Flight Test Overview for UAS Integration in the NAS Project

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The National Aeronautics and Space Administration is conducting a series of flight tests intended to support the reduction of barriers that prevent unmanned aircraft from flying without the required waivers from the Federal Aviation Administration. The most recent testing supported two separate test configurations. The first investigated the timing of Detect and Avoid (DAA) alerting thresholds using a radar-equipped unmanned vehicle and multiple live intruders flown at varying encounter geometries. The second configuration included a surrogate unmanned vehicle (flown from a ground control station, with a safety pilot on board) flying a mission in a virtual air traffic control airspace sector using research pilot displays and DAA advisories to maintain separation from live and virtual aircraft. The test was conducted over a seven-week span in the summer of 2015. The data from over 100 encounter sorties will be used to inform the RTCA Phase 1 Detect and Avoid and Command and Control Minimum Operating Performance Standards (MOPS) intended to be completed by the summer of 2016. Follow-on flight-testing is planned for the spring of 2016 to capture remaining encounters and support validation of the MOPS.

Nomenclature

ADS-B	=	Automatic Dependent Surveillance - Broadcast
C2	=	Command and Control
DAA	=	Detect and Avoid
FAA	=	Federal Aviation Administration
GCS	=	Ground Control Station
LVC	=	Live, Virtual, Constructive describing the simulation environment
MOPS	=	Minimum Operating Performance Standards
NAS	=	National Airspace System
NASA	=	National Aeronautics and Space Administration
NM	=	Nautical Miles
TCAS	=	Traffic Alert and Collision Avoidance System
UAS	=	Unmanned Aircraft System

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I. Introduction

THERE has been a tremendous increase in the interest of flying unmanned aircraft safely in the National Airspace System (NAS) in recent years.[1] The application of unmanned aircraft to perform national security, defense, scientific, and emergency management are driving the critical need for less restrictive access by Unmanned Aircraft Systems (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 in part to the lack of a common understanding of what is required to safely operate UAS in the NAS.[2] In response, the Federal Aviation Administration (FAA) has been mandated to "develop a comprehensive plan to safely accelerate the integration of civil unmanned aircraft systems (UAS) into the national airspace system".[3] While the FAA has proposed a framework for rules to guide the introduction of small UAS (those under 55 pounds), existing Federal Aviation Regulations do not allow for full integration of unmanned aircraft into the NAS.[4] In order to facilitate this integration, data supporting robust Detect and Avoid (DAA) and secure Command and Control (C2) capabilities need to be collected.[5]

In support of the community needs, the National Aeronautics and Space Administration (NASA) under the UAS Integration in the NAS Project (hereafter referred to as UAS-NAS Project) is investigating and integrating technologies that are intended to reduce technical barriers related to the safety and operational challenges associated with enabling routine UAS access to the NAS.[6] The project is focusing on airspace integration procedures and performance standards to enable UAS integration in the air transportation system, covering DAA performance standards, C2 performance standards, and human systems integration. To support these research areas, the project also has an integrated test and evaluation focus, providing the infrastructure for simulating traffic and collecting data. The test environment is comprised of air traffic control workstations, constructive and virtual aircraft simulators, UAS ground control stations (GCS) and live manned and unmanned aircraft that, operating together, provide researchers with a relevant NAS environment to test unmanned systems. Working closely with the researchers, the simulation and flight-test development team designs an environment that meets the needs for each specific data collection requirement.

This paper describes the objectives and requirements of the integrated flight tests planned by the UAS-NAS Project to collect the research data for the DAA, C2, and human systems focus areas. The designs and performance capabilities of the test infrastructure and data collection efforts are presented.

II. Background

A. UAS-NAS Project Overview

With inputs from UAS stakeholders, including academia, government, and industry, the UAS-NAS Project was formulated to address the need for routine access to the global airspace for all classes of UAS. Based upon that need, the Project identified the following goal: To provide research findings to reduce technical barriers associated with integrating UAS into the NAS utilizing integrated system level tests in a relevant environment.[6]

The project goal will be accomplished through the development of system-level integration of key concepts, technologies and/or procedures. In addition, these integrated capabilities will be demonstrated in an operationally relevant environment with the following objectives:

- Report research findings (including validated data, algorithms, analysis, and recommendations) to support key decision makers in establishing policy, procedures, standards and regulations, enabling routine UAS access in the NAS.
- Establish the infrastructure for the integrated test and evaluation environment for UAS Integration in the NAS simulations and flight demonstrations.

