview & Objectives), Mission Timeline, Weather & NOTAMS, Aircraft/GCS/Airfield Status, Comm Data, Mission Information (Mission Rules, Go/No-Go, and Flight Safety), Test Overview & Procedures, Test Card Review.

Day of Flight brief typically occurs a few hours prior to the flight and is used to discuss current weather, cover any changes, and generally to focus the team on the test.

4.1.2 Post-Flight Brief

The post flight debrief is used to review the mission in terms of timeline (i.e. what occurred), test results, aircraft squawks, lessons learned, issues, and future planning.

4.2 Standard Air Navigation Procedures

Pilots will comply with all standard flight rules as described within applicable FARs (14 CFR) and local guidelines as appropriate. The standard requirement to 'see and avoid' other aircraft (14 CFR Part 91.113) applies. The exception is Ikhana when operating within special use airspace where other mitigations (i.e. mission rules, SOPs, etc.) apply in order to help ensure safe flight operations.

4.2.1 Air Traffic Control

All airborne participants shall comply with local ATC rules as they apply in the execution of the flight test encounters. Within the Edwards Complex (R-2515), SPORT has ATC authority except during periods of time when operational control is assumed by Joshua Approach Control. For FM test encounters, the project is planning to coordinate with Joshua Approach Control for permission to use SPORT as the dedicated controller while operating in R-2508 airspace.

4.2.2 Visual Flight Rules

All flight test encounters shall be performed using visual flight rules (VFR) as described in 14 CFR Part 91.151, 153, 155 and 159 as they apply to operations within Class E airspace, except where organizational guidelines (NPR, company FOM, for example) take precedence (if more restrictive). Operations within the R-2508 Complex must comply with guidance provided by the R-2508 Complex Users Handbook, EAFBI 13-100, and the aforementioned sections of 14 CFR Part 91. This does not preclude the use of Ikhana, which has procedural means for fulfilling these rules in Restricted Airspace.

4.2.3 Weather

Weather considerations are based on operating in Visual Meteorological Conditions (VMC) at all times during flight test encounters. VMC, or clear of clouds, requires aircrew to operate with cloud ceilings exceeding 1,000 feet above or below the designated altitude block (as described on the test card) and visibility exceeding 5 statute miles (at or above 10,000 ft MSL) are required. Any other potentially prohibiting flight conditions such as wind, turbulence, and/or precipitation that exceed established criteria for launch or recovery cancels or delays tests until conditions are within tolerance. Any other conditions that interfere with successful flight test outcomes are taken under consideration by the team. Before each scheduled flight, the test team confers via Telecon (during the day of flight brief) to make a final “go/no-go” decision based upon the current and forecast weather or any other last minute changes in operational restrictions.

4.2.4 Aircraft Calibration Procedures

All participating aircraft are expected to have a current altimeter calibration in accordance with airworthiness certification requirements based on the type of FAA aircraft certificate held. Pilots are expected to perform an altimeter check prior to flight operations to determine whether the altimeter is within normal limits (±75 ft). For flight test operations that are planned to be ≥500 ft vertical separation, no airborne altimeter calibration check is planned. Pairwise self-separation encounters flown in the Edward Complex shall use 29.92 Hg altimeter setting.

All participating aircraft shall monitor GPS navigation error reporting and inform the test conductor if the navigation system reports lateral errors greater than 0.1 nmi (600 ft). Aircrew will monitor the reported GPS position quality (figure of merit) periodically during test runs to ensure that the reported error does not exceed test limits.

All participating aircrew will manage encounter timing based on GMT based on the clock located in the SAF. The test conductor, test director or project pilot will provide a time hack at the flight prebrief. In general aircrew will plan to meet mission timing (CPA) within ±8 sec. Timing tolerances for a given encounter will be identified on the respective encounter test card.

An airborne altimeter calibration check will be performed for all Pairwise and FM encounters that are planned to result in <500 ft vertical separation. An altitude calibration check test card will be developed and provide to aircrew prior to performing altimeter calibration checks. No airborne navigation calibration checks are planned.

4.3 Flight Test Coordination

Successful flight test requires a team effort executing a flight test plan that meets test objectives in a safe and efficient manner.

4.3.1 Flight Test Roles and Responsibilities

The test team has several members who support the test and this section will describe the key roles and responsibilities for conducting the test.

Test Conductor (TC) – The Test Conductor has overall responsibility for test execution and mission success. The TC coordinates flight test scenarios with the aircrew to ensure that flight test objectives are met. The TC is collocated with and interfaces with the Test Director to maintain an overall picture of the test activity. The TC communicates directly via two-way radio with the participating aircrew and local ATC on a mission discrete channel. The TC workstation is located in the SAF.

Test Director (TD) – The Test Director has the overall responsibility for mission safety. The TD is collocated with and interfaces directly with the TC and coordinates with other test team members on back channel nets as required in order to feed the TC with information to help maintain an overall test picture. The TD interfaces with the NASA Senior Ops Representative (SOR) to ensure their understanding of flight test activities. The TD workstation is located in the SAF.

Mission Director/Flight Test Engineer(s) – A Mission Director is assigned to each aircraft to help aircrew in the coordination and execution of the test scenarios and to ensure that mission rules are followed. For the unmanned aircraft, the Mission Director is located within the Ground Control Station and communicates with the aircrew to help in coordination and execution of test scenarios. A Flight Test Engineer flies in the jump-seat for manned aircraft and performs the role of Mission Director in assisting the aircrew in coordination and execution of test scenarios.

Aircrew – The aircrew consists of a pilot and a copilot. The aircrew flies test procedures outlined in this document adhering to navigation/timing constraints and abort procedures given for each flight test card. Aircrew also ensures that the aircraft stays within the vertical and lateral boundaries of the airspace that they have been cleared into. The aircrew coordinates test activities directly with the TC and local ATC to execute the test activity.

4.4 Flight Test Safety

Flight safety is foremost to all flight test planning and essential to executing responsible flight operations. NASA Armstrong has flight safety responsibility for flight test operations performed at AFRC. NASA Glenn has flight safety responsibility for operations performed out of GRC. Effective hazard analysis is the responsibility of all team members and are a required element to enabling the airworthiness and flight safety review board to make flight release decisions. Encounters that are separated vertically by 500 ft or greater are considered inherently safe based on the premise that standard acceptable NAS operations allow for IFR and VHR traffic to operate within the same airspace with 500 ft vertical separation. See and avoid requirements always remain in effect regardless of what flight rules a given pilot is operating under.

4.4.1 Flight Safety Process

AFRC will lead the development of the hazard analysis and follow processes described in DCP-S-001 and DCP-S-002. GRC is responsible for complying with center-required flight safety and airworthiness processes for their aircraft. All participants of FT3 are expected to support and contribute to the flight safety process for the flight test activities.

4.4.2 Mission Rules

Mission rules are mandatory operational procedures specific to the planned flight test and are designed to support safe flight operations. These rules apply to every flight unless specific exceptions are identified within a given rule. Mission rules typically cover standard weather limitations, mission specific constraints to ensure flight safety, and other pertinent operational procedures not covered by the flight manual or other established guidance.

4.4.3 Go / No-Go

A Go /No-Go list is a mandatory set of decision guidelines used to determine whether a mission can be accomplished if required equipment, systems, or personnel are functional, operational and/or available and ready for the intended flight activity.

