

National Campaign Development Test Executive Summary AAM-NC-054-001



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1.0 Abbreviations, Figures, and Tables

This section details the abbreviations, figures, and tables that are used throughout this document.

Abbreviation	Description
AAM	Advanced Air Mobility
ADS-B	Automatic Dependent Surveillance-Broadcast
AFB	Air Force Base
AFRC	Armstrong Flight Research Center
AFRL	Air Force Research Laboratory
AFSRB	Airworthiness & Flight Safety Review Board
AGL	Above Ground Level
AIRNAV	Airport Information Database
AOM	Airspace Operations Management
API	Application Programming Interface
ARC	Ames Research Center
ARINC	Aerial Radio Incorporated
ARMDD	Aeronautics Research Mission Directorate
ATC	Air Traffic Control
ATI	Airspace Test & Integration
ATM-X	Air Traffic Management-eXploration
CNS	Communication, Navigation, and Surveillance
COA	Certification of Authorization
ConOps	Concept of Operations
CRM	Crew Resource Management
DATR	Dryden Aeronautical Test Range
DMP	Data Management Plan
DRPO	Dry Run Primary Objective
DTO	Development Test Objective
EAFB	Edwards Air Force Base
eVTOL	Electric Vertical Takeoff and Landing
FAA	Federal Aviation Administration
FAF	Final Approach Fix
FAIR	Findability, Accessibility, Interoperability, and Reuse
FATO	Final Approach and Take-Off area
FIAPA	Flight Inspection Airborne Processor Application
FIMS	Flight Information Management System

FRR	Flight Readiness Review
FTI	Flight Test Infrastructure
FTS	Flight Test System
GCS	Ground Control Station
GNSS	Global Navigation Satellite System
GPS, dGPS	Global Positioning System, differential GPS
IMC	Instrument Meteorological Conditions
IRIG	Inter-Range Instrumentation Group
LaRC	Langley Research Center
LRU	Line Replaceable Units
LVC	Live, Virtual, Constructive
MAF	Mobile Acoustics Facility
MC	Mission Controller
MCC	Mission Control Center
MHz	Megahertz
MMAC	Mike Monroney Aeronautical Center
MOF	Mobile Operations Facility
MSL	Mean Sea Level
NAMS	NASA Access Management System
NASA	National Aeronautics and Space Administration
NC-DT	National Campaign Developmental Testing
ORD	Objective and Requirements Document
PCM	Pulse Control Modulation
PFD	Pilot Flight Display
PLASI	Pulse Light Approach Slope Indicator
PSU	Provider of Services for UAM
RF	Radio frequency
RMS	Root Mean Squared
RNAV/PBN	Area Navigation/Performance-Based Navigation
RVLT	Revolutionary Vertical Lift Technologies
SBSM	Surveillance Broadcast Service Monitor
SEL	Sound Exposure Level
SODAR	Sonic Detection And Ranging
STOL	Short Take-Off and Landing
TCL	Technical Capability Level
TPM	Technical Performance Measure
UAM	Urban Air Mobility
UAS	Unmanned Aircraft System

UDC	Universal Data Collector
UHF	Ultra-High Frequency
UPS	Uninterruptable Power Supply
UTC	Coordinated Universal Time
UTM	Unmanned Traffic Management
VFR	Very-High Frequency
VPN	Virtual Private Network
WAMS2	Wireless Acoustic Measurement System
XTM	Identifies the XTM Client Application. Formerly identified as the NOP. Experimental Traffic Management.

Figure	Title
8.1	Flight Test Infrastructure Spiral Development Process
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5.1	NC-DT Related Documents
9.1	Dry Run Activity ORD and Test Plan Reference
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12.1	Overall Development Test Outcome
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2.0 Purpose & Scope

NASA's vision for Advanced Air Mobility (AAM) is to provide safe, sustainable, accessible, and affordable aviation for transformational local and intraregional missions and includes the transportation of passengers and cargo as well as aerial work missions, such as infrastructure inspection or search and rescue operations. NASA's technical expertise, intergovernmental relationships, and high level of public trust will help this technology come to market concurrent with infrastructure readiness, public acceptance, and constructive regulation.

By advising and integrating disparate AAM efforts across the country and working collaboratively with the FAA, the National Campaign (NC) objective is to motivate industry progress and support the development of policy, regulatory, and technical standards in a manner that best ensures public safety and benefit to the American people.

NC began with the Dry Run and Developmental Test (NC-DT), which served as a pathfinder for collaboration and direct involvement with industry partners in integrated simulation exercises and flight tests. NC-DT culminated with an acoustics-gathering flight test in September 2021 with industry partner Joby's prototype S4 2.0 air vehicle, which delivered the first foundational baseline of noise levels present in Electric Vertical Takeoff and Landing (eVTOL) vehicles. Through the DT phase, the NC team built and tested the airspace and range infrastructure while assessing the readiness level of industry partners leading up to future NC events.

The purpose of this paper is to provide an overview of NC-DT.

3.0 Value

NC is an extension of the NASA Aeronautics Research Mission Directorate's (ARMD) mission to partner with U.S. industry on near-term sustainable aviation goals, keep U.S. companies on solid footing as they compete to bring to market the next generation of environmentally sustainable commercial transport aircraft, and persistently and consistently improve environmental sustainability, global mobility, and economic growth.

As emerging aviation markets such as eVTOL vehicles evolve around the world, barriers to public confidence include safety, security, affordability, noise, reliability of autonomy, vertiports, and certification. NASA believes an AAM ecosystem-wide strategy can serve as a valuable tool for the entire community to address these issues and increase the Urban Air Mobility (UAM) Maturity Level (UML) across government, industry, and academia together. U.S. government leadership in this effort will translate to American leadership in this emerging global industry, which already features several players in Europe and Asia.

NC challenges industry and other community participants to address foundational issues related to AAM vehicle design readiness and robustness for AAM operations. The NC infrastructure

provides a “proving ground” for participants to demonstrate the interoperability of their airspace concepts and technologies in an integrated AAM airspace environment. The demonstrations from NC help inform means and methods of compliance development with Federal Aviation Administration (FAA) standards development, airspace management system requirements, and desired future airspace services.

4.0 Objectives

National Campaign Goal:

Ensure AAM safety and accelerate scalability through integrated demonstration of candidate operational concepts and scenarios.

National Campaign Objectives:

- ◇ Accelerate certification and approval.
- ◇ Develop flight safety procedure guidelines.
- ◇ Evaluate communication, navigation, and surveillance trade-space.
- ◇ Demonstrate an airspace management architecture.
- ◇ Characterize community concerns.

Developmental Test Activities

NC Developmental Test (NC-DT) consisted of two primary activity periods:

- ◇ *Dry Runs*: Used to develop and verify the NC Flight Test Infrastructure (FTI) and conduct concurrent testing of UAM vehicle characteristics using a surrogate helicopter. Dry Run Primary Objectives (DRPOs) are documented in Section 7.0, *Dry Run Activities*.
- ◇ *DT-Joby Acoustics Test*: Used to conduct a preliminary assessment of the NC partnership concept and gather vehicle acoustics data desired by both NASA and partner Joby Aviation. This Activity was served to complete those aspects of the NC Development Test Objectives (DTOs) identified below that required an Industry partner and a representative UAM vehicle.

Developmental Test Objectives:

NC-DT Goal: Ensure that NASA is fully prepared to execute NC-1 event in a manner maximizing benefits to the AAM community.

- ◇ *DTO-1*: Assess Maturity & Robustness of NASA Proving Ground, accomplished during Dry Run Activities.
- ◇ *DTO-2*: Assess Effectiveness of NC Testing Processes, Logistics, & Data Collection, accomplished during Dry Run Activities.
- ◇ *DTO-3*: Preliminary Assessment of Partner Capabilities & System Performance, accomplished during DT-Joby Acoustics Testing.
- ◇ *DTO-4*: Assess the Suitability of NC-1 Scenarios, accomplished during Dry Run Activities.

5.0 Related Work

This report provides a summary of NC-DT activities and outcomes. Table 5.1 identifies the detailed test reports that document the results and conclusions of each aspect of NC-DT Activities referenced in this report.

Report Number	Title
AAM-NC-033-001	National Campaign Developmental Test Flight Test Infrastructure System Design Document
AAM-NC-072-001	National Campaign Flight Test Infrastructure Verification and Validation Report for Dry Run
AAM-NC-062-001	National Campaign Flight Test Infrastructure MOF-6 Verification and Validation Report
AAM-NC-068-001	National Campaign ATI Buildup Run 2 Flight Test Report
AAM-NC-069-001	Airspace Operations, Infrastructure and Data Services
Released by the FAA	UAM Surrogate Helicopter Flight Test Report
AAM-NC-114-001	NC-DT-Acoustics Flight Test Report

Table 5.1 – NC-DT Related Documents

6.0 Partner Organizations

The NC team partnered with both NASA and external organizations to accomplish Dry Run Activities and NC-DT Activities. Below are some of the key contributors to the success of Dry Run/NC-DT Activities.

NASA Air Traffic Management-eXploration (ATM-X) UAM Sub-Project

The ATM-X UAM Sub-Project developed airspace service software used within the Airspace System used for both Dry Run and NC-DT Activities. ATM-X also participated in NC Scenario development to ensure that the developed scenarios adequately test the airspace systems.

NASA Revolutionary Vertical Lift Technologies (RVLT) Project

The RVLT Project provided the acoustics testing equipment, Langley Research Center's Mobile Acoustics Facility (LaRC MAF), and the necessary expertise to develop the acoustic testing plans and Scenario 4 that will be tested as part of NC-DT flights with the vehicle partner.

The Federal Aviation Administration (FAA)

The FAA provided support in several key areas.

- ◇ AJF-13 organization at the Mike Monroney Aeronautical Center (MMAC) assisted with developing takeoff and landing, approach procedures, surfaces, and routes. They assisted with coding experimental routes/procedures into Aerial Radio Incorporated (ARINC) 424 for use in an Area Navigation/Performance-Based Navigation (RNAV/PBN) system for the

Dry Run. They provided an automatic flight inspection system, (Flight Inspection Airborne Processor Application [FIAPA] tablet and an operator) to evaluate the coded approach and landing procedures real-time during the Dry Run Build 2 Activity. They shared the recorded FIAPA and Surveillance Broadcast Service Monitor (SBSM) data with NASA.

- ◇ The AIR-714 organization embedded a Flight Test Engineer (FTE) in the NC Team and provided an evaluation pilot to conduct Dry Run Build 2 and Follow-on Flight Test Activities.
- ◇ The embedded FAA FTE was the primary author of AAM-NC-025-001 *NC UAM Surrogate Flight Test Plan*, the update used to conduct Follow-on Flight Test, and FAA-released *UAM Surrogate Helicopter Flight Test Report*.
- ◇ AFS-930 organization provided a liaison that participated in development of data products during post flight data analysis and contributed to AAM-NC-069-001, *Airspace Operations, Infrastructure and Data Services*.