The UAS-NAS Project research is divided into three main technical subprojects, each leading respective research areas: Separation Assurance/Sense and Avoid[††] Interoperability, Human Systems Integration, and Communication.

Detect and Avoid (formally Sense and Avoid) is defined as "the capability of a UAS to remain well clear from and avoid collisions with, other airborne traffic".[7] The research conducted under this subproject focuses on the interoperability between two aspects of DAA, self-separation and collision avoidance. Collision avoidance is the maneuvering of one or more aircraft required to prevent an imminent near-midair collision. Self-separation is intended to address the ability of a pilot to "see and avoid" other aircraft with support from sensors and advisory algorithms without triggering collision avoidance maneuvers in either aircraft. In order to improve safe flight and

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[††] The Detect and Avoid nomenclature was adopted from the previously used Sense and Avoid after formulation of the Project, hence the old terminology usage here.

interaction of unmanned aircraft with air traffic in the NAS, the human systems integration subproject researchers are investigating the display of necessary and sufficient information to the UAS pilot in the ground control station. This information includes the display of proximal aircraft and several levels of DAA maneuver advisories and alerts. The Communication subproject research includes the investigation of terrestrial based communication network that integrates line-of-sight ground station antennas to enable non-satellite based beyond line-of-sight control of unmanned aircraft from the ground. The Communications effort includes the development of prototype radios to test the terrestrial link performance characteristics and the C2 performance standards.

Integrating each of these research subproject concepts together, the integrated test and evaluation team handles the system requirements gathering and development of the integrated test infrastructure.

B. RTCA Minimum Operating Performance Standards (MOPS)

RTCA was charted by the FAA to operate advisory committees that develop solutions to real-world air transportation problems.[8] In order to safely integrate the multitude of UAS platforms into non-segregated airspace, the FAA and UAS stakeholders have determined that both a robust DAA and a robust and secure C2 Data Link capability need to be established. In response, the FAA established the Unmanned Aircraft Systems Integration Office to support integration of UAS safely and efficiently into the NAS. In addition, RTCA formed Special Committee 228 to develop the Minimum Operational Performance Standards (MOPS) for DAA equipment, with emphasis in an initial phase of standards development on civil UAS equipped to operate into Class A airspace under IFR flight rules. The Operational Environment for the Phase 1 MOPS is the transitioning of a UAS to and from Class A or special use airspace, traversing Class D and E, and perhaps Class G airspace. A second phase of MOPS development is envisaged to specify DAA equipment to support extended UAS operations in Class D, E, and perhaps G, airspace. Moreover, the UAS Integration Office is working closely with the UAS community to develop the MOPS for the C2 Data Link. An initial phase of development will provide standards for the C2 Data Link using L-Band Terrestrial and C-Band Terrestrial data links. A second phase of MOPS development is envisaged to provide standards for the use of SatCom in multiple bands as a C2 Data Link to support UAS. NASA is a key member of RTCA SC-228 and is a primary contributor to the C2 and DAA MOPS.

C. Flight Testing Overview

To support the collection of data for the development of the RTCA Phase 1 MOPS, the UAS-NAS Project has planned a series of human in the loop simulations as well as two flight tests, Integrated Flight Test 1 and 2. The flight testing events are designed to enable collection of data in a realistic operating environment, including the inherent uncertainties of real winds and on board sensors. However, since the testing includes the flight of unmanned aircraft, which cannot presently fly in the NAS without restrictions and waivers from the FAA, the integrated test team developed a distributed environment that combines live, virtual, and constructive (or background) traffic and intercept scenario to promote the safe testing of the concepts and technologies

While the live, virtual, and constructive (LVC) components[‡‡] of a test environment only encompass a portion of a full simulation or flight test, the test environment is widely known as an LVC. [9,10,11] Figure 1 shows the general usage of live, virtual and constructive assets contributing to the flight test environment. One of the significant aspects of the LVC environment is the support for integration of distributed assets to enable usage of equipment without the need for build-up of a local facility or deployment to a properly