4.4.4 Abort Procedures

Abort procedures are specific to each scenario flown and are annotated on the flight test cards. An abort is announced over the radio and all test participants must acknowledge including the TC.

Specific conditions which require an abort are outlined in the mission rules, but general guidance is that an abort is mandatory for the following circumstances:

- Unmanned aircraft goes Lost Link, or loses LOS Link (reverts to SATCOM)
- Timing constraints cannot be met within an acceptable tolerance as identified on flight test card
- “No Visual” after a specified distance between ownship and intruder aircraft
- An aircraft begins a maneuver in unplanned vertical direction
- When test participant observes an aircraft is in the wrong position or profile (executing the wrong test card)
- Judgment determines that the run cannot be continued safely

The general procedures for an abort are as follows:

1. Ownship Abort Procedure:

   Shall maintain present heading, through and past the CPA, and change altitude as specified on the flight test card.

2. Intruder Abort Procedure:

   If the intruder aircrew has a visual on the ownship aircraft then the intruder aircraft can maneuver to remain well clear; otherwise, the intruder shall initiate a turn and begin a vertical maneuver as specified on the flight test card.

   If the intruder pilot has a corrective TCAS RA advisory before or during an abort, the pilot follows the abort procedure.

4.5 Pairwise Flight Test Encounters (Configuration 1)

Pairwise encounters, also identified as Configuration 1 (more specifically Configuration 1A and 1B), are self-separation flight encounters involving a single ownship aircraft (manned or unmanned) and one (or more) intruder aircraft performing flight maneuvers that are geometrically paired and segregated geospatially either vertically or horizontally (or both).

Pairwise encounters involving the NASA AFRC Ikhana aircraft are Configuration 1A or Pairwise, Low Speed encounters. These encounters are flown entirely within restricted airspace in the Edwards Complex (R-2515). Pairwise encounters that require a high speed ownship aircraft (>180 KGS), such as the S-3B, are Configuration 1B or Pairwise, High Speed encounters. These encounters will be flown either within the Edwards Complex (R-2515).

Pairwise encounters conducted within the Edwards Complex will be planned to use scheduled airspace that will be reserved for aircraft participating in the flight test. The following areas within R-2515 will be reserved for project use: Mercury Spin Area, East/West Ranges (PIRA), Four Corners and Buckhorn MOA (Figure 4-1).

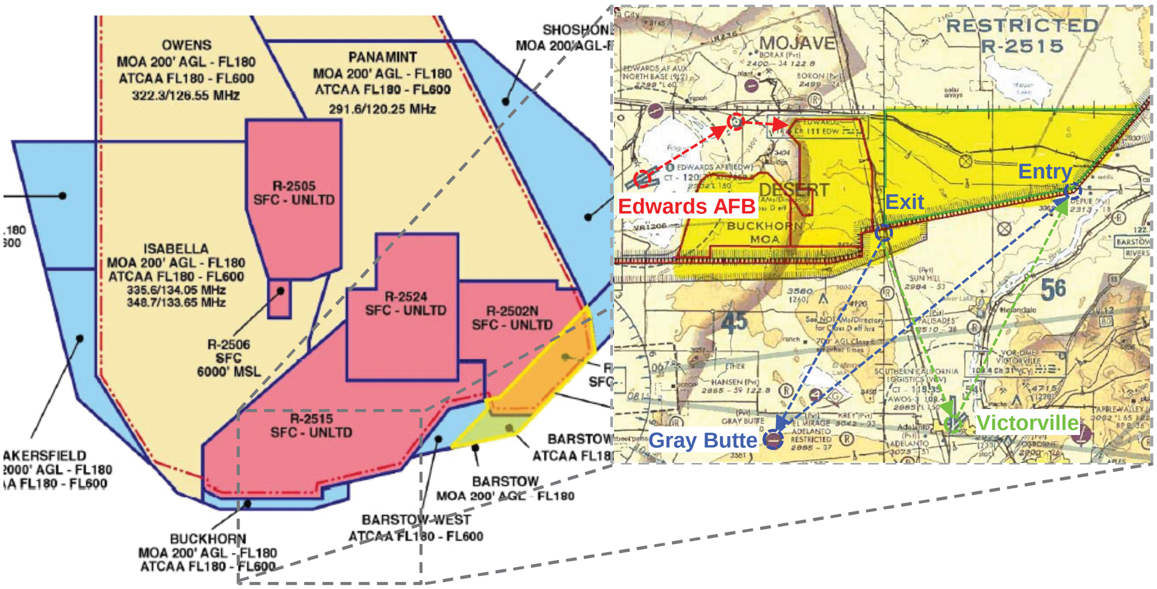


Figure 4-1. R-2515 Areas for Pairwise Encounters.

Pairwise encounters are planned in FalconView and are depicted as navigation legs between two or three waypoints depending upon whether a lateral blunder maneuver is intended. Figure 4-2 depicts an example of a typical pairwise self-separation encounter. Both the ownship and intruder begins the encounter at a designed initial point (IP) and the encounter terminates at the closest point of approach (CPA). Only intruder aircraft are planned to perform lateral blunder maneuvers; therefore on some encounters, an additional waypoint is planned between the IP and CPA. Vertical maneuvering is also planned for either the ownship or intruder aircraft on some encounters. At no time will encounters include both aircraft maneuvering vertically (reducing separation) prior to an alert. Test cards will be developed for each planned encounter and will be provided to the aircrews performing the test. Some SS encounters are planned with multiple intruders. Based on past experience, 15-20 encounters per flight day are expected.

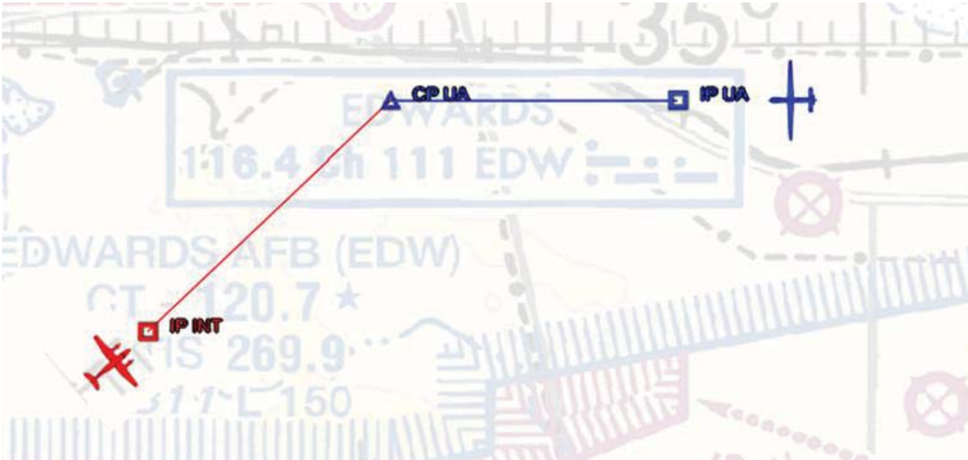


Figure 4-2. Example of a Self - Separation Encounter.