Flight Research, Incorporated (FRI)

FRI provided the OH-58C surrogate helicopter, complete with an on-board data system, and mounting location for the NASA external differential Global Positioning System (dGPS) antenna. FRI also provided maintenance support and the Pilot-In-Command (PIC) to conduct Dry Run Build 2 and Follow-on Flight Test Activities. The FRI PIC supported development of flight test plans and hazard assessments.

Joby Aviation

Joby Aviation signed a flight annex Space Act Agreement (SAA) for NC-DT and made both their Fort Hunter Liggett-based flight test operations and S4-2.0 remotely-piloted prototype vehicle available for the NC-DT Joby Acoustics Flight Test Activity. Joby operated and maintained the vehicle and coordinated with NASA NC and RVLT personnel to incorporate NASA needs into a flight test plan that they then conducted with NASA support to gather acoustics data in accordance with NC Scenario 4, *Noise Evaluations and Community Impact*.

7.0 Activities

Scenarios

A key concept of the National Campaign was a set of seven UAM operational scenarios that increased in complexity from Scenario 1 through Scenario 7. The concept was to use these operational scenarios as a tool to increase the UAM Maturity Level (UML) across government, industry, and academia together. The approach was to progress through the scenarios as UAM-enabling technologies were ready for demonstration, verifying and validating the interoperability of technologies within a representative UAM ecosystem. The seven Scenarios included:

- ◇ *Scenario 1: Trajectory Planning & Compliance*
- ◇ *Scenario 2: Integrated Flight Operations with Activated Contingency*

- ◇ *Scenario 3: UAM Ports and Approaches*
- ◇ *Scenario 4: Noise Evaluation & Community Impact*
- ◇ *Scenario 5: Communications, Navigation, and Surveillance (CNS) Contingencies*
- ◇ *Scenario 6: Air-to-Air Conflict Management*
- ◇ *Scenario 7: Constrained Conflict Management*

The scenarios are illustrated in the Appendix. Dry Run testing used Scenarios 1, 2, and 3 to verify and validate both the Scenarios and the Flight Test Infrastructure to the extent possible with a surrogate UAM aircraft. Joby DT testing used the concepts of Scenario 4 as the basis to evaluate the acoustics of the Joby vehicle.

Dry Runs

From October of 2020 through August of 2021, NC conducted the Dry Run flight test program to verify the NASA NC Flight Test Infrastructure and Operational Scenarios prior to validation during NC-DT. Dry Run led to the development of data collection systems, refinement of NC scenarios and test techniques, and capturing of foundational vehicle operational data that will enable the advent of AAM in the National Airspace System (NAS). The Dry Run Activity provided risk reduction for NC-DT across several areas.

The ten Dry Run primary objectives enabled NC to accomplish DT objectives DTO-1, DTO-2, and DTO-4. DT objectives can be traced to Dry Run Objectives, which were derived to define, develop, and verify the systems necessary to support future NC Activities. The ten Dry Run Primary Objectives (DRPO)s included:

1. Demonstrate integrated aircraft & test infrastructure.
2. Demonstrate deployable integrated test infrastructure.
3. Demonstrate connectivity and functionality between range assets and Provider of Services for UAM (PSU) network.
4. Demonstrate operations procedures and processes.
5. Collect, manage, and store data.
6. Demonstrate data handling, storage sharing processes, and hardware.
7. Collection and distribution of weather data.
8. Evaluate route design techniques between Area A and the X-33 site.
9. Evaluate terminal operations and procedures.
10. Evaluate UAM scenarios 1-3.

Dry Run Primary Objectives and the FTI were verified during integrated testing in four activities, including:

- ◇ *ATI Connectivity Test, October 2020: Verification of the Airspace Test Infrastructure (ATI) subsystem set up in the NASA Armstrong Mission Control Center (MCC) and used to track a TG-14 aircraft flying prescribed routes.*

- ◇ *Build 1 (Familiarization) Flights, December 2020:* Evaluation of Armstrong-area routes and infrastructure, such as heliports and a representative vertiport, using a UAM Surrogate Helicopter.
- ◇ *Build 2 Flight Test, March 2021:* Verification of the integrated FTI, as well as evaluation of UAM vehicle characteristics and UAM task elements, using the NASA Armstrong MCC and a UAM Surrogate Helicopter, and including routes, heliports, vertiports, weather, video, Pulse Light Approach Slope Indicator (PLASI) and an on-vehicle high-fidelity space position instrumentation pallet (dGPS Pallet).
- ◇ *Mobile Operations Facility (MOF) Verification and Validation (V&V) Test, August 2021:* V&V of the NC Mobile Operations Facility (MOF) in a representative operational environment using a TG-14 aircraft flying prescribed routes.
- ◇ *UAM Surrogate Follow-On Flight Test, November – December 2021:* Further validation of the MOF in an operational setting, additional exploration of UAM vehicle characteristics and UAM task elements, and refinement of UAM routes and approaches.

NC-DT Joby Acoustics

The purpose of Developmental Test was to execute a flight test with a partner at an external range, using an instantiation of the NC FTI tailored to the requirements of the Activity. In this Activity, the partner was Joby Aviation providing the remotely piloted S4-2.0 prototype. There were four DT objectives for the Joby flight test at Fort Hunter Liggett.

- ◇ Collect air vehicle data during Joby flight operations.
- ◇ Collect acoustics to inform eVTOL noise evaluation database.
- ◇ Collect Airspace System data using a NASA-provided Automatic Dependent Surveillance-Broadcast (ADS-B) Ping Station and a mobile version of the Airspace system known as ‘ATI On-the-Go’.
- ◇ Collect terminal area weather data using NASA AFRC Sonic Detection And Ranging (SODAR) and stationary weather equipment.

The NC-DT Joby Acoustics Activity was conducted in September 2021 on the range located at Fort Hunter Liggett, California.

8.0 NC UAM Flight Test Infrastructure System Overview

NC developed a simulated UAM System, collectively referred to as the NC Flight Test Infrastructure (FTI) to facilitate future testing in a representative UAM environment. It is a modular framework designed to make adding, updating, or swapping subsystems straightforward. It is designed to ensure scalability (ability to grow to meet the developing requirements of the AAM ecosystem), availability (ability to ensure both data and systems are available to users) and security (ensuring that both data and systems are protected against attacks or unauthorized access). This flexibility and security enable the FTI to be configured as required to support flight demonstrations with industry partners, and the ability to add capability

as the NC series evolves. Figure 8.1 illustrates the development process employed to update the FTI.

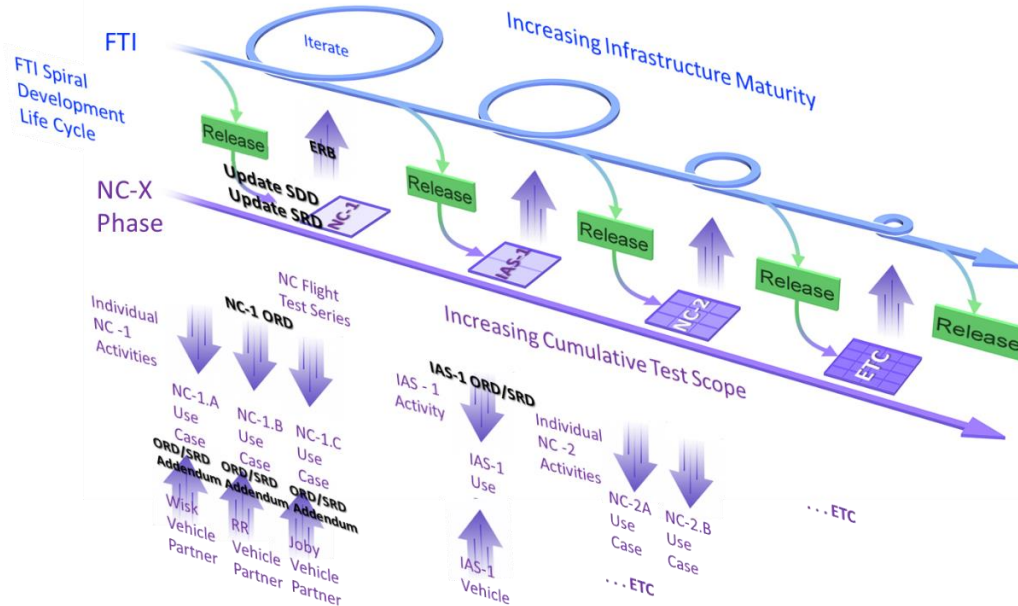


Figure 8.1 – Flight Test Infrastructure Spiral Development Process

The FTI includes the following Systems, which are documented and verified as referenced below:

- ◇ *Airspace System*: configuration description and employment in the FTI can be found AAM-NC-068-001, *National Campaign ATI Buildup Run 2 Flight Test Report*.
- ◇ *Range System (including Test Site Infrastructure)*: configuration description and verification can be found in AAM-NC-072-001, *National Campaign Flight Test Infrastructure Verification and Validation Report*.
- ◇ *Vehicle System*: NC envisions the vehicle as both provided and documented by Activity partners. The NASA-developed and managed Instrumentation Box and Carry-on Instrumentation, described and verified in AAM-NC-045-001, *NC Instrumentation Operation and Inspection Procedure*.

Figure 8.2 depicts the high-level architecture and interfaces between the Airspace, Range, and Vehicle Systems within the Flight Test Infrastructure system-of-systems. Both real-time and post flight interfaces are depicted and annotated. The general flow of data is from upper left in the vehicle subsystem (purple), down to the range assets on the bottom (green), to the right through a cloud network (gray). Vehicle, airspace, and environment data, both real-time and post-flight, make their way through the system via the cloud and other networks for real-time visualization and long-term storage in a secure data repository (blue).