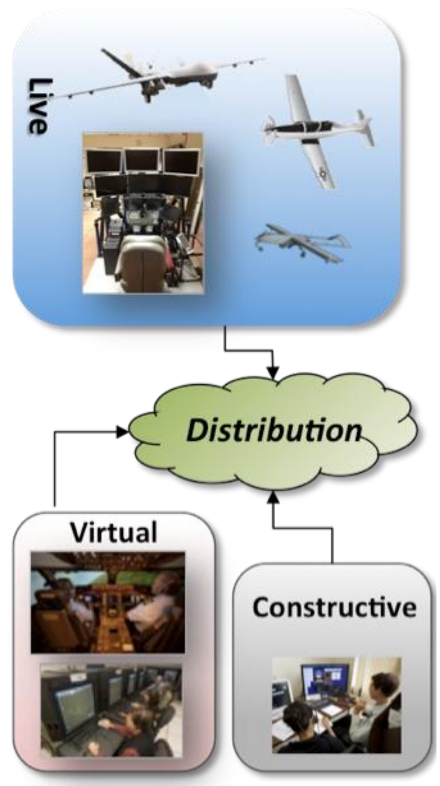

Figure 1. LVC Environment Concept of Operations. *An LVC environment promotes the integration of multiple live and virtual data sources.*

‡‡ A "constructive" simulation generally has no interactive human involvement in simulated conditions. Instead, scenarios unfold using rule-based decisions that control the interactions between simulated actors. "Virtual" simulations involve human participants operating simulated systems (e.g. a pilot flying a flight simulator). A "live" test environment involves human participants operating real systems.

equipped test range. Instead the distributed LVC environment promotes a test-in-place concept that allows researchers and technologies to utilize assets in situ. A more detailed discussion of the UAS-NAS Project's LVC environment is described by Murphy, et. al.[12]

For the UAS-NAS Project flight-testing, data collection is divided into two distinct test configurations. The first involves a UAS aircraft equipped with representative cooperative (e.g. GPS based ADS-B transponder) and non-cooperative sensors (e.g. on board due regard radar) and flown with live intruder aircraft against a series of different scripted encounters to test the timing of the alerting from DAA collision avoidance, self-separation algorithms and interoperability with certified traffic collision avoidance systems (TCAS). All flights are conducted in restricted airspace in order to minimize risk. The second flight configuration integrates a surrogate UAS aircraft flown from a research ground control station equipped with pilot displays that provide advisories of potential conflicts and loss of separation. The ownship[§§] (UAS) aircraft is equipped with cooperative and non-cooperative sensors as required for the test and flown in special use airspace. The location of the ownship aircraft is translated into a virtual air traffic control airspace populated with a mix of live and virtual background and intruder aircraft, providing a realistic environment. The pilot of the ownship aircraft is given a virtual "mission" to perform, while using the DAA advisories to maintain well clear of the live and virtual aircraft.

In addition the UAS-NAS Project is planning a "Capstone" event. During this demonstration, the UAS aircraft will be flown in the NAS (with any necessary waivers from the FAA) to demonstrate the performance of the DAA technologies. It is not intended for the Capstone event to collect data supporting the MOPS, but provide an opportunity for the industry to witness the Project's testing and provide outreach to the general public.

III. Integrated Flight Test 1 Description

The UAS-NAS Project requires several levels of flight test and simulation activities in order to collect the appropriate data to support validation of the DAA and C2 MOPS. As such, the Integrated Flight Test (IFT1), internally referred to as Flight Test 3, had six primary research goals:

1. Validate results previously collected during project simulations with live data
2. Validate performance models previously used during project simulations with live data
3. Evaluate TCAS II/self-separation interoperability
4. Test a fully integrated system in a relevant live test environment
5. Collect data to inform final DAA and C2 MOPS
6. Reduce risk for follow-on flight testing

These goals were derived from previous UAS-NAS Project simulations supporting an evidenced based build-up of the research. As described above, this flight test was divided into two distinct configurations (DAA Scripted Encounters and Full Mission), detailed in the sections below.

A. Detect and Avoid Scripted Encounters Configuration

The Scripted Encounters configuration generated data to evaluate the acceptability of the DAA alerts and advisories. This configuration had the following high-level objectives:

- Validate closest point of approach prediction accuracy and self-separation alerting logic in realistic flight conditions
- Validate self-separation trajectory model including maneuvers
- Validate sensor and tracking models
- Evaluate TCAS/self-separation interoperability
    - Ownship TCAS/self-separation interaction
    - Compatibility with intruder's TCAS
- Evaluate DAA performance in multi-threat encounters
- Evaluate TCAS II as installed performance on a UAS
- Qualitatively evaluate pilot impression of self-separation advisories
- Inform final RTCA Phase 1 DAA and C2 MOPS

In order to achieve the required test points, the Scripted Encounters configuration utilized NASA's Ikhana MQ-9 Predator-B aircraft as "ownship" aircraft. The Ikhana was equipped with a due regard radar, ADS-B, TCAS II, and a data fusion/tracker algorithm provided by Honeywell. Live intruders included a T-34C equipped with ADS-B and

[§§] The ownship is the aircraft that contains the systems under test and evaluation.