4.5.1 Ownship Requirements

The NASA AFRC MQ-9 Ikhana aircraft is planned for Flight Test 3 ownship low speed pairwise encounters (Configuration 1A). Ikhana will be equipped with the GA-ASI EDM radar, ADS-B, TCAS II, SAA Avionics, and GPS. Some pairwise encounters require a high speed ownship (Configuration 1B). The plan is to use the NASA GRC S-3B for those encounters. Air surveillance radar is desired for the high speed ownship aircraft although ADS-B is required for all high speed ownship aircraft. Ownship aircraft must be available to support the planned flight schedule.

4.5.2 Intruder Requirements

Intruder aircraft require ADS-B, and GPS. TCAS II with onboard data recording is desired for some pairwise encounters. Further, a small number of planned encounters require a high speed intruder aircraft. Some pairwise encounters require two intruder aircraft (one of which must be high speed capable).

4.5.3 Minimum Separation

The minimum geospatial offsets planned are 300 ft vertically and 0 ft horizontally. Test encounters will include an acceptable lateral offset of 3000 ft (0.5 nmi) which allows for some built-in lateral offset that still meets well clear volume requirements and test data collection objectives.

All participating aircraft will ensure that the aircraft altimeter system meets manufacturer calibration specifications and requirements for normal operation in the NAS.

A maximum of 600 ft (0.1 nmi) navigation error (GPS derived position) is allowed for each aircraft based on the system's built-in navigation accuracy readout.

4.5.4 Test Flow

Figure 4-3 and 4-4 depicts the Pairwise self-separation encounters required by NASA ARC and LaRC (respectively) self-separation researchers. The pairwise encounters are further divided into the following flight test groupings:

- Pairwise, low speed–low speed encounters that requires Ikhana ownship versus a low speed intruder aircraft (C90 or T-34C) [Configuration 1A];
- Pairwise, low speed–high speed encounters that requires Ikhana ownship versus S-3B (or G3) [Configuration 1A];
- Pairwise, low speed–low/high speed encounters that requires Ikhana ownship versus multi-intruder aircraft (one low speed intruder (T-34C or C90) and one high speed intruder (S-3B or G3)) [Configuration 1A];
- Pairwise, high speed–low speed encounters that requires S-3B ownship versus a low speed intruder (T-34C or C90) [Configuration 1B].

Priority for test sequence will be driven by UAS-NAS PE requirements, test aircraft availability, weather conditions, airspace constraints, and test execution considerations (i.e. encounter repeat runs such as aborts, resets, system performance issues, etc.).

The test conductor will design a flight test order of cards prior to each flight test day that outlines the test card flow for that flight test period. Typically 20 test cards will make up the card order with potentially 5-10 additional cards placed in the card deck as backup or nice to have encounters that have the lowest priority for that day.

On a given test day, the order of cards will be executed based on the sequence briefed during the T-1 briefing. The order of cards with the assigned card numbers will be covered during the prebrief plus any red line changes to the cards that were not previously briefed will be discussed. The ownship aircraft will depart Edwards AFB (EAFB) main runway and proceed to the test area located within R-2515. The intruder aircraft will depart from either EAFB (T-34C or S-3B) or Van Nuys Airport (C90) and proceed to the test location. If a calibration run is required, that card will be run first before any test encounters are accomplished. After the calibration run is completed (if required) the encounters will be performed in accordance with the briefed test sequence.

In general each participating aircraft is expected to maneuver within the assigned airspace to be on conditions to arrive at the CPA within ±8 sec (or as identified on the applicable test card) of the briefed CPA time for that run. The test conductor will announce the CPA time over the TC/SPORT net (VHF). Each pilot performing the run will acknowledge the CPA time and offer alibies (if any). Aircrew are expected to be on conditions at the IP for each encounter; therefore, any adjustments to timing must be made prior to departing the IP. On condition is defined as on airspeed (ground speed), on course, on altitude at the IP in order to make good the CPA time. The IP to CPA leg will be approximately 3 minutes in length.

Once the run has commenced, aircrew will manage airspeed, altitude, cross track and timing to arrive at the CPA within the timing constraints. For runs with ≤500 ft vertical separation, manned participating aircraft are required to call out visual at least 1 nmi prior to CPA. The test run will continue until test objectives are met (alert maneuver or aircraft have reached CPA), at which point, the Test Conductor will call “end of run” signifying that the completion of that run. When well clear, aircrew will maneuver to their assigned altitude to be in position at the IP for the next test encounter as called out by the TC.

All participating aircraft will comply with any abort calls by following the abort procedure located on the applicable test card being flown. If an abort is called, all participating aircraft and the TC will acknowledge the abort call. The TC will announce the next test card to be run. If an abort is called, the team will normally transition to the next card unless there is a priority placed on rerunning the aborted test run.