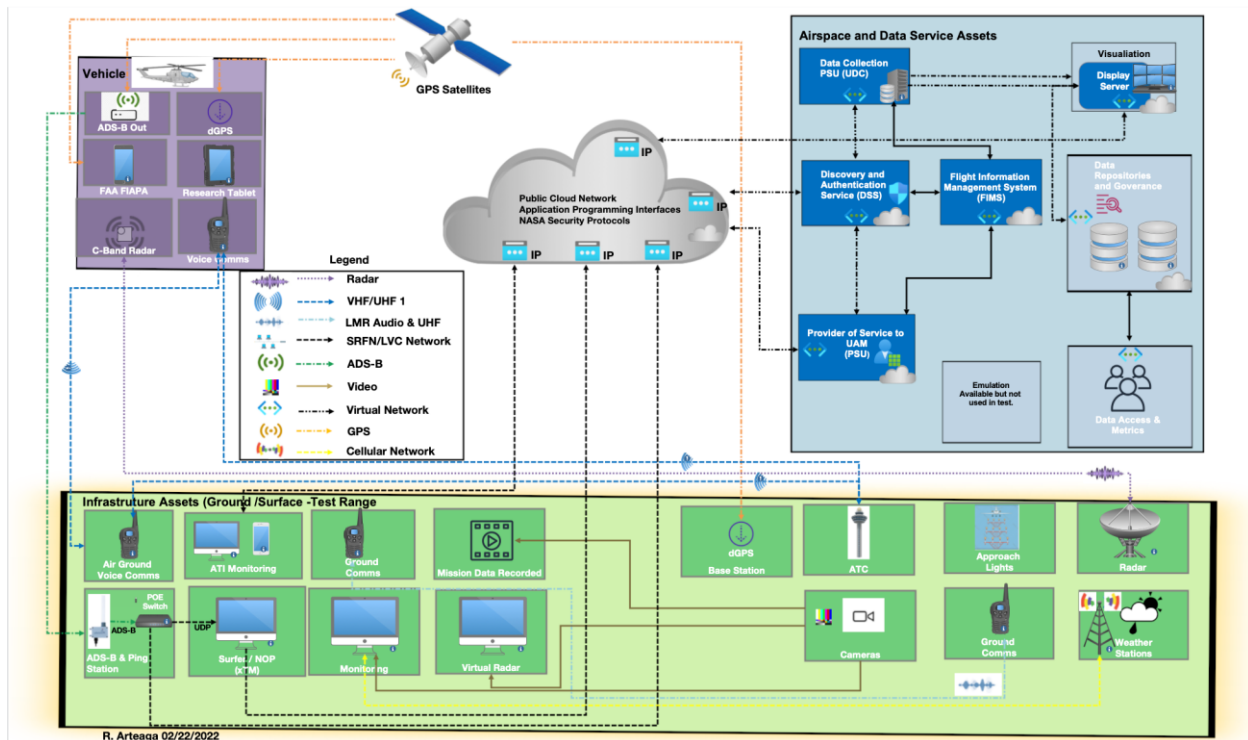


Figure 8.2 - FTI Architecture and Interfaces

It is expected that as the UAM concept of operations matures, the FTI will evolve, and new capabilities will be added, which will be verified and validated as they are introduced. The FTI will be continually developed to advance and mature UAM airspace concepts with a goal to inform airspace standards development.

The FTI was verified against System-level requirements in accordance with AAM-NC-072-001, *National Campaign Flight Test Infrastructure Verification and Validation Report*.

The FTI System Breakdown Structure was defined as required to meet objectives for Dry Runs and NC-DT Joby Acoustics. The differences between Dry Run and NC-DT configurations illustrate the modular and tailorable characteristics of the FTI.

Dry Runs

The Dry Run as-tested configuration is depicted in Figure 8.3. System requirements were derived from NC Dry Run Objectives and can be found in AAM-NC-017-001, *Range NC-DT System Requirements Document* (SRD). The NC team developed and verified the FTI through the four Dry Run Activities from October 2020 through August 2021.

Note that for Dry Run, the following elements envisioned during the requirements phase of the life cycle were not implemented:

- ◇ Vehicle messaging was not enabled in the available version of the NASA Provider of Services to UAM (NPSU) system Traffic; therefore, urban layer simulations and the pilot tablet were not included in the FTI.
- ◇ Acoustics test capabilities defined by the NASA Langley Mobile Acoustics Facility (LaRC MAF) and associated microphone arrays were evaluated in NC-DT with Joby rather than in Dry Run, since a representative UAM vehicle was desired.
- ◇ The Range System Crew Rest Trailer was a non-developmental, not needed for Dry Run testing at Armstrong, but included in the FTI deployed to Fort Hunter Liggett for Joby Acoustics Testing.
- ◇ Range System radio repeaters were non-developmental, not needed for testing at AFRC, and therefore were not included for either configuration but are reserved for future FTI instantiation if needed.

For Dry Run Activities through *Build 2* in March of 2021, the Armstrong Mission Control Center (MCC) was used in lieu of the MOF. Subsequently, the MOF and its interfaces to the rest of the FTI were verified and validated in the August 2021 *MOF Verification & Validation* activity.

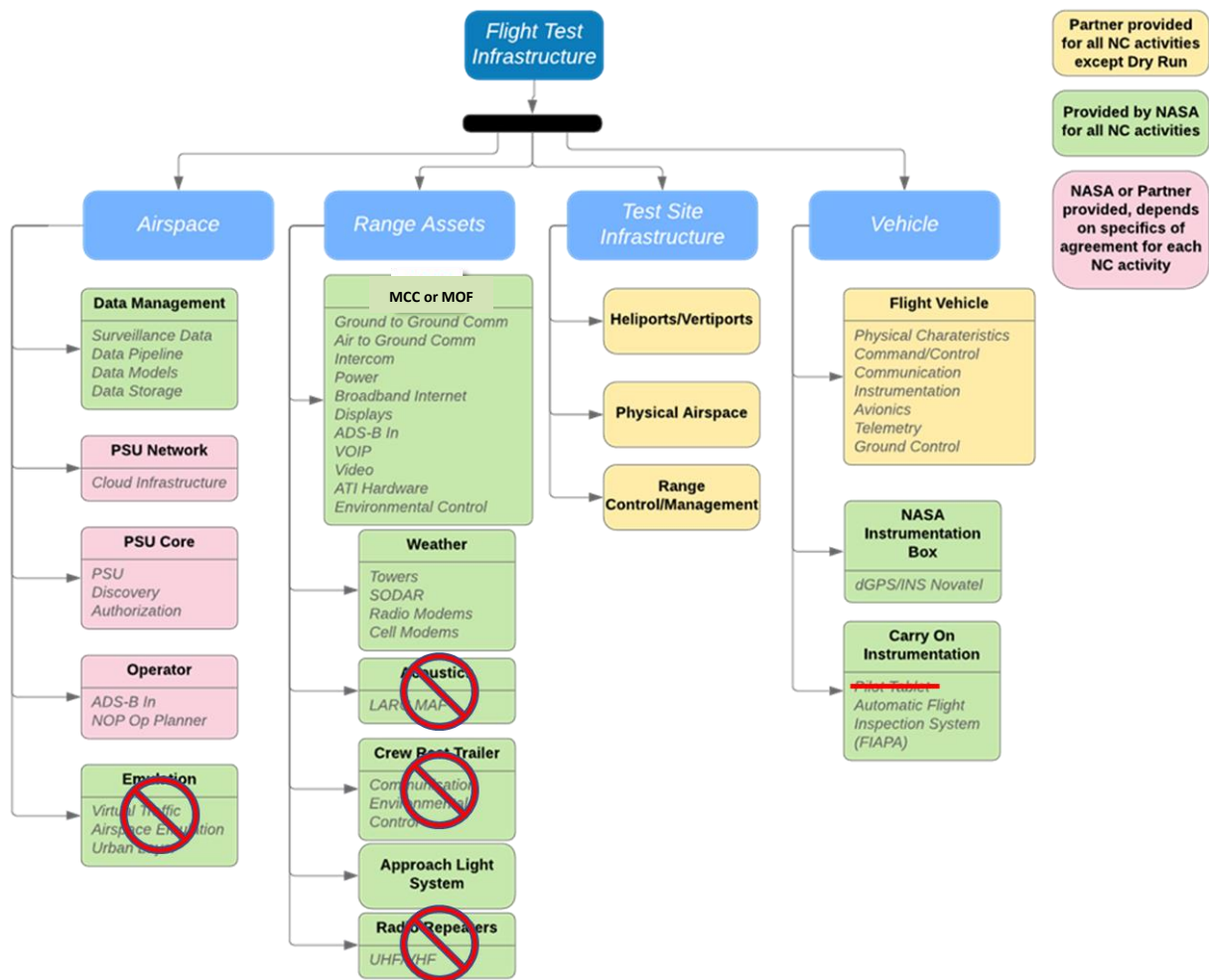


Figure 8.3 – FTI System Breakdown Structure for Dry Runs

NC-DT Joby Acoustics

The NC-DT as-tested configuration is depicted in Figure 8.4. System requirements were derived from NC DT Objectives and can be found in AAM-NC-050-001, *NC-DT-Joby at Fort Hunter Liggett* (SRD). The NC team tailored the FTI as required to meet NC-DT Activity objectives.

Note that for NC-DT, the following elements envisioned during the requirements phase of the life cycle were not implemented:

- ◇ Traffic, urban layer simulations, and pilot tablet since vehicle messaging was not enabled in the available version of the NASA Provider of Services to UAM (NPSU) system.
- ◇ Airspace emulation and the Pilot Tablet are future capabilities that will be developed when needed.

- ◇ Radio repeaters are non-developmental aspects of the Range System, were not needed for testing at AFRC, and therefore not included for either configuration but are reserved for future FTI instantiation if needed.

FTI features specific to NC-DT include:

- ◇ The Joby Ground Control System (GCS) was used in lieu of the NASA MOF.
- ◇ Acoustics test capability defined by the NASA Langley MAF and associated microphone arrays; evaluated in NC-DT with Joby rather than in Dry Run, since a representative UAM vehicle (rather than a OH-58C surrogate helicopter) was desired.
- ◇ The Crew Rest Trailer, a non-developmental aspect of the FTI not needed for Dry Run testing at Armstrong but included in the System deployed to Fort Hunter Liggett for Joby Acoustics Testing.

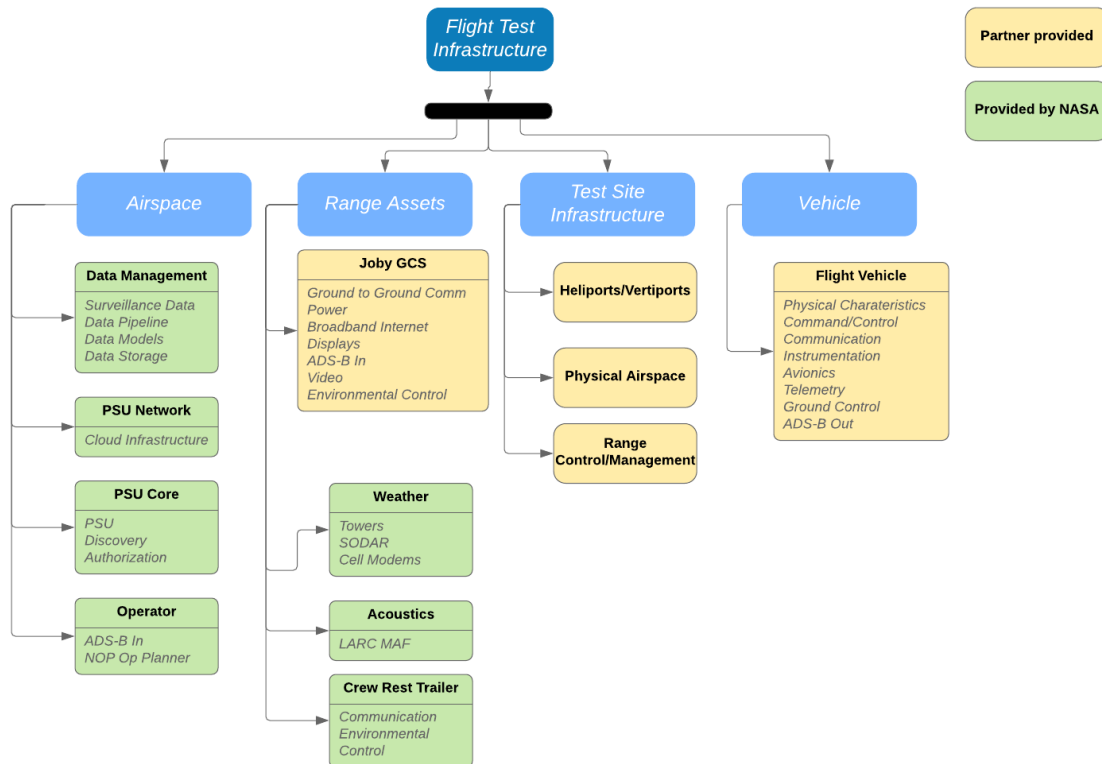


Figure 8.4 – FTI System Breakdown Structure for NC-DT Joby Acoustics

FTI Baseline Configuration

Upon completion of NC-Dry Runs and NC-DT Joby Acoustics Test, the FTI configuration initial baseline was established and documented in AAM-NC-033-001, *National Campaign Developmental Test Flight Test Infrastructure System Design Document*. Future use of the FTI will

be tailored based upon individual Activity requirements and subject to spiral development in accordance with process depicted in Figure 8.1.