TCAS I, and a King Air, equipped with ADS-B and TCAS II. The Ikhana sensor data was transmitted to the ground via a Ku-Band beyond line-of-sight link and sent to the DAA algorithms for analysis as shown in Figure 2. All test points were flown in the R-2515 restricted airspace near NASA Armstrong.

Three different DAA algorithms were tested (each during different test points). The first was the Conflict Prediction and Display System (CPDS) developed by General Atomics and TU Delft, which provided its own display to the pilot.[13] CPDS shows the ownship with proximal traffic and represents advisories as vertical and horizontal warning zones. Encounters tested with the CPDS included Ikhana climb/Intruder descent, Ikhana with multiple simultaneous intruders (illustrated in Figure 3), and close encounters with an intruder to test the DAA interoperability with TCAS alerting. Test points included the DAA algorithm fed by individual and fused sensor data.

The second was the JAVA Architecture for DAA Extensibility and Modeling (JADEM) from NASA Ames Research Center[14], which used the Vigilant Spirit Control Station's (Vigilant Spirit) primary flight display to show advisories as a standalone unit next to the pilot. Vigilant Spirit is a fully implemented interface between a pilot in a GCS and an aircraft under control. It was developed by the Air Force Research Laboratory for flying UAS and is used as a test interface for the UAS-NAS Project.[15] Tested encounters included "display scenarios" where the pilot of the Ikhana maneuvered the aircraft as directed by the DAA algorithm and "TCAS/self-separation interoperability scenarios" where the pilot does not maneuver the aircraft until the intruder's TCAS has been alerted.

The third was the Stratway+ algorithm from NASA Langley Research Center, which was originally developed to perform tactical resolution advisories for manned aircraft.[16] Stratway+ presented its advisories on a standalone display next to the pilot via the Multi-Aircraft Control System (MACS) software.[17] Test points were designed to validate Closest Point of Approach predictions collected during earlier simulations using Stratway+.[18] Specific encounters were also designed to operate on the edge of the alert threshold to collect data on the algorithm sensitivity to flight condition uncertainties. Additional test points included simultaneous multi-intruder encounters in both the vertical and horizontal domains and characterization of the due regard radar "edge" cases.

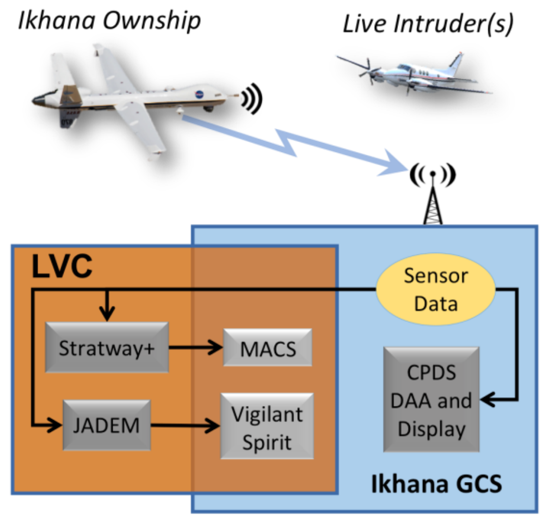

Figure 2. High-Level Architecture for the Scripted Encounters. *The system diagram showing the flight assets and LVC system components used for the Scripted Encounter testing. Only one DAA algorithm was run during any given test point.*

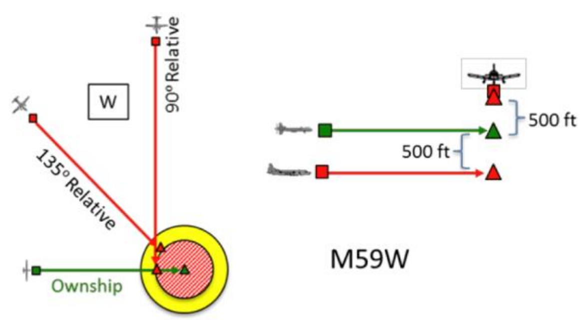

Figure 3. Scripted Encounter Example. *An example of multiple intruder encounter with an equipped UAS "ownship".*

B. Full Mission Configuration

The Full Mission configuration was designed to support the evaluation of the display of the DAA self-separation alerts provided to the UAS pilot. This configuration had the following high-level objectives:

- Evaluation of integrated self-separation algorithms, GCS traffic displays, and prototype C2 systems in a realistic environment
- Evaluate the effect of self-separation alerting and guidance information on pilots' ability to maintain well clear
- Gather objective and subjective pilot data to evaluate/validate well-clear definition
- Analyze the performance of fourth generation C2 systems

Figure 4 depicts a simplified diagram of the LVC architecture used for the Full Mission configuration. The primary components included virtual air traffic control and constructive background traffic running at the NASA Ames Distributed Systems Research Laboratory, a live surrogate UAS aircraft controlled by the Vigilant Spirit at NASA Armstrong Research Ground Control Station Laboratory, DAA algorithms running in the NASA Armstrong LVC Laboratory, and live intruder aircraft.

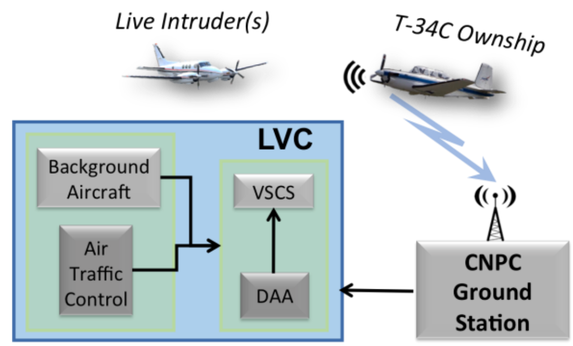

Figure 4. High-level LVC architecture used for the Full Mission configuration. *Connectivity of the Background traffic and air traffic control clients running at NASA Ames with the live aircraft, DAA algorithm and the ground control station and NASA Armstrong.*

The surrogate UAS aircraft (henceforth known as the "ownship") was flown under an IFR flight plan in scenarios with live and virtual aircraft. The constructive background aircraft, enabled through the LVC environment, consisted of IFR and VFR traffic. Confederate controllers set up interaction between the background aircraft and the ownship to ensure that the DAA system provided advisories to the pilot based on the definition of Well Clear Volume parameters. In order for "well clear" to be violated all of the following conditions must be met:

- The horizontal closest point of approach or the current horizontal range is less than 0.8 NM
- The time to horizontal closest point of approach is below 40 seconds
- The time to co-altitude is below 40 seconds or the current vertical separation distance is below 500 ft.

The scenario for this test was a UAS aircraft controlled by a GCS stationed in southern California, with the aircraft deployed to scout for active wildfires in the San Francisco Bay area (see Oakland airspace descriptor below). The JADEM software provided the DAA algorithm for the test. The ownship was a T-34C aircraft flown as a surrogate UAS aircraft from a GCS using Vigilant Spirit at NASA Armstrong. The T-34C was equipped with ADS-B to enable cooperative sensing of other ADS-B equipped aircraft. The T-34C and live intruder aircraft flew in special use airspace near NASA Armstrong (R-2515), with the coordinates of the virtual Oakland Center sector (combined sectors 40/41) translated to that airspace. Constructive traffic and the confederate controllers were provided from a laboratory at NASA Ames interacting with the subject pilot and Vigilant Spirit via the distributed LVC system. Similar to the system used for the Scripted Encounters, the Full Mission system received data for the ownship and live intruder aircraft from the sensors on-board the T-34, sent to the ground via the C2 communication link. The virtual and live data were sent to and filtered by JADEM to determine which were candidates for processing by the algorithm and displayed to the pilot.

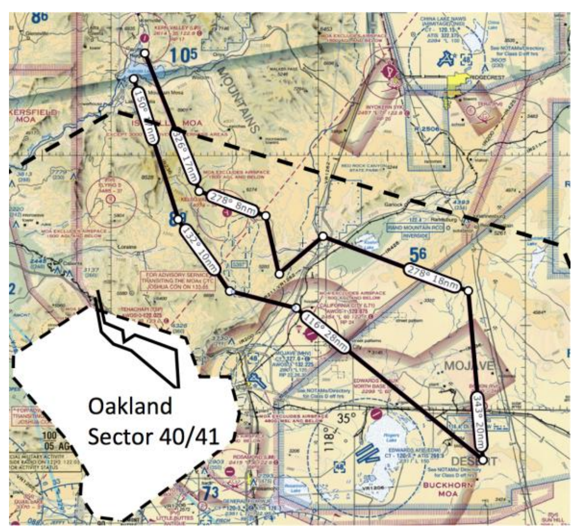

Figure 5. Overlay of Path of Aircraft and Airspace. *The path of the aircraft (solid line) within the virtual Oakland Center airspace (dashed boundary) was translated to the R-2508 and R-2515 airspace that surrounds NASA Armstrong. Inset: depiction of the actual Sector 40/41 boundary points for reference.*