Flight Test 3 Pairwise Combined Encounter Matrix & Flight Test Cards

		1	2	3	4	5		6	7	8	9	10	11			
			General Scenario Setup													
	Scenario #	Scenario Name	Angle Into	Lateral Offset (ft)	GS OWN	GS INT1	GS INT2	Ownship Initial Altitude	Ownship Vertical Velocity	Ownship Final Altitude	Intruder 1 Initial Altitude	Intruder 1 Vertical Velocity	Intruder 1 Final Altitude	Intruder 2 Initial Altitude	Intruder 2 Vertical Velocity	Intruder 2 Final Altitude
Head-On Level/Ascending/Descending	1	Scenario PW1	0	3000.0	150	180	NA	12000	0	12000	12400	0	12400	NA	NA	NA
	2	Scenario PW2	20	3000.0	150	180	NA	12000	0	12000	12400	0	12400	NA	NA	NA
	3	Scenario PW3	0	3000.0	130	180	NA	12000	1000	14000	14500	0	14500	NA	NA	NA
	4	Scenario PW4	20	3000.0	130	180	NA	12000	1000	14000	14500	0	14500	NA	NA	NA
	5	Scenario PW5	0	3000.0	130	180	NA	15000	-1000	13000	12500	0	12500	NA	NA	NA
	6	Scenario PW6	20	3000.0	130	180	NA	15000	-1000	13000	12500	0	12500	NA	NA	NA
	7	Scenario PW7	0	3000.0	130	180	NA	12000	1000	14000	16500	-1000	14500	NA	NA	NA
	8	Scenario PW8	0	0 / 3000	150	180	150	13000	0	13000	13500	0	13500	12500	0	12500
	9	Scenario PW9	20/-20	0.0	150	180	150	13000	0	13000	13500	0	13500	12500	0	12500
	10	Scenario U/D 211	0	0.0	150	120	NA	16500	0	16500	12000	1000	14500	NA	NA	NA
	11	Scenario U/D 311	0	0.0	150	130	NA	12000	0	12000	16500	-1000	14000	NA	NA	NA
	12	Scenario U/D 411	0	0.0	120	150	NA	12000	1000	14500	16500	0	16500	NA	NA	NA
	13	Scenario U/D 511	0	0.0	120	150	NA	16500	-1000	14000	12000	0	12000	NA	NA	NA
	14	Scenario T111	0	0.0	150	180	NA	12000	0	12000	13000	0	13000	NA	NA	NA
	15	Scenario T112	0	0.0	150	180	NA	12000	0	12000	12500	0	12500	NA	NA	NA
	16	Scenario T113	0	0.0	150	180	NA	12000	0	12000	12300	0	12300	NA	NA	NA
45° Crossing Level/Ascending /Descending Left-to-Right	17	Scenario PW10	45	3000.0	150	180	NA	12000	0	12000	12400	0	12400	NA	NA	NA
	18	Scenario PW11	45	3000.0	130	180	NA	12000	1000	14000	14500	0	14500	NA	NA	NA
	19	Scenario PW12	45	3000.0	130	180	NA	15000	-1000	13000	12500	0	12500	NA	NA	NA
	20	Scenario PW13	45	3000.0	130	180	NA	12000	1000	14000	16500	-1000	14500	NA	NA	NA
	21	Scenario PW14	45	3000.0	150	180	NA	14500	0	14500	12000	1000	14000	NA	NA	NA
	22	Scenario PW15	45	3000.0	150	180	NA	12000	0	12000	14500	-1000	12500	NA	NA	NA
	23	Scenario PW16	0/45	3000.0	150	180	150	13000	0	13000	13500	0	13500	12500	0	12500
	24	Scenario PW17	45/90	0.0	150	180	150	13000	0	13000	13500	0	13500	12500	0	12500
	25	Scenario T121	45	0.0	150	180	NA	12000	0	12000	13000	0	13000	NA	NA	NA
	26	Scenario T122	45	0.0	150	180	NA	12000	0	12000	12500	0	12500	NA	NA	NA
	27	Scenario T123	45	0.0	150	180	NA	12000	0	12000	12300	0	12300	NA	NA	NA
	28	Scenario U/D 221	45	0.0	150	120	NA	16500	0	16500	12000	1000	14500	NA	NA	NA
	29	Scenario U/D 321	45	0.0	150	130	NA	12000	0	12000	16500	-1000	14000	NA	NA	NA
	30	Scenario U/D 421	45	0.0	120	150	NA	12000	1000	14500	16500	0	16500	NA	NA	NA
	31	Scenario U/D 521	45	0.0	120	150	NA	16500	-1000	14000	12000	0	12000	NA	NA	NA
	32	Scenario U/D 161	Turning 45	0.0	150	180	NA	12000	0	12000	14000	0	14000	NA	NA	NA
90° / 110° Crossing Level/Ascending/Descending Left-to-Right	33	Scenario PW18	90	3000.0	150	180	NA	12000	0	12000	12400	0	12400	NA	NA	NA
	34	Scenario PW19	90	3000.0	130	180	NA	12000	1000	14000	14500	0	14500	NA	NA	NA
	35	Scenario PW20	90	3000.0	130	180	NA	15000	-1000	13000	12500	0	12500	NA	NA	NA
	36	Scenario PW21	90	3000.0	130	180	NA	12000	1000	14000	16500	-1000	14500	NA	NA	NA
	37	Scenario PW22	90	3000.0	150	180	NA	14500	0	14500	12000	1000	14000	NA	NA	NA
	38	Scenario PW23	90	3000.0	150	180	NA	12000	0	12000	14500	-1000	12500	NA	NA	NA
	39	Scenario PW24	0/90	3000.0	150	180	150	13000	0	13000	13500	0	13500	12500	0	12500
	40	Scenario T131	90	0.0	150	180	NA	12000	0	12000	13000	0	13000	NA	NA	NA
	41	Scenario T132	90	0.0	150	180	NA	12000	0	12000	12500	0	12500	NA	NA	NA
	42	Scenario T133	90	0.0	150	180	NA	12000	0	12000	12300	0	12300	NA	NA	NA
	43	Scenario U/D 231	90	0.0	150	120	NA	16500	0	16500	12000	1000	14500	NA	NA	NA
	44	Scenario U/D 331	90	0.0	150	130	NA	12000	0	12000	16500	-1000	14000	NA	NA	NA
	45	Scenario U/D 431	90	0.0	120	150	NA	12000	1000	14500	16500	0	16500	NA	NA	NA
	46	Scenario U/D 531	90	0.0	120	150	NA	16500	-1000	14000	12000	0	12000	NA	NA	NA
	47	Scenario U/D 141	110	0.0	150	180	NA	12000	0	12000	14000	0	14000	NA	NA	NA
	48	Scenario U/D 171	Turning 90	0.0	150	180	NA	12000	0	12000	14000	0	14000	NA	NA	NA
135° Overtaking Level/Ascending /Descending Left-to-Right	49	Scenario PW25	135	3000.0	150	180	NA	12000	0	12000	12400	0	12400	NA	NA	NA
	50	Scenario PW26	135	3000.0	130	180	NA	12000	1000	14000	14500	0	14500	NA	NA	NA
	51	Scenario PW27	135	3000.0	130	180	NA	15000	-1000	13000	12500	0	12500	NA	NA	NA
	52	Scenario PW28	135	3000.0	130	180	NA	12000	1000	14000	16500	-1000	14500	NA	NA	NA
	53	Scenario PW29	135	3000.0	150	180	NA	14500	0	14500	12000	1000	14000	NA	NA	NA
	54	Scenario PW30	135	3000.0	150	180	NA	12000	0	12000	14500	-1000	12500	NA	NA	NA
	55	Scenario PW31	0/135	3000.0	150	180	150	13000	0	13000	13500	0	13500	12500	0	12500
	56	Scenario PW32	90/135	0.0	150	180	150	13000	0	13000	13500	0	13500	12500	0	12500
High Speed Level Encounters 0/45/90/135/180	57	Scenario PW33	0	3000.0	150	300	NA	12000	0	12000	12400	0	12400	NA	NA	NA
	58	Scenario PW34	45	3000.0	150	300	NA	12000	0	12000	12400	0	12400	NA	NA	NA
	59	Scenario PW35	90	3000.0	150	300	NA	12000	0	12000	12400	0	12400	NA	NA	NA
	60	Scenario PW36	135	3000.0	150	300	NA	12000	0	12000	12400	0	12400	NA	NA	NA
	61	Scenario PW37	0/45	3000.0	150	300	150	13000	0	13000	13500	0	13500	12500	0	12500
	62	Scenario PW38	0/90	3000.0	150	300	150	13000	0	13000	13500	0	13500	12500	0	12500
	63	Scenario PW39	0/135	3000.0	150	300	150	13000	0	13000	13500	0	13500	12500	0	12500
	64	Scenario U/D 111	0	0.0	130	210	NA	12000	0	12000	14000	0	14000	NA	NA	NA
	65	Scenario U/D 112	0	0.0	130	250	NA	12000	0	12000	14000	0	14000	NA	NA	NA
	66	Scenario U/D 113	0	0.0	210	130	NA	12000	0	12000	14000	0	14000	NA	NA	NA
	67	Scenario U/D 114	0	0.0	250	130	NA	12000	0	12000	14000	0	14000	NA	NA	NA
	68	Scenario U/D 121	45	0.0	130	210	NA	12000	0	12000	14000	0	14000	NA	NA	NA
	69	Scenario U/D 122	45	0.0	130	250	NA	12000	0	12000	14000	0	14000	NA	NA	NA
	70	Scenario U/D 123	45	0.0	210	130	NA	12000	0	12000	14000	0	14000	NA	NA	NA
	71	Scenario U/D 124	45	0.0	250	130	NA	12000	0	12000	14000	0	14000	NA	NA	NA
	72	Scenario U/D 131	90	0.0	130	210	NA	12000	0	12000	14000	0	14000	NA	NA	NA
	73	Scenario U/D 132	90	0.0	130	250	NA	12000	0	12000	14000	0	14000	NA	NA	NA
	74	Scenario U/D 133	90	0.0	210	130	NA	12000	0	12000	14000	0	14000	NA	NA	NA
	75	Scenario U/D 134	90	0.0	250	130	NA	12000	0	12000	14000	0	14000	NA	NA	NA
	76	Scenario U/D 151	180	0.0	210	130	NA	12000	0	12000	14000	0	14000	NA	NA	NA
	77	Scenario U/D 152	180	0.0	250	130	NA	12000	0	12000	14000	0	14000	NA	NA	NA
Radar Runs for GA	78	Scenario GA1	0	3000.0	150	180	NA	MSA	0	MSA	MSA + 500	0	MSA + 500	NA	NA	NA
	79	Scenario GA2	45	3000.0	150	180	NA	MSA	0	MSA	MSA + 500	0	MSA + 500	NA	NA	NA
	80	Scenario GA3	90	3000.0	150	180	NA	MSA	0	MSA	MSA + 500	0	MSA + 500	NA	NA	NA
	81	Scenario GA4	0	3000.0	150	180	NA	MSA + 2000	0	MSA	MSA + 2500	0	MSA + 2500	NA	NA	NA
	82	Scenario GA5	45	3000.0	150	180	NA	MSA + 2000	0	MSA	MSA + 2500	0	MSA + 2500	NA	NA	NA
	83	Scenario GA6	90	3000.0	150	180	NA	MSA + 2000	0	MSA	MSA + 2500	0	MSA + 2500	NA	NA	NA
	84	Scenario GA7	0	3000.0	150	180	NA	MSA + 4000	0	MSA	MSA + 4500	0	MSA + 4500	NA	NA	NA
	85	Scenario GA8	45	3000.0	150	180	NA	MSA + 4000	0	MSA	MSA + 4500	0	MSA + 4500	NA	NA	NA
	86	Scenario GA9	90	3000.0	150	180	NA	MSA + 4000	0	MSA	MSA + 4500	0	MSA + 4500	NA	NA	NA