9.0 Test Approach

In general, test requirements and plans were derived from sequential releases of the AAM-NC-020-001/002/003 *NC-DT Objectives and Requirements Document[s]* (ORD). Detailed test objectives, requirements, and plans are in accordance with Table 9.1 for Dry Runs, and Table 9.2 for NC-DT with Joby.

Dry Runs

The approach to Dry Run testing was documented to incrementally develop and verify FTI capabilities and System culminating in a complete System Demonstration during Build 2. The Dry Run Activity Life Cycle was peer reviewed by an Independent Review Team (IRT) and Flight Readiness Review (FRR) Team hosted by NASA Armstrong. The documentation and approach to development and testing of the FTI is documented on the NC Sharepoint site in Folder 2.05, *Flight Readiness Review*.

Supply chain shortages prevented acquiring all the components necessary to complete the MOF. Therefore, the NASA Armstrong MCC was used as a surrogate up through Build 2. When the MOF was completed and verified, a flight test was conducted to validate its ability to perform its intended role within the FTI System. Follow-on Flight Test was conducted to collect data from test conditions missed during Build 2 flight test.

ORD: AAM-NC-020-001 Test Plans	Dry Run Activity
AAM-NC-034-001 <i>ATI V&V Test Plan</i>	ATI Connectivity Flight Test
TB-NCDR-FAA-FRI <i>Fam Flights Tech Brief-003</i>	Build 1 Familiarization Flights
ORD: AAM-NC-020-002 Test Plans	Dry Run Activity
AAM-NC-027-001 <i>NC Dry Run FTI V&V Plan</i>	Build 2 Flight Test
AAM-NC-025-001 <i>NC UAM Helicopter Flight Test Plan</i>	Build 2 Flight Test
AAM-NC-058-001 <i>NC Mobile Operating Facility (MOF) Verification and Validation Test Plan</i>	MOF V&V
AAM-NC-025-001-1 <i>UAM Surrogate Helicopter Follow-on Flight Test Plan Supplement</i>	Follow-on Flight Test

Table 9.1 – Dry Run Activity ORD and Test Plan Reference

The test plans identified in Table 9.1 provide detailed test configuration, objectives, procedures, and test conditions for each Activity. The detailed operations approach for each Activity is captured in the corresponding Activity Technical Brief and flight test cards.

NC-DT Joby Acoustics

The approach to NC-DT Joby Acoustics testing was conducted as a Partner-led Activity with NASA participation. Therefore, no IRT or FRR was conducted. The documentation baseline established during Dry Runs was updated as required for the specific objectives, requirements, and plans of the NC-DT Joby Acoustics flight test. The Activity was conducted in accordance with the Joby flight test plan and safety review processes.

ORD: AAM-NC-020-003 Test Plans	Dry Run Activity
<i>Joby Acoustics Flight Test Matrix</i>	NC-DT Joby Acoustics Flight Test
<i>NC DT – Joby Tech Brief</i>	

Table 9.2 – NC-DT Activity ORD and Test Plan Reference

The Joby test plan provides detailed test configuration, objectives, procedures, and test conditions for the Activity. The detailed operations approach for NC-DT is captured in the corresponding Activity Technical Brief and Joby flight test cards.

10.0 Data Collection

Dry Runs

The following data were generated and captured for Dry Runs, and uploaded to the NASA Box cloud server after each flight as depicted in Figure 10.1:

◇ During Operations

- *ADS-B and Operations data:* using software applications SURFER, UDC, and the xTM Client (see AAM-NC-068-001 *National Campaign ATI Buildup Run 2 Flight Test Report* for a description of these applications).
- *Interactive Authoring Display Software (IADS):* The OH-58C helicopter was equipped with the IADS an instrumentation system, which recorded vehicle parameters identified in Section 9.
- *Air-to-Ground Audio Data:* Flight audio data consisted of air-to-ground and ground-to-ground communications across continuous, two-way UHF and VHF radio frequencies. Audio files included interactions between active mission participants (primary source) as well as operations personnel. Participants include the pilot, the Flight Test Engineer (FTE) and the MCC or MOF.
- *Integrated Differential GPS and Inertial Measurement Unit (dGPS/IMU):* a NovAtel PwrPak7-E1 equipped with Epson G320N MEMS IMU was installed onboard the vehicle. The B2 IMU measured the aircraft's force, angular rate, and attitude (roll, pitch, and yaw) through a combination of accelerometers and gyroscopes. Timestamps in the data output were GPS synchronized.

- *Flight Inspection Airborne Processor Application (FIAPA)*: the FIAPA YUMA-7 tablet was secured onboard the vehicle (glare shield) for B2, with a geometry for the antenna of 4'4" vertical, forward 2'8" and right 2'8" from the reference point. The tablet had a Global Navigation Satellite System (GNSS) sensor and an EM-100 sensor module for additional sub-meter accuracy.
- *Weather*: captured using the weather stations and SODAR located as described in Section 8.

◇ Post Flight

- *ADS-B Surveillance and Broadcast Monitoring System (ABDS-B SBSM)*: The FAA shared a secondary, postflight source of ADS-B data leveraging its Surveillance and Broadcast Services Monitor (SBSM) system, which is a constellation of ADS-B receivers that provide sweeping coverage of the National Airspace System (NAS) in order to collect time, space, and position information (TSPI) for air traffic improvements at airports and other interstitial locations. More information regarding SBSM can be found here: https://www.faa.gov/documentLibrary/media/Order/8200_45_ADS-B.pdf
- *RADAR*: C-Band Beacon tracking downlinked vehicle position information to Range radar station and the Mission Controller (MC) display using the standard DATR network. Raw data from the C-Band Beacon was exported to .rdf and space delimited .txt formats using the Radar Information Processing System (RIPS).
- *Video*: recorded from existing Armstrong flight ramp and Long Range Optics (LRO) cameras.
- *Test Cards*: Two collections of B2 flight decks, annotated by the FTE within the test vehicle and the Chief Engineer (CE) within the control room, were scanned and placed in the access-controlled repository in the NASA Box.

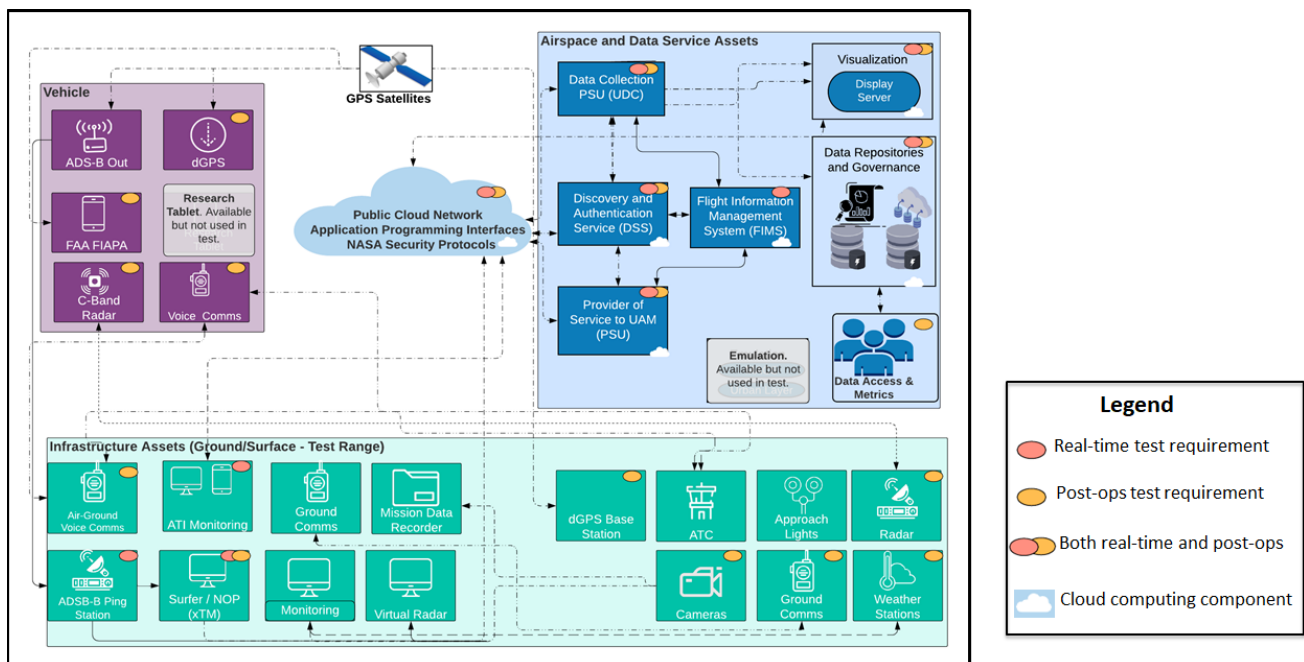


Figure 10.1 – Data Sources Within the FTI Architecture

Post-processing to collect, synchronize and store data is described below:

- ◇ *Time Stamping:* each postflight data source was synchronized with the Global Positioning System (GPS) time scale maintained by GPS satellites and provided by atomic clocks in the GPS ground control stations. GPS times were also normalized to the UTC time stamp standard by Extract, Transform, and Load (ETL) Data adapters when UTC was not available in the raw output. Synchronization is illustrated in Figure 10.2.