The mix of live and virtual aircraft provided the pilot with a realistic air traffic environment. The fire-scouting mission was also intended to keep the pilot occupied to prevent focusing too much on intruder aircraft, hence a "Full Mission" environment. The controllers managed the traffic as test confederates, enabling intruder traffic to interact with the ownship. Figure 5 shows the depiction of the flight path of the ownship aircraft (solid line) during flight. The background shows the terrain of the actual airspace it was flying (i.e. R-2515), while the dashed line represents the relative position of the Oakland Center sector boundary in the virtual airspace of the scenario. In order to seamlessly combine the live and virtual traffic, the Oakland Center airspace (airways, sector boundaries) and virtual traffic were mapped into the R-2515 airspace.

Each pilot flew two "Fire Mission" scenarios flying the same path, but with slightly different encounter geometries. In each scenario, the pilot was shown either a basic display of information or an enhanced display (shown in Figure 6). The basic information consisted of only the identification of the intruder based on the DAA alerts, while the enhanced display showed additional intruder symbols and maneuver advisories in the form of fly/no-fly bands. These have been coined "omni-bands" since they provide advisories for all viable flight headings.

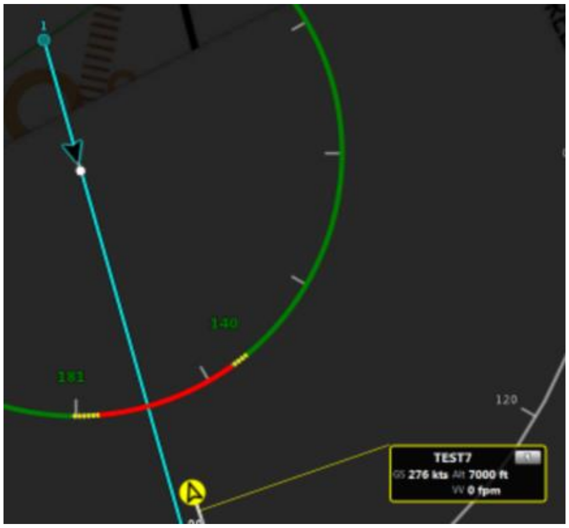

Figure 6. "Enhanced" display of DAA to the pilot. *This shows the expanded concept for display of DAA information to a pilot, including the "basic" information and additional maneuver advisories via the "omni-bands", depicting clear of conflicting heading maneuvers*

IV. Integrated Flight Test 1 Data

In support of the Scripted Encounters, a total of 11 Integrated Flight Test 1 flights were conducted between 17 June 2015 and 24 July 2015. During those flights, 108 of the 120 planned encounters vignettes were flown with Ikhana as the ownship. A total of 42.8 gigabytes of data were collected with a total of 2376 data files. The Appendix provides a list of the data collected and a detailed description of the data can be found in the Data Management Plan.[19] The data are under analysis by the DAA research teams and results will be published separately.

The Full Mission configuration was run from 10-12 August 2015, with 3 pilots evaluating the display of DAA alerts in a realistic environment. The initial test plan called for a total of 10 test subjects, however significant problems with the data collection were documented during the preliminary integration testing and could not be resolved completely as execution of the flight test commenced. The most significant issue was with the command and control of the T-34C used as the surrogate ownship aircraft. During certain specific maneuvers, latencies between the time a maneuver was selected in the Vigilant Spirit and the time it was received and performed by the T-34C auto-pilot were recorded to be over 10 seconds. While observed on occasion during the check-out flights, this was an issue with the second and third test subjects and was a primary reason for ending the data collection early.

In addition, significant data drop-out from the T-34C to the ground was observed. As seen in Figure 7, the telemetry from the ownship aircraft that was being transmitted via the C2 data link would occasionally drop for up to 60 seconds at a time. This could have been accepted if these data-drop instances occurred only while the aircraft was not under a test encounter. However, several occurrences while the aircraft was either preparing to maneuver or maneuvering due to a DAA advisory were observed.

Ultimately, the value of the data being collected was questionable and the data collection efforts were postponed. It was decided to move all remaining test points for the Full Mission configuration to the final integrated flight test to be conducted the following year.