Figure 4-3. Configuration 1 Flight Test 3 Combined Encounters

Details for this section are TBD.

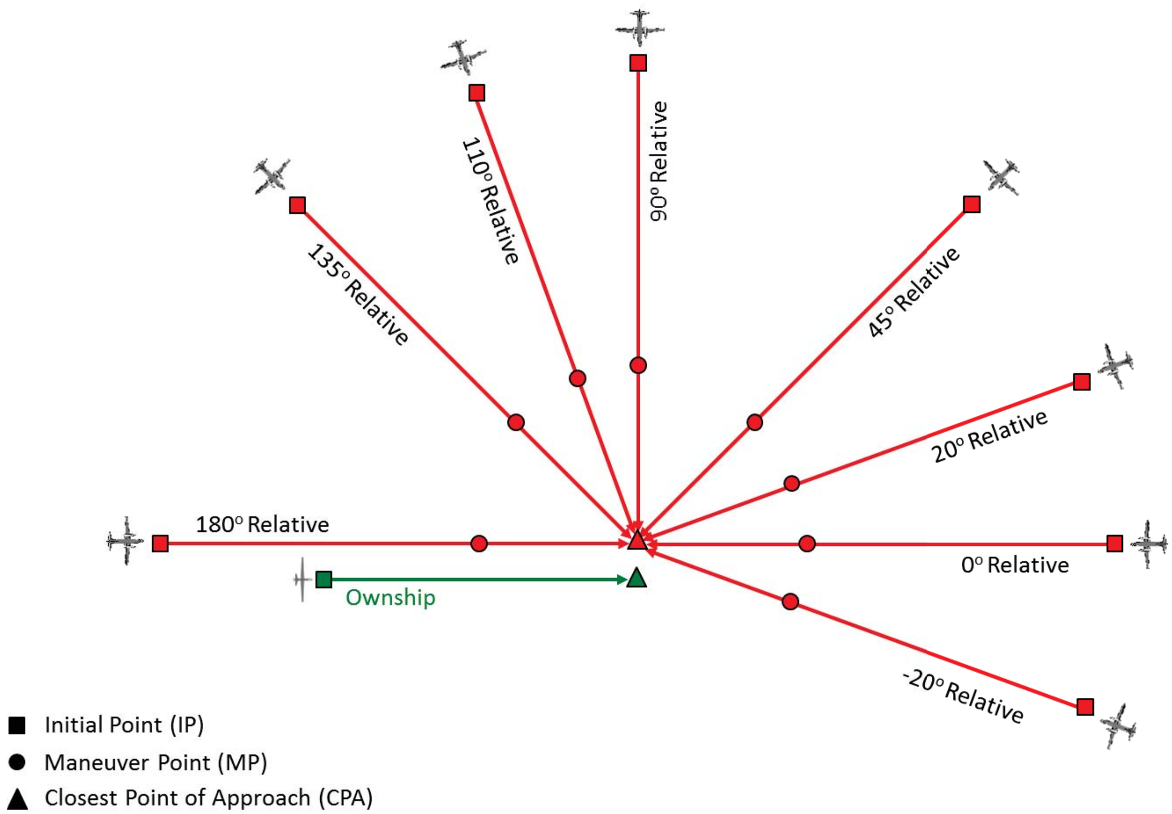


Figure 4-4. Configuration 1 (Pairwise) Test Encounter Geometries

Details for this section are TBD.

4.5.5 Minimum Success Criteria

- Complete highest priority flight test encounters according to the priority set by project PEs.
- Meet minimum established target CPA tolerances required by project PEs.
- Record sufficient self-separation data to evaluate CPA prediction accuracy, self-separation alerting logic, and self-separation trajectory models for ownship aircraft.
- Collect sufficient data to evaluate TCAS/self-separation interoperability.
- Collect sufficient data to inform non-cooperative aircraft predictive models using a radar sensor

4.6 Full Mission Flight Test Encounters (Configuration 2)

Full Mission (FM) flight encounters, also identified as Configuration 2, (Figure 3-4) follow a preplanned flight plan that represents a fictitious fire line mission flown in Oakland Center Class E airspace that has been previously used for IHITL and Full Mission simulation exercises. These missions involve a single ownship aircraft (UAS Surrogate) navigating a flight plan and one (or more) intruder aircraft performing flight encounters that are generally scripted but has flexibility in execution to accommodate real-time changes that may occur during the test runs.

The baseline plan is to perform these missions entirely within The R-2508 Complex operating out of Edwards AFB. Due to the length of the Full Mission flight plan, several areas within the complex will be scheduled including: R-2515; plus Isabella, Bakersfield and Porterville MOAs. Intruder aircraft will be preposition at staging points within the test area to facilitate 4 live flight encounters.

4.6.1 Mission Plan

FM flights are planned for approximately 40 minutes of flight duration with an additional 20 minutes required (if flown completely) to reset the mission and to fly subsequent test runs. At least three complete runs are planned each test day. Missions are planned to be flown at 12-15Kft MSL. At least one delay for UAS surrogate and low speed intruder refueling may be required during a test day that will require at least a one hour delay between test runs to complete the fuel stop.