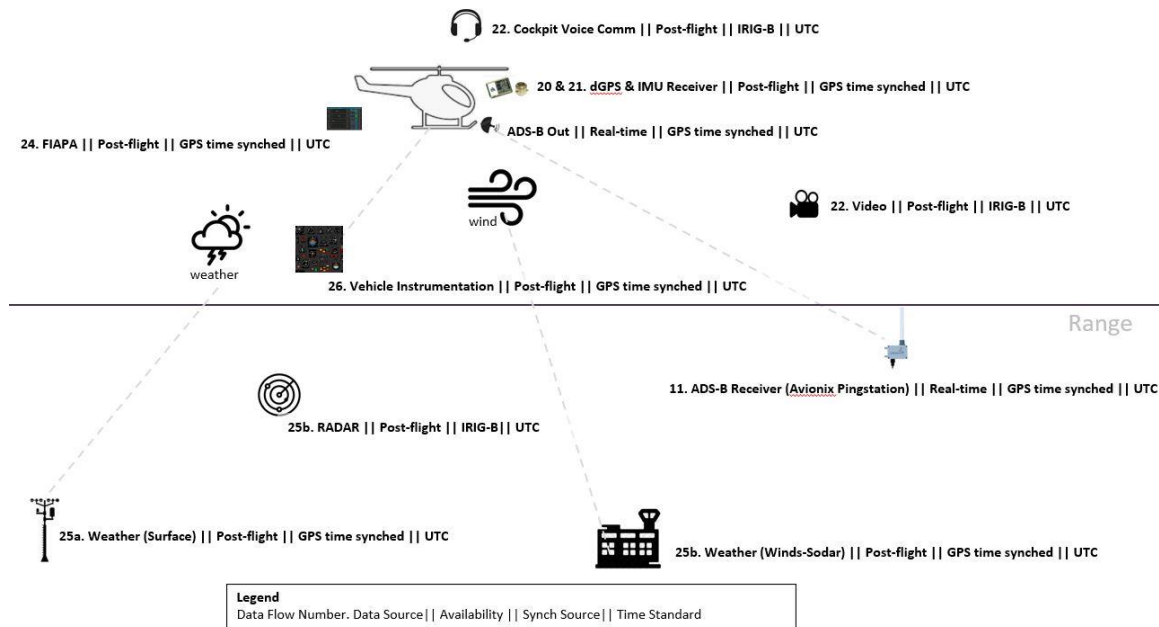


Figure 10.2 – Time Synchronization Across Data Sources

- ◇ *Post-Flight Data Transfer:* NC representatives with NASA PIV provisions were assigned to transfer each data source generated by Vehicle and Range domains to an access-controlled Box cloud-storage location. The data transfer process is illustrated in Figure 10.3, and described in detail in AAM-NC-068-001, *National Campaign ATI Buildup Run 2 Flight Test Report*

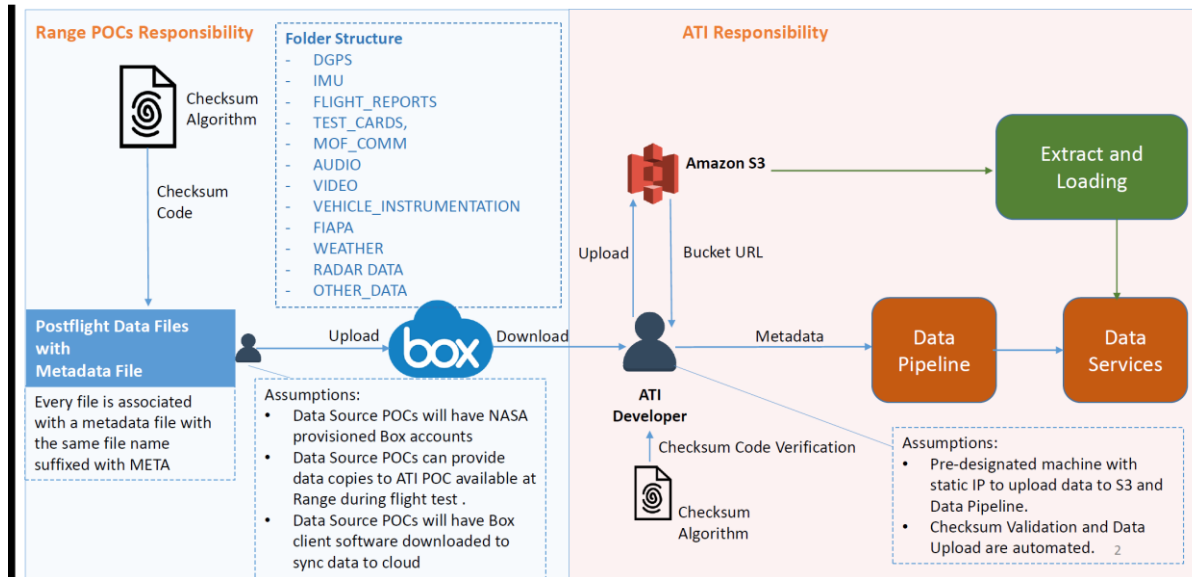


Figure 10.3 – Post Flight Data Transfer Protocol

- ◇ **Data Fusion and Modeling:** At the conclusion of the flight test series, data from various sources were fused into the AAM Integrated Data Product (IDP) – a combined dataset that provides a holistic view of each individual sortie. Refer to AAM-NC-068-001, *National Campaign ATI Buildup Run 2 Flight Test Report* for a snippet of the AAM IDP data dictionary that was developed to define each field of the integrated dataset.

Governance: Data was managed as a business asset, and formal accountability was established. Data quality was defined and managed consistently across the life cycle of data, in compliance with Findability, Accessibility, Interoperability, and Reuse (FAIR) principles. In addition to the official records maintained by NASA Access Management System (NAMS), the Data Management Team documented data sharing on Confluence. These records also included low-level decisions that did not impact governance policy or the National Campaign project as a whole. Higher-level data sharing decisions were brought up by the Data Management Team through AAM NC Management, Agency (NASA, FAA, etc.), Aeronautics Research Mission Directorate, Center Boards, other Boards (Security Management, Applications, Cloud, etc.) and the NASA Data Governance Board (DGB) as appropriate. Figure 10.4 depicts the NC data sharing protocol.

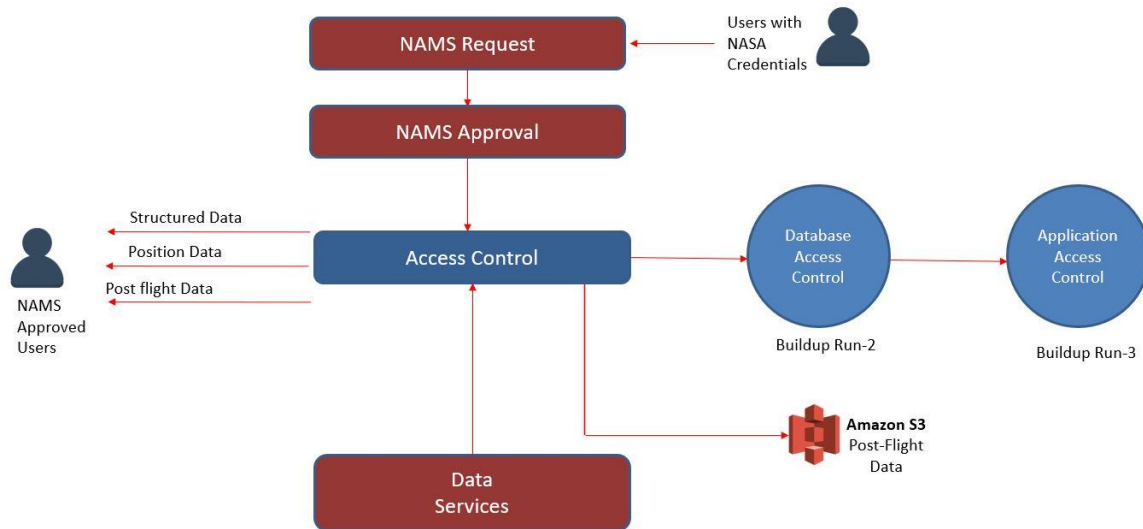


Figure 10.4 – NC Activity Data Sharing Protocol

The data handling processes were verified and refined during Dry Run Activities. They will serve as the baseline for the data requirements, plans, capture, and sharing approach for future NC Activities.

NC-DT Joby Acoustics

The data collection, processing, time stamping, and governance validated in Dry Runs were used for the NC-DT Joby Acoustics Activity. Additionally, acoustic data received by the Wireless Acoustic Measurement System (WAMS2) was transmitted to and collected by the RVL Acoustics Team using the Mobile Acoustics Facility (MAF) for later processing.

11.0 Test Results

Dry Run Activities

The combined NC, FAA, and FRI Team successfully executed planned Dry Run testing. Over the course of five Activities from October 2020 through December 2021, using a combination of NASA TG-14 and FRI OH-58C surrogate vehicles, test plan objectives were accomplished.

Data was acquired to satisfy Data was acquired to support Dry Run Primary Objectives (DRPO) 1 to 10, which detailed how Development Test Objectives 1, 2, and 4, were satisfied. Table 11.1 identifies the reports that provide detailed test results and conclusions for each Dry Run Activity.

Dry Run Activity	Test Report
ATI Connectivity	AAM-NC-068-001
Build 1/2 FTI Verification and Validation	AAM-NC-072-001
MOF V&V	AAM-NC-062-001
UAM Surrogate Helicopter Flight Test/ Follow-on Flight Test	<i>Report released by the FAA</i>
NC Development of Airspace Operations, Infrastructure and Data	AAM-NC-069-001

Table 11.1 – Dry Run Test Results to Activity Reference

Data was gathered to draw conclusions in three primary areas:

- ◇ NC Flight Test Infrastructure (FTI) was evaluated as an initial prototype UAM System by which future National Campaign (NC-1 and beyond) simulations and flight demonstrations can be accomplished.
- ◇ Methods to assess UAM vehicle performance and handling qualities were evaluated using a surrogate helicopter.
- ◇ Initial iterations of UAM flight rules and terminal area procedures were assessed using a surrogate helicopter.

NC-DT Joby Acoustics

The combined NC, RVLT Acoustics, and Joby Aviation Team successfully executed planned NC-DT testing. The Team measuring the vehicle acoustic signature during representative flight conditions for hover, departure, cruise, approach, and transition to and from wing-borne flight. A summary of test scope is included in Table 11.2

Test overview	
Test days	6
Total flight time	5 hrs
Total planned test conditions	~100
Total test records	31
Approximate size of raw dataset	230 GB

Table 11.2 – NC-DT Joby Acoustics Testing Summary

Data was acquired to support DTO-3, *Preliminary Assessment of Partner Capabilities & System Performance*, and DTO-4, *Assess the Suitability of NC-1 Scenarios*, specifically with respect to Scenario 4, *Noise Evaluation and Community Impact*.

- ◇ Vehicle tracking and state data was gathered to assess existing noise prediction tools and determine their applicability to AAM.
- ◇ Acoustic pressure time series data was gathered to quantify typical noise levels.

- ◇ Constant airspeed level flyover data of the thrust-borne to wing-borne transition envelope and full wing-borne cruise configurations was processed to form emission angle and frequency-dependent vehicle acoustic signatures.
- ◇ Computed Sound Exposure Level (SEL) isolines for near-vertiport operation (i.e., departure and approach) were parameterized – within the vehicle prototype's envelope – over acceleration and flight path angle.
- ◇ Wireless communication between the Mobile Acoustics Facility (MAF) and Wireless Acoustic Measurement System (WAMS2) was demonstrated. Signal-to-noise ratio was assessed over the frequency range of interest.
- ◇ Statistical information regarding acoustic symmetry, repeatability, and variability was assessed to aid in planning future acoustic flight tests with other industry partners.