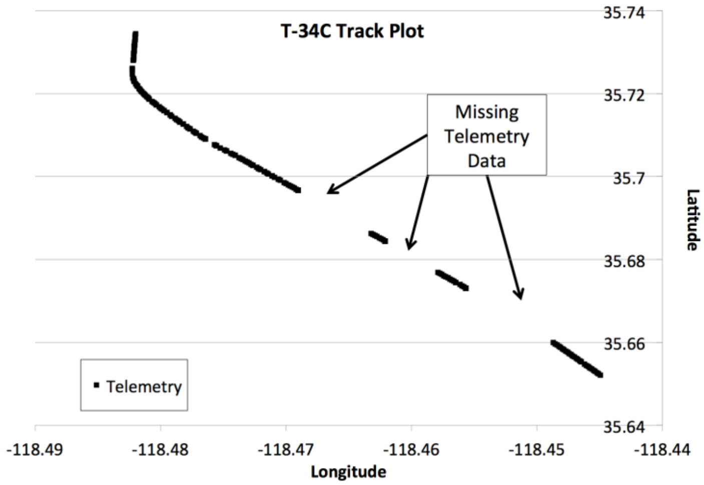

Figure 7. Display of T-34 Surrogate ground track. *Aircraft position reports from the telemetry data shown as squares depict significant data drop for the ownship aircraft.*

V. Integrated Flight Test 2 Description

Integrated Flight Test 2 (IFT2) provides the researchers with an opportunity to expand on the data collected during the first flight tests. Following IFT1, additional scripted encounters with different aircraft performance and sensors will be conducted. The date for the IFT2 is being planned to ensure collection of data to support the validation of the final RTCA Phase 1 DAA MOPS. There are 9 primary objectives associated with this goal:

- Evaluate the performance of the DAA system against cooperative and non-cooperative aircraft encounters
- Evaluate the performance of an integrated DAA and Communications link that is representative of the C2 MOPS latency
- Evaluate UAS pilot performance in response to DAA maneuver guidance and alerting with live intruder encounters
- Evaluate the effectiveness of the DAA system to enable timely coordination between UAS pilots and air traffic control
- Evaluate TCAS/self-separation interoperability
- Support validation of simulations used to develop the final Phase 1 DAA MOPS
- Characterize the performance of the flight test and simulation environment
- Demonstrate flight test and simulation environment readiness to support the Capstone flights/effort

As with IFT1, this flight test series will have two primary configurations, the first will be a series of scripted encounters, supporting the collection of data to validate the interoperability of self-separation and collision avoidance algorithms. The second configuration will again include a full UAS pilot mission in a relevant test environment, including a realistic set of live and virtual traffic in the virtual airspace (though with a significantly increased number of encounters). For the Scripted Encounters, it is anticipated that the Ikhana will once again be ownship for the test. However, due to the problems with the latencies for control of the T-34C as a surrogate, a different aircraft may be obtained as ownship for the Full Mission configuration. Additional surrogate aircraft testing has been planned to ensure either the T-34C or the alternate aircraft meet the research requirements.

VI. Capstone Description

The Capstone demonstration is intended to provide a meaningful review of the technologies under research in the UAS-NAS Project. The purpose of the demonstration is to highlight the advancements in the state-of-the-art for safe UAS flight to industry and the general public.

Two flights are planned for this demonstration. The first is a replication of the Full Mission configuration for the flight tests, but moved out to actual NAS airspace. Since the Project does not yet have an actual UAS aircraft that has both the C2 radios and sensors that provide data to the DAA algorithms, the T-34C surrogate will be flown to show how the integration between air and ground and pilot and aircraft can be integrated. The second flight attempts to stretch the bounds of Project technologies by flying the Ikhana aircraft in the NAS. The Ikhana will have on-board sensors and connection to a GCS (though through a SatCom and line of sight links instead of the prototype C2 radios). This demonstration will include unrestricted airspace, featuring a flight from NASA Armstrong into Class E airspace to the Class D terminal airspace at Victorville and back. It is anticipated that this will require a waiver or exemption from the FAA. This is intended to show the safety of the technologies while providing a preview of the anticipated Phase 2 MOPS airspace.

VII. Conclusions

Despite the problems incurred during the Full Mission portion of the IFT1, significant data contributing to the Phase 1 DAA MOPS has been collected. Nearly all Scripted Encounter test points were run, with the data collected and archived by the UAS-NAS Project's integrated test and evaluation team. While the Full Mission configuration experienced latency and surrogate control issues, the UAS-NAS project has documented each of the lessons learned and are applying those to reduce risk and ensure a successful execution of IFT2.