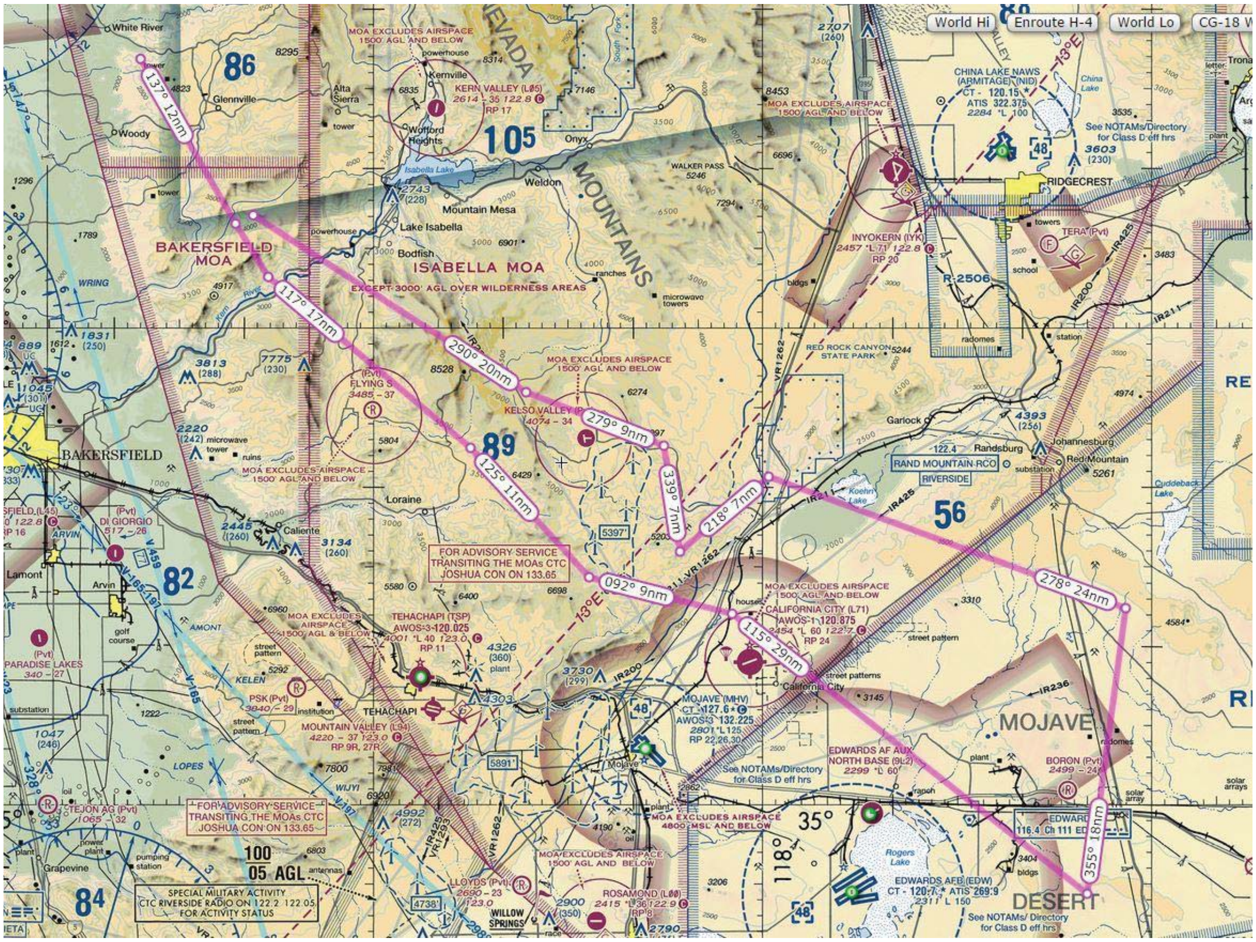


Figure 4-5. Example of a Full Mission flight flown in R-2508 Complex

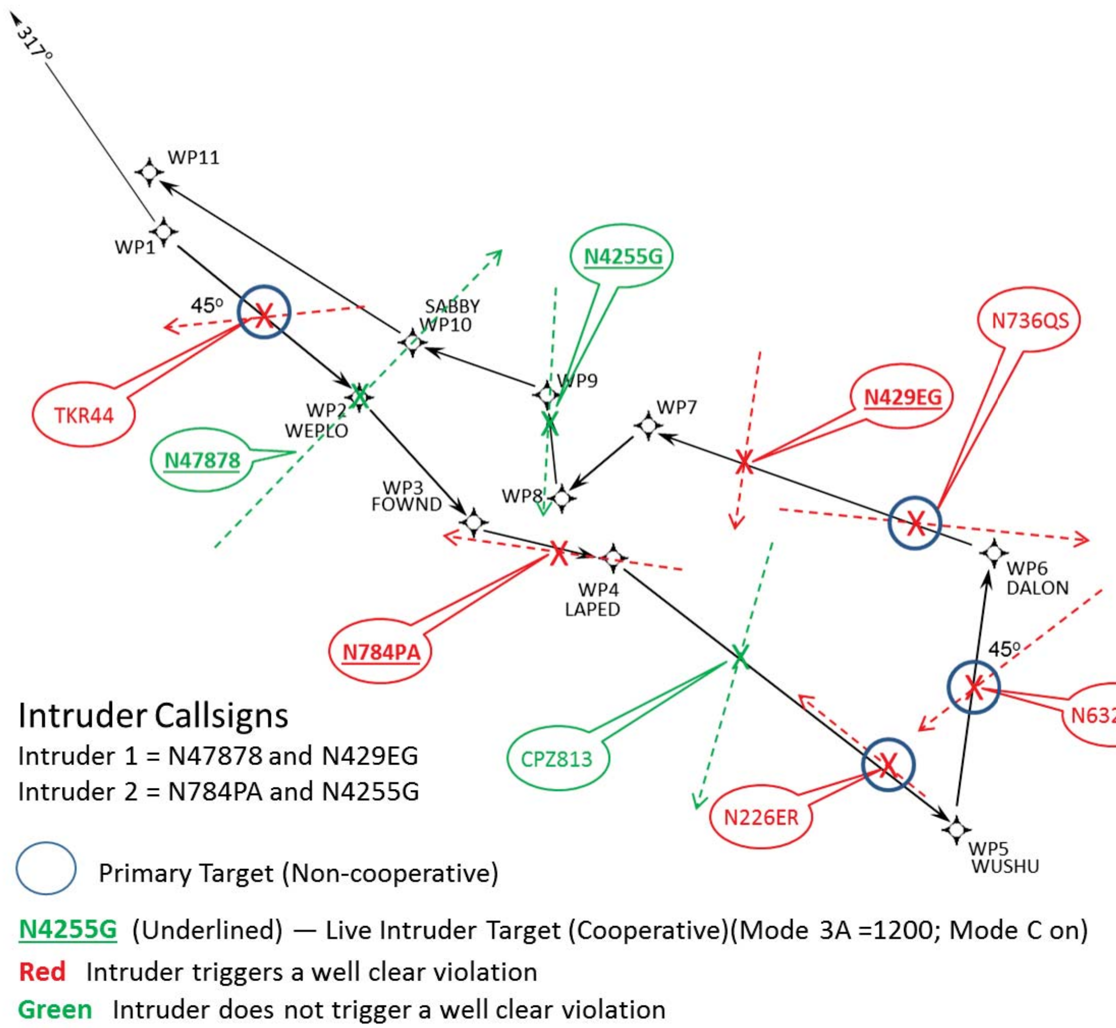


Figure 4-6. Example of a Full Mission Track with Encounter Points

4.6.2 Test Encounters

Full mission flight encounters are planned for 4 live intruder aircraft encounters and 6 virtual aircraft test encounters. The subject pilot will operate the UAS surrogate while positioned at the RGCS using three different self-separation displays under test. Each mission will be run in its entirety starting at the northwestern waypoint proceeding southeast, then proceeding northeast and then turning northwest essentially reversing the original course along a flight plan that represents a fire line mission within Class E airspace (Figure 4-6). To the subject pilot, the fire line scenario is being flown in Oakland Center airspace (ZOA).