Detailed test results are documented in AAM-NC-114-001, *NC-DT Acoustic Flight Test Report*.

12.0 Conclusions and Lessons Learned

Specific conclusions are presented in the test reports referenced in Section 11, above. General observations and lessons learned from Dry Run and Development Test activities are presented below. The data gathered from all DT test activities indicate that Development Test Objectives were fully met, as indicated in Table 12.1.

Development Test Objective (DTO)		Results	Activity
1	Assess Maturity & Robustness of NASA Proving Ground	Full Success	Dry Runs; Deployment
2	Assess Effectiveness of NC Testing Processes, Logistics, & Data Collection	Full Success	Dry Runs
3	Preliminary Assessment of Partner Capabilities & System Performance	Full Success	NC-DT Joby Acoustics
4	Assess the Suitability of NC-1 Scenarios	Full Success	Scenarios 1 – 3: Dry Runs Scenario 4: NC-DT Joby Acoustics

Table 12.1 – Overall Development Test Outcome

Dry Runs

The data obtained from Dry Run activities indicate that all Dry Run Primary Objectives were met as indicated in Table 12.2.

Dry Run Primary Objective (DRPO)		Results
1	Demonstrate integrated aircraft & test infrastructure	Full Success
2	Demonstrate deployable integrated test infrastructure	Full Success
3	Demonstrate connectivity and functionality between range assets and PSU network	Partial Success. The airspace system provided, functionality to support 3D, but not 4D, trajectory planning. Connectivity and functionality were fully demonstrated.
4	Demonstrate operations procedures and processes	Full Success
5	Collect, manage, and store data	Full Success
6	Demonstrate data handling, storage sharing processes, and hardware	Full Success
7	Collection and distribution of weather data	Full Success
8	Evaluate route design techniques between Area A and the X-33 site	Full Success
9	Evaluate terminal operations and procedures	Full Success. Foreflight application was used in lieu of a vehicle RNAV system, which was not available in the FRI surrogate vehicle.
10	Evaluate scenarios 1-3	Full Success. Scenarios 3B and 3C required revision to make them operationally relevant.

Table 12.2 – Dry Run Test Outcome

Dry Run Activities were also sufficient to fully satisfy DTO-1, DTO-2, and DTO-4. General conclusions and lessons learned from each of the Dry Run Activities are provided below.

◇ Completed testing:

- Verification and Validation testing of the FTI was satisfactorily completed.
- Scenarios 1, 2, and 3a-c were flown multiple times each to evaluate integrated FTI/airspace. Scenarios were refined and validated for use with UAM partners.
- Vehicle maneuvering characteristics testing were partially completed in the Build 2 Activity, and fully completed during Follow-On Flight Test.
- UAM task elements testing in winds up to 12 knots were completed during Build 2 and up to 25 knots during Follow-On Flight Test.
 - Visual aids (tetherball and vertical stop) provided enhanced cues for pilot positioning during specific test points.
 - Tetherball visual cue was an excellent aid for Pirouette test point maneuvers.
 - 01H vertical markers located on B4833 (Shuttle hangar) provided excellent cueing references for the vertical reposition and hold test point.
- Nominal UAM approach parameters were defined.

- Performed multiple simulated UAM instrument approaches up to 1000ft at Final Approach Fix, 30 – 90 kts, 6-12° approach paths.
- Nominal approach w/surrogate helicopter: 500 ft/60 kts/9°
- Conducted abused approaches up to 11° and 10 knots tailwind to validate results.
- Incorporated passenger ride quality criteria for enroute and approach profiles.
 - Routes as defined did not consider ride quality, e.g., climb/descent, accel/decel & turn rates.
 - Changes made during testing to incorporate ride quality considerations; routes re-flown.
- ◇ The Range and Test Site Infrastructure were suitable for conducting future NC Activities. Adapting the site infrastructure at remote locations is possible with advanced planning.
 - Real-time adjustment of PLASI azimuth possible, which enables refined test point execution.
 - Pilots noted that sun angle affects PLASI visibility.
- ◇ Planned MOF video/ADS-B/audio and embedded Airspace and Weather Systems capabilities should provide satisfactory situational awareness for future NC Activities.
- ◇ The Crew Rest Trailer (CRT) was suitable to provide shelter for non-participating team members, and situational awareness for test observers.
- ◇ ARINC 424 Coding requirements worked well for simulated UAM environment – came down the learning curve by implementing route/approach changes during execution.
- ◇ Approach to UAM task elements using standard heliport markings (vs. ADS-33-style course) appeared to work well.
- ◇ Frequent, location-based ADS-B dropouts greater than 80 seconds. These dropouts experienced were found to be compliant by FAA SBSM, but UAM operations will likely require tightened compliance requirements.
- ◇ The 1Hz update rate from the vehicle ADS-B transmitter is not a realistic compliance requirement.
- ◇ For the airspace system, vehicle data dropouts not the same as pilot non-conformance to flying the route. The surveillance system status should be independently tracked from route conformance.
- ◇ Significant coordination was required for wind calls on UAM approach and landing task element tests. Significant coordination was required that increased MC workload. A real-time local wind station display in control room/MOF was needed (developed and incorporated for Follow-On Flight Test).
- ◇ Refer to individual test reports identified in Section 5 for more detailed description of results and lessons learned.
- ◇ Note that results of UAM Surrogate helicopter flight testing during Build 2 and Follow-On Flight Test will be released by the FAA Flight Test Engineer assigned to support National Campaign Dry Run Flight Testing.

Specific verification and validation findings for the Flight Test Infrastructure are summarized below.

- ◇ Airspace System Testing: test objectives were accomplished, and significant data and insights were used to improve the airspace system for subsequent NC Activities. The following observations were made, and recommendations implemented based upon Airspace System test lessons learned:
 - The Airspace System provided good situational awareness of vehicle position and speed to the mission team.
 - Frequent and repeatable ADS-B data dropouts occurred at consistent locations on the planned flight routes. For Follow-On Flight Test, an additional ADS-B receiver was activated along the X-33 site access road to address dropouts at lower altitudes given limited 'line of site' to the vehicle. This partially addressed the problem, but further analysis and study of the suitability of ADS-B for vehicle position reporting in the envisioned UAM airspace is needed.
 - Filtering out ADS-B data was needed at the interface/device level. This result was used to update the ping station settings to allow this filtering for Build 2 and subsequent Activities.
 - Considerable mission team effort was directed to capturing event times for post-processing data. Several individuals were capturing event time by hand. During post processing, this caused confusion. Variability in event time capture made it difficult to find the right time slice for data processing. An event logger was developed and implemented for Follow-On Flight Test so that event times and labels could be easily captured with low variability by a single individual for the entire team. Standardized radio communications from the vehicle at the start and completion of each event ensured the right time slice was captured.
- ◇ Range and Test Site Infrastructure were evaluated against the verification matrix in the System Requirements Document during the Build 2 Activity. 9 requirements were not verified, with disposition as follows.
 - The CRT was not included in the Dry Run configuration. Seven total requirements for the Crew Rest Trailer were not verified during Build 2. The CRT was used for basic shelter, without modification, during NC-DT. Functionality modifications of the CRT were later incorporated for Follow-On Flight Test and these seven requirements verified to be acceptable.
 - Two requirements associated with passing real-time weather were not verified during Build 2. Real-time weather display was incorporated into the MOF for Follow-On Flight Test. The NC Team made the decision to delete the requirement for real-time data transmission to outside of the MOF.
 - Radio repeaters, non-developmental items, were not included in the FTI for Dry Runs. Radio repeaters will be installed and verified when needed.
- ◇ The Mobile Operations Facility (MOF) was evaluated against the verification matrix in the System Requirements Document. The MOF was deemed suitable for use. However, the following discrepancies were identified during the activity:

- An Uninterruptable Power Supply (UPS) capable of powering the MOF for up to 30 seconds had been purchased but not delivered in time for the verification test. Therefore, the power interrupt requirement test was deferred until 3rd Quarter of 2022, when the UPS was installed, and testing completed.
- Radio repeaters were not employed for the MOF V&V Activities. The extended range requirement verification will be deferred until such time as repeaters are needed for an Activity.
- The MOF VOIP telephone was not available for testing. Verification will be deferred until such time as a VOIP phone is needed and installed.
- The MOF is designed and built to record four (4) HD video streams from the Secondary Site cameras for the duration of the operational mission flight day. However, only 2 video streams were available for this test sequence. The additional 2 video streams were verified by similarity.
- The generator that was purchased for the MOF was not initially capable of supporting the power requirements. It was determined that peak loads during air conditioning startup exceeded generator capacity. “Soft Start” kits were purchased and installed for each air conditioning unit to reduce start-up loads. Verification testing of MOF start-up using generator power was completed in the 3rd Quarter of 2022.
- Broadband internet connectivity to ATI laptops and the Data Pipeline were provided by linking to SATCOM for access to the internet. The SATCOM service subscription, at 3MBPS down/1 MBPS up, appeared to be too slow to meet system performance requirements, resulting in failure to provide real-time data to the laptops, and corrupted video data to the pipeline. Increasing subscription bandwidth to 20MPS down/5MPS up for Follow-On Flight Test resolved the issue.

Overall, the FTI, including the Airspace System and the MOF, were determined to be suitable for use in future NC Activities. Significant findings were addressed, changes incorporated, and verification completed.

Specific conclusions and lessons learned from testing during Dry Runs can be found in the detailed test reports as described in Table 12.3.

Dry Run Activity	Test Report
ATI Connectivity	AAM-NC-068-001
Build 1/2 FTI Verification and Validation	AAM-NC-072-001
MOF V&V	AAM-NC-062-001
UAM Surrogate Helicopter Flight Test/ Follow-on Flight Test	<i>Report released by the FAA</i>
NC Development of Airspace Operations, Infrastructure and Data	AAM-NC-069-001

Table 12.3 – Dry Run Conclusions and Lessons Learned to Activity Reference

NC-DT Joby Acoustics

The results of DC-DT Joby Acoustics testing were sufficient to satisfy Development Test Objective DTO-3, *Preliminary Assessment of Partner Capabilities & System Performance*. Test objectives identified in Section 7 were met, including evaluation of Scenario 4, *Noise Evaluation and Community Impact*, using a prototype eVTOL vehicle. The detailed results and conclusions can be found in AAM-NC-114-001 NC-DT, *Acoustics Flight Test Report*. General Activity conclusions and lessons learned include:

- ◇ *Partner Test Preparation*. The planning for the Joby acoustic test required a significant effort upfront to prepare for the NASA Tech Brief. The task for determining airworthiness was assigned to the Range IPT OE and CE. Since the airworthiness requirements for a 'data buy' agreement were not specifically defined by NPR 7900.3 or AFRC guidance, the team took the approach of treating the data buy as either a public use requirement or a commercial air services requirement to define those approaches to derive potential data buy requirements based upon the process of elimination. Joby provided a significant body of artifacts to support this task which were maintained on a NASA Box account. The artifacts were generated by Joby for the US Air Force AFRL AFWERX/Agility Prime project. These artifacts were key resource materials used to develop the National Campaign airworthiness evaluation of emerging eVTOL vehicles. Additionally, the AFRC Chief Engineer provided guidance on ground rules for performing a 'data buy' test activity – where NASA observes a flight test conducted by a partner organization (in this case Joby Aviation). This guidance became the 'RoE' (Rules of Engagement) for how NC will work with eVTOL companies conducting collaborative, in-kind agreement test events.
- ◇ Acoustics Flight Test conclusions and lessons learned:
 - Acoustic pressure time series can, in addition to better understanding typical noise levels, be leveraged in future NASA research to derive acoustic metrics which correlate to community acceptance and human response. Moreover, the vehicle tracking, and state data allow assessment of existing noise prediction tools to determine their applicability to AAM.
 - Subsequent research building on emission angle and frequency-dependent vehicle acoustic directivity data, spanning conditions throughout the thrust-borne to wing-borne transition envelope and full wing-borne cruise, will identify dominant noise source mechanisms and vehicle state dependencies.
 - Computed Sound Exposure Level (SEL) isolines for near-vertiport operation (i.e., departure and approach) test points, which were parameterized – within the vehicle prototype's envelope – over acceleration and flight path angle provided a first look into the potential noise exposure of vertiport-adjacent communities.
 - Wireless communication between the Mobile Acoustics Facility and Wireless Acoustic Measurement System (WAMS2) each channel demonstrated a near

100% success rate. Signal-to-noise ratio assessments were also found to be adequate over the frequency range of interest.