Furthermore, the LVC test infrastructure, technologies, and techniques developed by the integrated test and evaluation team during conduct of the IFT1 are anticipated to provide not only a foundation for the conduct of IFT2, but for future manned and unmanned aviation research. As such, the development team is documenting the LVC environment and its usage, as well as its interfaces to the client assets. This will be made available at the end of the UAS-NAS Project in September 2016.

As the UAS-NAS Project prepares for its final Human in the Loop simulations and IFT2, the DAA, Human Systems, and C2 researchers are working closely with the RTCA SC-228 stakeholders to ensure the correct data are being collected moving towards successful Verification and Validation of the Phase 1 C2 and DAA MOPS. To support this effort and future analyses, all archived data will be made available for analysis by NASA research partners.

Appendix

Listing and description of the data files captured during IFT1.

System Component	File Description	Data Description	Scripted Encounters	Full Mission
LVC Gateway (Data Logger)	Comma separated ASCII data (CSV)	Time and content of every message passed through the LVC Gateway, ASCII format	Yes	Yes
LVC Gateway (Data Collector)	Binary data file (bin)	Time and content of every message passed through the LVC Gateway, binary format, used for playback	Yes	Yes
JADEM	CSV	Ownship flight state data	Yes	Yes
JADEM	CSV	Intruder state data (used for analysis)	Yes	Yes
JADEM	CSV	Intruder state data (truth)	Yes	Yes
JADEM	CSV	SAA threat results	Yes	Yes
JADEM	CSV	SAA resolutions	Yes	Yes
JADEM	CSV	SAA Release messages	Yes	Yes
JADEM	CSV	Ownship constraints (from flight intent)	Yes	Yes
JADEM	CSV	Encounter stats	Yes	Yes
JADEM	CSV	Unresolved threats	Yes	Yes
JADEM	CSV	Filtered conflicts (not analyzed)	Yes	Yes
JADEM	CSV	Ownship path stretch metrics	Yes	Yes
JADEM	CSV	Ownship resolution data	Yes	Yes
JADEM	CSV	Ownship resolution attempts	Yes	Yes
Stratway+	Custom log output	Flight State	Yes	No
Stratway+	Custom log output	Customized Events	Yes	No
Stratway+	Custom log output	Pilot Inputs and Flight Deck Events	Yes	No
Stratway+	Custom log output	FMS Trajectories	Yes	No
Stratway+	Custom log output	GCS Pilot Inputs and Flight Deck Events	Yes	No
Stratway+	Custom log output	Closest Point of Approach Data	Yes	No
Stratway+	Custom log output	Stratway Input Data	Yes	No
Stratway+	Custom log output	Stratway Output Data	Yes	No
Stratway+	Custom log output	Stratway Band Data	Yes	No
CPDS	bin	Internal DAA algorithm data	Yes	No
Sense and Avoid	Custom log output	Ownship and intruder position data, ARINC 735B format	Yes	No

Processor (SAAP)				
C90 TPA-100B	Custom log output	Time and content for each Traffic Alert and Resolution Advisory generated by the TCAS system onboard the Intruder aircraft	Yes	Yes
Thales ADS-B	ASTERIX CAT21 format	Aircraft position data	Yes	Yes
Vigilant Spirit	Custom log output	Chat logs, Standard Tasks logs, Simulation Injections	No	Yes
Vigilant Spirit	Custom log output	Aircraft/UAS messages, telemetry data from aircraft, route replanning data	No	Yes
Vigilant Spirit Smart Eye	GAZEDATA	Eye Tracker Output File	No	Yes
Camtasia	Video file	Movie of the UAS pilot's primary flight display	No	yes
C2	Custom log output	Amount/Duration of voice communications between Pilot/Air Traffic Control	No	Yes
C2	Custom log output	Latency of voice communications Pilot/Air Traffic Control	No	Yes
C2	Custom log output	Number of targets ADS-B & Radar Latency of target information Air/Ground	No	Yes
C2	Custom log output	Percentage of telemetry information successfully received from aircraft Latency of commands to aircraft Latency of telemetry from aircraft	No	Yes
Survey Forms	Excel spreadsheets (from handwritten questionnaires)	Survey responses (to be transcribed into Excel)	No	Yes
Survey Forms	Excel spreadsheets (from handwritten questionnaires)	Survey responses (to be transcribed into Excel)	No	Yes

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