Due to the complexity of system architecture required to perform UAS surrogate operations, a complete understanding of normal and abnormal conditions, flight operations procedures and flight safety analysis is expected by all participating aircrew and support elements of the flight test. The following is a brief CONOPS of how the RGCS pilot, who is the subject pilot under test, performs his/her task and what is involved by the UAS Surrogate aircrew and other participating mission positions.

The RGCS pilot will fly the mission from the RGCS station using VSCS as his/her primary user interface. The RGCS pilot will 'fly' the fire line mission as if the mission is being flown within Oakland ARTCC (ZOA) airspace. The RGCS pilot will 'command' the 'autonomous' UAS Surrogate through keyboard and mouse interface in order to navigate a preplanned mission plan (fire line route). Self-separation alerts will be depicted on either the VSCS display or a standalone display. The RGCS pilot will respond to alerts as appropriate while adhering to mission constraints (such as airspace boundaries, ATC directions, aircraft performance limitations, etc.). The RGCS pilot will communicate with ATC (virtual) via CPNC link. This comm link keys a VHF radio onboard the T-34C that transmits RF signals on the Virtual ATC Net via local and distant connectivity links to a controller located at Ames. When the RGCS pilot receives an alert and needs to communicate with ATC (virtual), he/she is expected to request permission to respond to the alert prior to actually issuing the command using VSCS. When a command is issued by the RGCS pilot, the UAS Surrogate aircrew will receive these commands via the CNPC link and respond accordingly. The T-34C UAS Surrogate aircraft is capable of autonomous lateral (heading) control; therefore, when the RGCS pilot issues a heading change, the T-34C UAS Surrogate aircraft autopilot will automatically respond to the heading change command. Pitch, directional, and speed commands will be displayed to the T-34C pilot who will, in turn, consent or manually perform the appropriate control inputs to effect the maneuver expected by the RGCS pilot. The Test Conductor via mission net (separate VHF radio) will communicate with the T-34C aircrew and participating intruder aircraft to facilitate actual mission coordination. A dedicated SPORT controller is expected to support the mission on Mission Net and provide traffic callouts and other coordination calls as required.

The Test Conductor will coordinate with the Ghost Controller via the Ghost Net to ensure that real and virtual intruder aircraft encounters are managed appropriately to ensure that the subject pilot meets HSI test objectives (Figure 2-5). Encounter geometries and timing are important elements of the test therefore the Test Conductor and Ghost Controller will need to ensure that any variability to the real world trajectory of the UAS Surrogate are managed behind the scene in order to provide the subject pilot with the realism and consistency desired by the HSI researchers.

4.6.3 Ownship Requirements

The NASA GRC T-34C UAS Surrogate aircraft is planned for Flight Test 3 ownship full mission flight encounters. The T-34C will be equipped with the CNPC, ADS-B, and GPS. Ownship aircraft must be available to support the planned flight schedule.

4.6.4 Intruder Requirements

Intruder aircraft require ADS-B, and GPS. Intruder aircraft may be sourced from NASA AFRC, NASA GRC and Honeywell.

4.6.5 Virtual Aircraft Requirements

Virtual aircraft are manned IFR and VFR (squawking) aircraft generated by simulation sources developed by NASA ARC.

4.6.6 Minimum Separation

The minimum geospatial offsets planned are 500 ft vertically and 0 ft horizontally.

All participating aircraft will ensure that the aircraft altimeter system meets manufacturer calibration specifications and requirements for normal operation in the NAS.

A maximum of 600 ft (0.1 nmi) navigation error (GPS derived position) is allowed for each aircraft based on the system's built-in navigation accuracy readout.

4.6.7 Minimum Success Criteria

- Complete 3 runs using different displays for each of 10 subject pilots as required by project PEs.
- Validate self-separation display performance in a relevant environment.
- Collect sufficient data to evaluate objective and subjective pilot data to determine display acceptability as a self-separation decision-making tool.
- Collect sufficient data to inform self-separation MOPS.
- Collect sufficient data to inform communication MOPS.

Placeholder page for FT3 Configuration 1A, 1B and 2 Overview Table

5 Test Reporting

Several reports shall be developed by specific members of the test team and distributed as described in this section.

5.1 Deficiency Report

During testing any deficiencies that are found in the system or any component of the system will be reported to the Test Conductor. The circumstance of the testing during the deficiency will be noted. At the discretion of the Test Conductor the test may continue, or be terminated. During the Post-test Brief, any deficiency reports will be reviewed. The Test Conductor and Project Engineers will determine whether any steps need to be taken to mitigate the deficiency before continuing with the next set of tests

5.2 Progress Report

The IT&E sub-project will deliver preliminary test results to the UAS-NAS Project Office during testing on a per request basis. After each debrief, the AFRC IT&E PE will compile and submit a daily test run sheet to the Project Office including runs/events planned versus successfully accomplished on that day, a summary of deficiencies identified during the day, and a brief statement of the next test period/day's planned runs.

5.3 Test and Preliminary Results Report

This report documents the tests that were conducted along with a report of the data collected. This report does not provide analysis of the data, but documents the compilation of the daily data runs form the daily debrief report and a summary of the data collection.

5.4 Analysis Reports

The formal Analysis Reports are detailed reports that present analyses, evaluation, results, and the conclusions and recommendations of the research under test. Each subproject involved in the test will produce an Analysis Report.

5.5 Flight Test Report

After completion of Flight Test 3, the IT&E Ops lead will develop a report that details the flight test execution and results to be submitted to the UAS-NAS Project Office.

6 Data Collection

The IT&E Data Management Plan, IT&E DMP-001, documents the following data management activities required for FT-3:

- Purpose of data collection;
- Sources and types of data to be collected by each flight test participant;

- Quick-Look at data on day-of-flight;
- Reception and archival in a central data repository; and
- Providing data from the central data repository to test participants.

Each participating organization captures data relevant to the FT-3 flights received by its aircraft or generated by that aircraft, including surveillance and tracking data (both ownship and other aircraft), inter-aircraft data communications, air-ground data communications, as well as data provided to and actions produced by the on-board TCAS.

A "quick-look" on each day of FT3 test flights will be performed to assess the prospects of successful flight tests both during the flights and immediately post-flight. Refer to IT&E DMP-001 for a description of roles and responsibilities related data analysis pertaining to "quick-look" activities and post-flight data analysis.