- Statistical information regarding acoustic symmetry, repeatability, and variability will continue to be assessed as additional data is gathered in future Activities.

In summary, the NC-DT Joby Acoustics flight test validated the ability of the National Campaign Team and Flight Test Infrastructure System to be configured and deployed in support of an industry partner demonstration and provided a baseline for noise levels generated by a representative eVTOL vehicle. The deployment reduced risk for future NC Activities. The Acoustics data will enhance understanding of community acceptance and contribute to future EPA/FAA policies on noise and air traffic in areas in and around eVTOL tracks and vertiports.

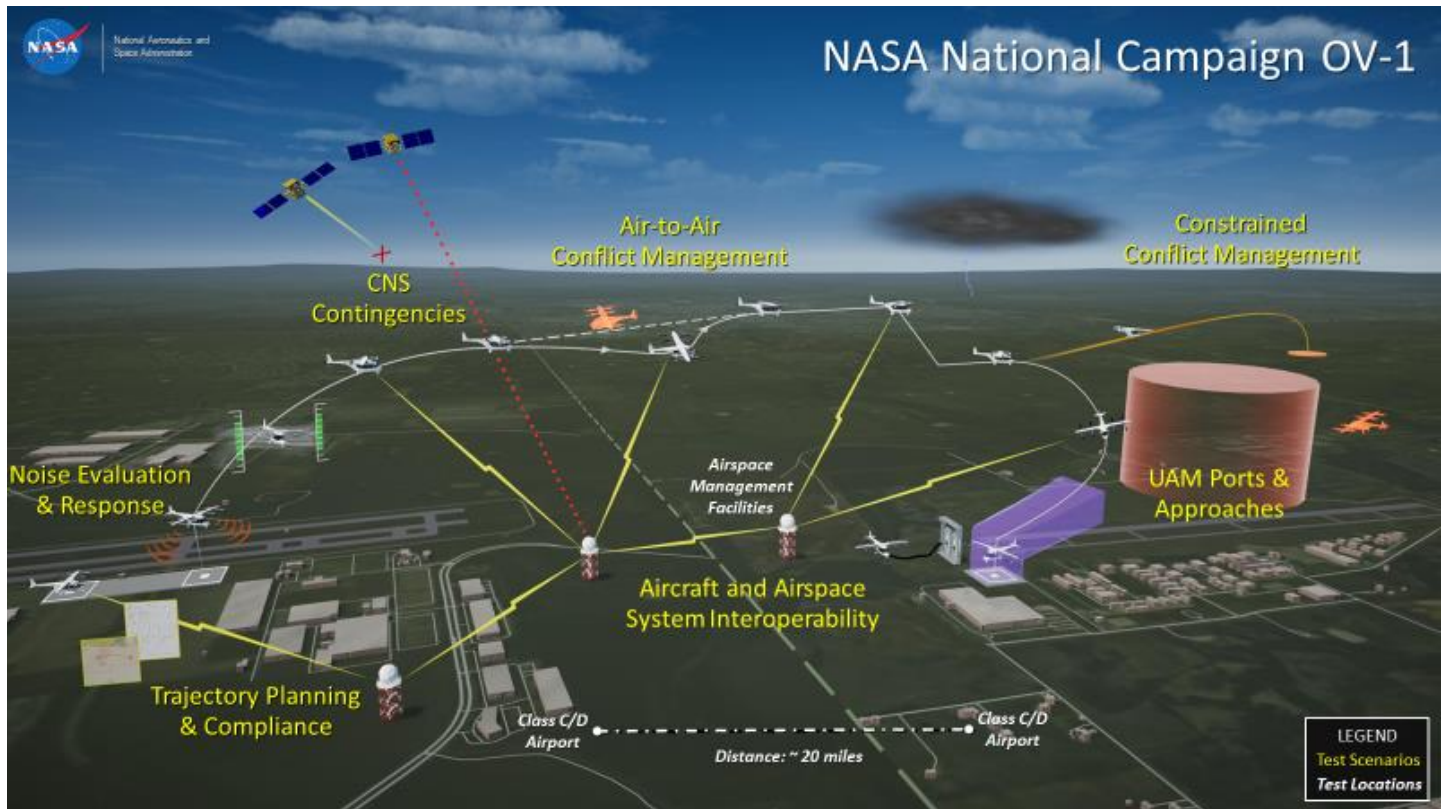
Detailed conclusions and lessons learned are documented in AAM-NC-114-001, *NC-DT Acoustic Flight Test Report*.



APPENDIX - NATIONAL CAMPAIGN SCENARIOS

To Support ACO Release for NG1

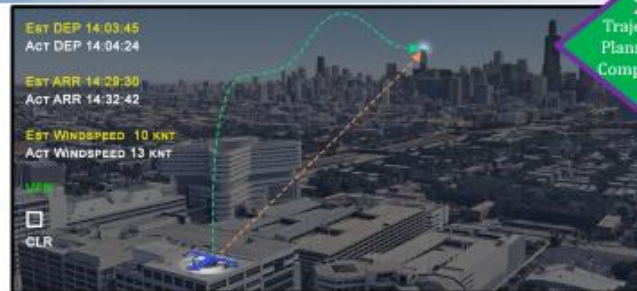
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Scenario 1

Scenario 1 – Trajectory Planning & Compliance

Flight and operation planning for nominal operations that accommodates airspace system and aircraft constraints as well as precision of aircraft trajectory conformance to the flight plan across a range of density altitudes. Evaluate format for exchange of trajectory information between aircraft and an airspace system (PSU) in addition to ANSP communications.



Vehicle Functional Objectives

- Airspace Data Transmission – Demonstrate transmission of telemetry data from the vehicle to the ground for ingestion into the supporting client interface and third-party airspace service provider (PSU).
- Pre-departure Plan – Pre-departure flight plans developed in alignment with the intended nominal flight paths for Scenario 1.
- Execute Flight Plan – Takeoff at pre-approved time and execute approved flight plan (via closed loop guidance and control) while continually reporting telemetry.
- Trajectory/Operation Intent Conformance – Evaluate lateral, altitude (vertical), and temporal deviations from intended 4-D flight plan and associated operation volumes in environmental conditions.

Airspace Functional Objectives

- Airspace Integration – Demonstrate the pre-departure planning and operation execution with vehicle in the loop supported by third party airspace service provider (PSU), client interface, and associated visualizations.
- Pre-departure Plan – Pre-departure flight plan developed by flight crew and subject matter experts incorporated into an operation plan submitted to the third-party airspace service provider (PSU).
- Infrastructure – Demonstrate Communication Navigation Surveillance infrastructure to support 4-D trajectory planning, tracking, and monitoring.
- Execute Flight Plan – Exchange data between client interface and third-party airspace service provider (PSU) throughout each phase of the test vehicle's flight, transitioning operation states accordingly, while receiving telemetry data and sending to third party airspace service provider (PSU) for conformance monitoring.



Scenario 2

Scenario 2 – Integrated Flight Operations with an Activated Contingency

In-flight re-planning, negotiation and execution that accommodates PSU system and vehicle constraints and responds to real-world uncertainties. Exercise exchange of trajectory information, PSU system and vehicle constraints, and user preferences between vehicle and airspace management systems.



Vehicle Functional Objectives

- All functional objectives from Scenario 1 apply to Scenario 2.
- Flight Plan Changes – Vehicle receives and responds to PSU system advisories for in-flight changes of planned routes, including new scheduled time of arrival, new landing location, etc.
- Flight Plan Changes – Vehicle generates and requests in-flight trajectory changes and negotiates with PSU system.
- Interoperability – Evaluate airspace and vehicle system interactions with communications and negotiations.
- Flight Path Changes – nominal flight path performance will be evaluated, including energy reserves.

Airspace Functional Objectives

- All functional objectives from Scenario 1 apply to Scenario 2
- Flight Plan Changes – PSU system generates, sends and negotiates updated advisories (directly or indirectly) to the vehicle in-flight. E.g., new scheduled time of arrival, new landing location, conflict management, new routing, etc.
- Flight Path Changes – PSU system receives and responds to in-flight trajectory changes from the vehicle.
- Interoperability – Evaluate airspace and vehicle system interactions with communications and negotiations.
- Flight Path Changes – Trajectory conformance to the negotiated clearance will be evaluated.

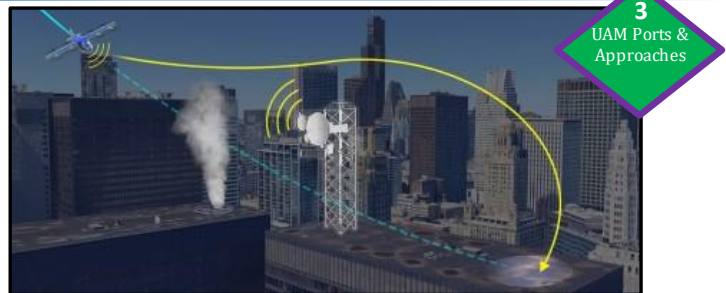
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Scenario 3

Scenario 3 – UAM Ports & Approaches

Develop scalable UAM Port design and procedures, and explore influencing factors such as turn-around times, ground operations, airspace scheduling impacts around UAM ports, localized weather information, and impacts of balked landings/go-arounds.



Vehicle Functional Objectives

- UAM Port Procedures- Demonstrate UAM Port Procedures that include approach, landing, surface operations, takeoff, departure, Actual Navigation Performance (ANP) / Required Navigation Performance (RNP), sequencing, holding patterns, operations at closely spaced UAM ports and pads, and stationary obstacles (e.g., trees, buildings, telephone poles and lines, power lines, water tower, etc.)
- Turn-around Operations- Demonstrate time to launch a prepped aircraft from "cold" start and time to quickturn the aircraft for new flight and evaluate mission planning system including mission turnaround, recharge/refuel, servicing and ground maintenance, vehicle pad and passenger occupancy time, etc.
- Port Design- Develop and Evaluate other best practices for fire safety, downwash considerations, first responder access, closely spaced ports, etc.
- Terrain and other obstacles (i.e., ground collision avoidance) Demonstrate ability to perform conflict resolution maneuvers with awareness of surrounding obstacles and terrain
- Balked Landing- Demonstrate ability to perform a balked landing, including touchdown at original landing pad, through a variety of dynamic environmental conditions.

Airspace Functional Objectives

- UAM Port Procedures - Demonstrate UAM Port Procedures that include approach, landing, surface operations, take-off, departure, Actual Navigation Performance (ANP) / Required Navigation Performance (RNP), sequencing, holding pattern, operations at closely spaced UAM ports and pads, and stationary obstacles (e.g., trees, buildings, telephone poles and lines, power lines, water tower, etc.)
- Scheduling - Evaluate throughput of UAM port operations considering vehicle turnaround times, closely spaced UAM ports and pads, airspace and port capacity, traffic flow management, fleet resource optimization, and density of landing/takeoffs
- Weather information - Measure wind for crosswind check. ATM system broadcast measurements to vehicles.
- Terrain and other obstacles - Demonstrate ability to generate conflict resolution advisories providing awareness of surrounding obstacles and terrain
- Balked Landing - PSU system demonstrates ability to safely and efficiently provide the vehicle that performed a go-around another approach/landing attempt.

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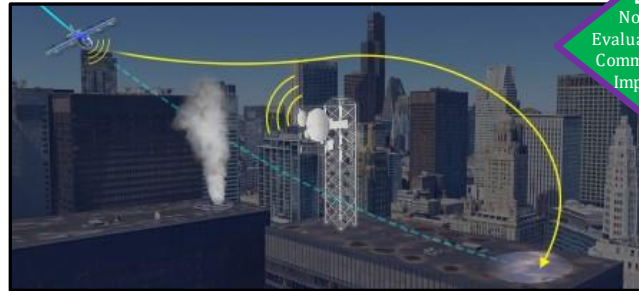


Scenario 4

4
Noise
Evaluation &
Community
Impact

Scenario 4 – Noise Evaluation and Community Impact

Evaluate aircraft noise and response through typical AAM mission flight profiles, including takeoff, climb, transition, cruise, descent, and landing. Exercise integrated (aircraft and airspace) planning, in-flight modification, and execution of low noise flight trajectories and profiles to minimize fleet noise impacts from AAM operations. This will enable characterization of community noise impacts of AAM aircraft through acoustic measurements. The flight conditions will be tailored to the operational envelope and typical procedures of each participating vehicle.



Vehicle Functional Objectives

- Noise Characterization – Measure aircraft noise through standard flight conditions, maneuvers and profiles, including takeoff/landing, transition, cruise, etc. Precise and repeatable flight conditions flying over a microphone array.
- Noise Variability – Measure the source variability and repeatability on the noise produced by AAM vehicles given non-unique trim states and changes in environmental conditions.
- Low Noise Flight Profiles – Calculate and demonstrate flight profiles (all phases of typical AAM missions) to minimize noise exposure on the ground towards minimizing fleet noise impacts in the areas of AAM vehicle operations. Integrate local atmospheric measurements and predictions into the calculation of low noise flight profiles and/or accept low noise flight profiles from Airspace service provider system.
- Community Impact – Assess community impact of noise exposure from AAM vehicles using the acoustic measurements for the aircrafts included in the National Campaign.

Airspace Functional Objectives

- Flight Profile Planning– Demonstrate prediction and planning of low noise flight profiles within the airspace management system. Integrate local atmospheric measurements and predictions into the calculation of low noise flight profiles, as well as considerations for the time of day.
- Flight Profile Impact – Evaluate the impact of low noise flight profiles and trajectories on airspace system performance (efficiency, predictability, throughput).
- Noise Exposure Management– Demonstrate multi-aircraft flight plan prediction and management to minimize the fleet noise impact in areas of AAM vehicle operations.

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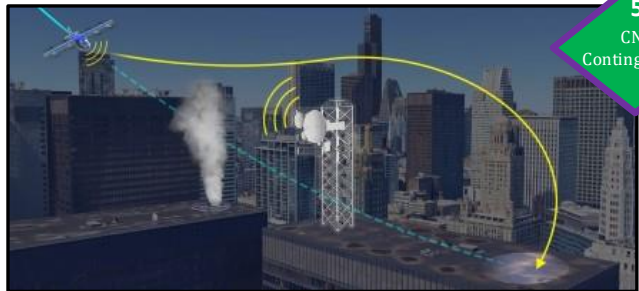


Scenario 5

5
CNS
Contingencies

Scenario 5 – CNS Contingencies

Identification, mitigation, and response to contingencies related to degradation/loss of primary aircraft navigation, aircraft and airspace communications, and/or airspace surveillance. Exercise ConOps that incorporate robust, reliable, and fault tolerant CNS system, including the ability to safely land in event of failure(s).



Vehicle Functional Objectives

- Degraded Navigation– Evaluate system response and accuracy to primary navigation system sensor jamming/denial/degradation. Participant to simulate loss of primary navigation system upon NASA command, and use backup to execute response strategy.
- aircraft Lost Link – For remotely piloted aircrafts, loss of aircraft communication / control from the ground station. Demonstrate ability to recover from loss of communications.
- Airspace Lost Link – For all aircrafts, loss of communications between aircraft and airspace systems. Demonstrate aircraft and mission procedures for loss of communications.
- Airspace Interoperability – Appropriate coordination with airspace management system in response to CNS contingency situations.
- Automation – Demonstrate automatic aircraft control and procedures in response to CNS contingency situations.
- Precautionary/Emergency Landing– Through a variety of dynamic environmental conditions, demonstrate precautionary landing with an on-board system failure.

Airspace Functional Objectives

- Degraded Navigation– Evaluate airspace system response to loss of precision navigation of as single or multiple aircrafts following a loss of their primary navigation system.
- aircraft Lost Link – Evaluate airspace redundancy plan based on ConOps for loss of communications with one or more aircrafts, accommodation of non-conforming aircrafts, real-time response to aircrafts that do not follow current instructions.
- Degraded Surveillance– Evaluate airspace system response and mitigation procedures to loss of surveillance of aircrafts in small or large areas of operations.
- aircraft Interoperability – Appropriate coordination with aircraft and the ATM in response to CNS contingency situations.
- Precautionary/Emergency Landing– Airspace service provider system responds to aircraft declaration of emergency by clearing required airspace and making appropriate reroutes

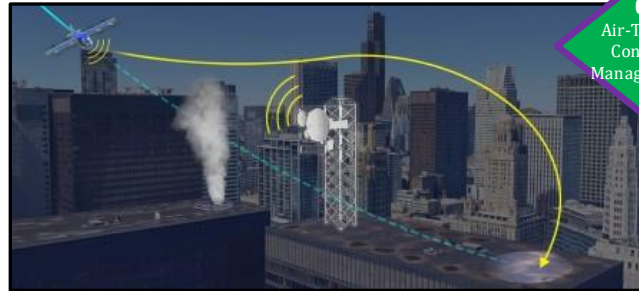
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Scenario 6

Scenario 6– Air-to-Air Conflict Management

Demonstrate individualized components of traffic conflict management in order to evaluate interplay between essential layers of separation assurance and collision avoidance



Vehicle Functional Objectives

- Intra-Urban Tactical Conflict Management – Demonstrate in-flight separation assurance, collision avoidance, and appropriate airspace management information exchange (i.e., flight plan amendments) including:
 - Various geometry setups, test altitudes, aircraft sizes (general aviation, sUAS, Urban Passenger transport), cooperative and non-cooperative and speed of airborne intruders
 - Various environment backgrounds (sun, clouds, terrain clutter, etc.)
- Legacy Aircraft Tactical Conflict Management – Demonstrate interoperability with legacy aircraft (e.g. commercial, general aviation, etc), specifically when operating in terminal areas, including coordination with ATC, TCAS/ACAS interoperability, etc

Airspace Functional Objectives

- Intra-Urban Tactical Conflict Management – Demonstrate in-flight separation assurance services, ability of airspace management system to support/provide traffic conflict management, provide airspace advisories, and detect secondary conflicts
- Legacy Aircraft Tactical Conflict Management – Demonstrate interoperability of UAM aircraft with legacy aircraft (e.g. commercial, general aviation, etc), specifically when operating in terminal areas, including coordination with legacy ATC, TCAS/ACAS interoperability, etc
- Scheduling- Demonstrate ability of UAM Airspace service provider system scheduling to respond to traffic conflict resolutions including negotiating route updates and STA's for all impacted aircraft

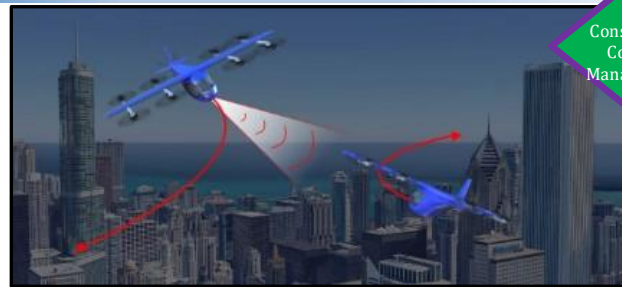
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Scenario 7

Scenario 7– Constrained Conflict Management

Conflict management that considers simultaneous issues across the aircraft and airspace service provider system that must be solved together while considering spatial constraints (e.g., no-fly zones), temporal constraints (e.g., sequencing and scheduling), service boundaries (e.g., CNS service areas), and aircraft state of health (e.g., when aircraft is in a degraded mode). Builds upon Scenario 6, increasing complexity of operations.



Vehicle Functional Objectives

- Obstacle and Aircraft Avoidance – Demonstrate ability to detect and avoid ground and air obstacles, including non-cooperative intruder aircrafts intersecting intended flight path.
- Cooperation with other UAM aircrafts – demonstrate ability of UAM aircrafts to perform tactical collision avoidance maneuvers without triggering follow-on collision avoidance maneuvers, including when the aircraft is in a degraded state
- Cooperation with an airspace service provider system – demonstrate ability to perform tactical collision avoidance without creating cascading effects to the Airspace service provider system, including when the aircraft is in a degraded state

Airspace Functional Objectives

- Obstacle and Aircraft Avoidance – Airspace service provider system responds appropriately to avoid cascading failures when an aircrafts depart from planned trajectories due to an obstacle/aircraft avoidance maneuver
- Cooperation with other Airspace service provider system – airspace service provider systems can interoperate with other airspace service providers, not sending instructions to aircraft that will disrupt other airspace service provider's traffic management
- Cooperation with UAM aircrafts – demonstrate ability to send directions to aircrafts that do not create cascading impacts of tactical maneuvers from aircraft to avoid collisions, including when aircrafts are in degraded states

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