6.1 Summary of Data Sources from Flight Test Aircraft

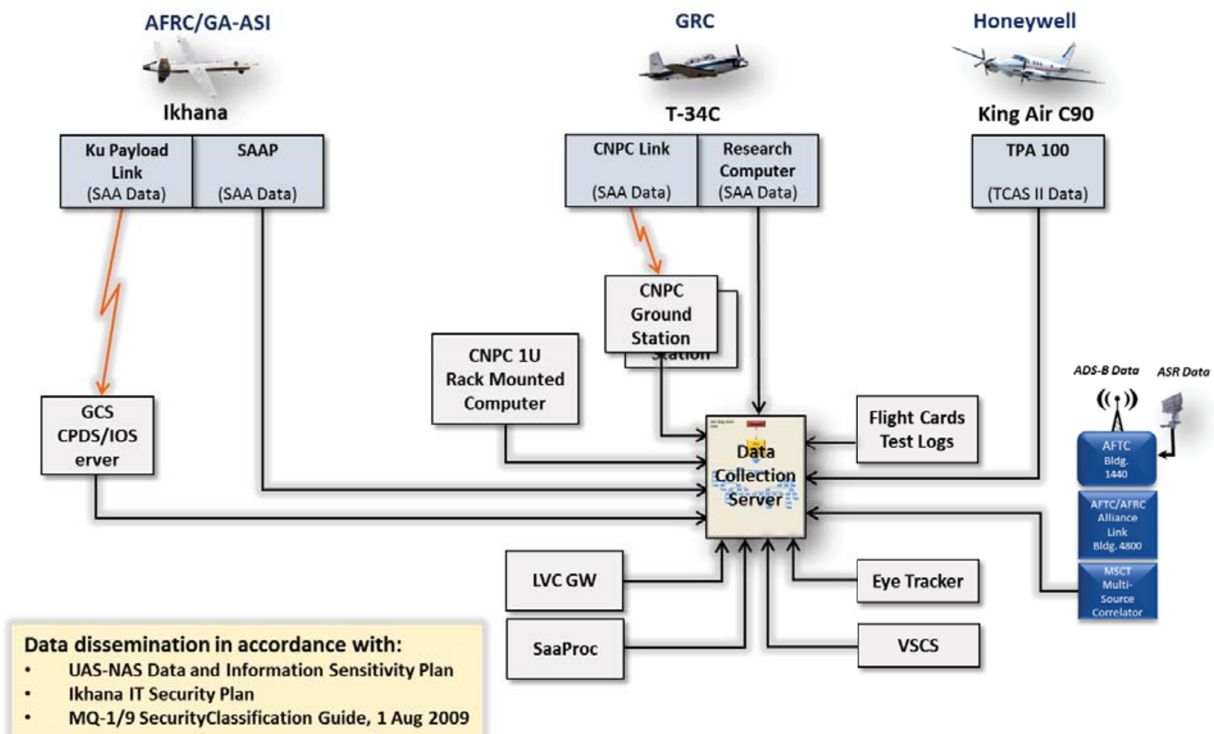


Figure 6-1. FT3 Data Collection Sources

Details for this section are TBD.

7 Appendices

Details for this section are TBD.

Appendix A Reference Documents

Document Number	Document Title
OIEP SRD-01	Ownship and Intruder Equipage and Performance SRD
14 CFR Part 91	General Operating and Flight Rules
EAFBI 13-100	Edward AFB Instruction Flying and Airfield Operations

Details for this section are TBD.

Appendix B Acronyms

ACAS	Airborne Collision Avoidance System
ACE	Active Coordination Emulation
ADRS	Aeronautical Data Link and Radar Simulator
ADS-B	Automatic Dependent Surveillance-Broadcast
AESA	Active Electronically Scanned Array
AFRC	Armstrong Flight Research Center
AFRL	Air Force Research Laboratory
AFSR	Airworthiness and Flight Safety Review
AFTC	Air Force Test Center
APL	Applied Physics Laboratory
ARC	Ames Research Center
ARTCC	Air Route Traffic Control Center
ATAR	Air-To-Air-Radar
ATC	Air Traffic Control
C2	Command and Control
CA	Collision Avoidance
CAS	Collision Avoidance Systems
CDTI	Cockpit Display Of Traffic Information
CFR	Civil Flight Regulations
COA	Certificate of Authorization
COMM	Communications
CONOPS	Concept of Operations
CoPE	Co-Project Engineers
CNPC	Control and Non-Payload Communications
CPA	Closest Point of Approach
CPDS	Conflict Prediction and Display System
CV	Collision Volume
CVSRF	Crew Vehicle Simulation Research Facility
DAA	Detect and Avoid
DAIDALUS	Detect & AvoID Alerting Logic for Uncrewed Systems
DATR	Dryden Aeronautical Test Range
DCP	Dryden Centerwide Procedure
DHS	Department of Homeland Security
DO	Director of Operations

DPMf	Deputy Program Manager for
DRR	Due Regard Radar
DSRL	Distributed System Research Laboratory
EAFBI	Edwards Air Force Base Instruction
EC	Experimental Certificate
EDM	Engineering Development Module
EP	Entry Point
ERAM	En Route Automation Modernization
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FBO	Fixed Base Operator
FDDRL	Flight Deck Display Research Laboratory
FM	Full Mission
FOM	Figure of Merit
FP	Flight Prototype
FRR	Flight Readiness Review
FT3	Flight Test 3
FTP	Flight Test Plan
GA-ASI	General Atomics Aeronautical Systems Inc
GCS	Ground Control Station
GPS	Global Positioning System
GRC	Glenn Research Center
HSI	Human Systems Integration
HITL	Human In The Loop
HLA	High Level Architecture
IFR	Instrument Flight Rules
IP	Initial Point
IT&E	Integrated Test and Evaluation
ITAR	International Traffic In Arms Regulations
JADEM	Java Architecture for DAA Extensibility and Modeling
KGS	Kilograms
LaRC	Langley Research Center
LOS	Loss of Separation or Line of Sight
LVC	Live Virtual Constructive
MACS	Multi Aircraft Control System
MD	Mission Director

MHz	Mega Hertz
MOA	Military Operating Area
MOPS	Methods of Performance Standards
NAS	National Airspace System
NASA	National Air and Space Administration
NOTAMS	Notice To Airmen
NPR	NASA Procedural Requirements
PE s	Project Engineers
PT4	Part Task Four
RAIF	Research Aircraft Integration Facility
RGCS	Research Ground Control Station
RTCA	Radio Technical Commission for Aeronautics
RUMS	Remote User Monitoring System
SAA	Sense and Avoid
SAF	Stand Alone Facility
SATCOM	Satellite Communication
SGT	Stinger Gaffarian Technologies
SimMgr	Simulator Manager
SMO	Spectrum Management Office
SPORT	Call Sign for AFFTC Radar Control Facility
SS	Self-Separation
SSI	Separation Assurance/Sense and Avoid Interoperability
STARS	Standard Terminal Automation Replacement System
STM	Surveillance Tracking Module
TBD	To Be Determined
TC	Test Conductor
TCAS	Traffic Alert And Collision Avoidance System
TD	Test Director
ToR	Terms of Reference
TRM	Threat Resolution Module
UAS	Unmanned Aircraft Systems
VFR	Visual Flight Rules
VHF	Very High Frequency
VSCS	Vigilant Spirit Control Station
WAAS	Wide Area Augmentation System
ZOA	Oakland Air Route Traffic Control Center

Appendix C Definition of Terms

Details for this section are TBD.