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UTM Field Test (UFT) Final Report

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Executive Summary

The Unmanned Aircraft Systems (UAS) Traffic Management (UTM) Field Test (UFT) was an important activity for validating and field testing the next set of industry and Federal Aviation Administration (FAA) capabilities needed to support UTM. The activities within the UFT project helped to bring UTM further towards future implementations of operational UTM services. UFT was established as an important component in continuing the collaboration between FAA, National Aeronautics and Space Administration (NASA), and industry to mature UTM.

The FAA, NASA, and industry partners worked to demonstrate important capabilities during UFT, including:

- Capabilities proposed by standards including strategic coordination.
- Enhancements to UTM functionalities (e.g., data correlation).
- Updated security management to secure UTM data exchanges.
- Concept elements such as authorized historical data queries.

UFT used several components in the UTM ecosystem including UAS Service Suppliers (USSs), FAA's Flight Information Management System (FIMS), Discovery and Synchronization Service (DSS), and authorization servers. The partners providing these capabilities for UFT included:

- **Test Sites:** New York UAS Test Site (NYUASTS) and Mid-Atlantic Aviation Partnership (MAAP) with the Lone Star UAS Center of Excellence and Innovation (LSUASC).
- **Industry USS Partners:** ANRA, AX Enterprize, CAL Analytics, Collins, OneSky, Wing.

UFT started in July of 2022 with test activities completed in April of 2023. The testing evaluated various elements of the ASTM USS Interoperability Standard, including strategic conflict detection, conformance monitoring, constraint management and processing, and priority operations. UFT provided useful insights to inform the FAA and industry as UTM transitions from research and development into implementation of UTM services, including the following.

- The increase in relevant operational information provided to operators helped to increase situational awareness and improve operator's ability to plan or re-plan their flight.
- The automated test harness concept proved effective in verifying USS functionality.
- UFT developed and tested key ASTM standard elements for strategic deconfliction. Further progress is needed to address implementation gaps of the ASTM standard, such as availability arbitration and aggregated intent conformance monitoring.
- Industry should evaluate important governance issues, such as service quality, and ensure agreement on the approach to meet the FAA requirements on safety, security, and privacy. This supports maturation of elements in UTM such as Cooperative Operating Practices (COPs) and authorization server implementation.
- UFT validated that the ASTM standard should support strategic deconfliction and conformance monitoring among multiple USSs and operators. Further maturation of UTM services requires evaluation through real-world operations.

Version History

Date	Revision	Version
11/6/2023	Initial Release	1.0

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1 Introduction

The Unmanned Aircraft Systems (UAS) Traffic Management (UTM) Field Test (UFT) is an important activity for developing, expanding, validating, and field testing the next set of industry and Federal Aviation Administration (FAA) capabilities needed to support UTM. *UFT validation and testing focuses on the technical feasibility of UTM capabilities and standards. While UFT observations are used to inform policy development, they do not imply any policy decisions.* In winter and spring of 2023, the FAA, National Aeronautics and Space Administration (NASA), and industry partners successfully completed UFT test and evaluation activities. This final report documents and concludes the UFT project.

1.1 Progression of UAS Traffic Management (UTM)

UTM is the way the FAA will support UAS operations conducted in low-altitude airspace. UTM utilizes industry's ability to supply services under the FAA's regulatory authority. It is a community-based, cooperative traffic management system in which operators, UAS Service Suppliers (USSs), and other participants are responsible for the coordination, execution, and management of operations, with rules established by the FAA. Due to this cooperative nature, it will be important for industry to define FAA-approved UTM Cooperative Operating Practices (COPs) that address how operators manage their operations. Implementation of a safe and efficient UTM service environment, including supporting infrastructure, is necessary to enable the incorporation of routine Beyond Visual Line of Sight (BVLOS) operations in low-altitude airspace (i.e., below 400 feet Above Ground Level [AGL]).

To support UTM implementation, collaborative research and test activities have been established. This started with the UTM Research Transition Team (RTT) Technical Capability Level (TCL) demonstration activities, which concluded in 2020. As technologies and capabilities were transferred to the FAA, the UTM Pilot Program (UPP) was established to support deployment of UTM capabilities within FAA systems and concluded in 2021 with the release of the Phase 2 Final Report [1]. Continuing the collaboration between the FAA, NASA, and industry, UFT was established to execute flight test activities, support industry in validating standards, and evaluate the maturation of UTM services.

UTM development and implementation establishes requisite services, roles and responsibilities, data exchange protocols, and performance requirements to enable the management of low-altitude UAS operations. Figure 1 is the high-level UTM architecture.

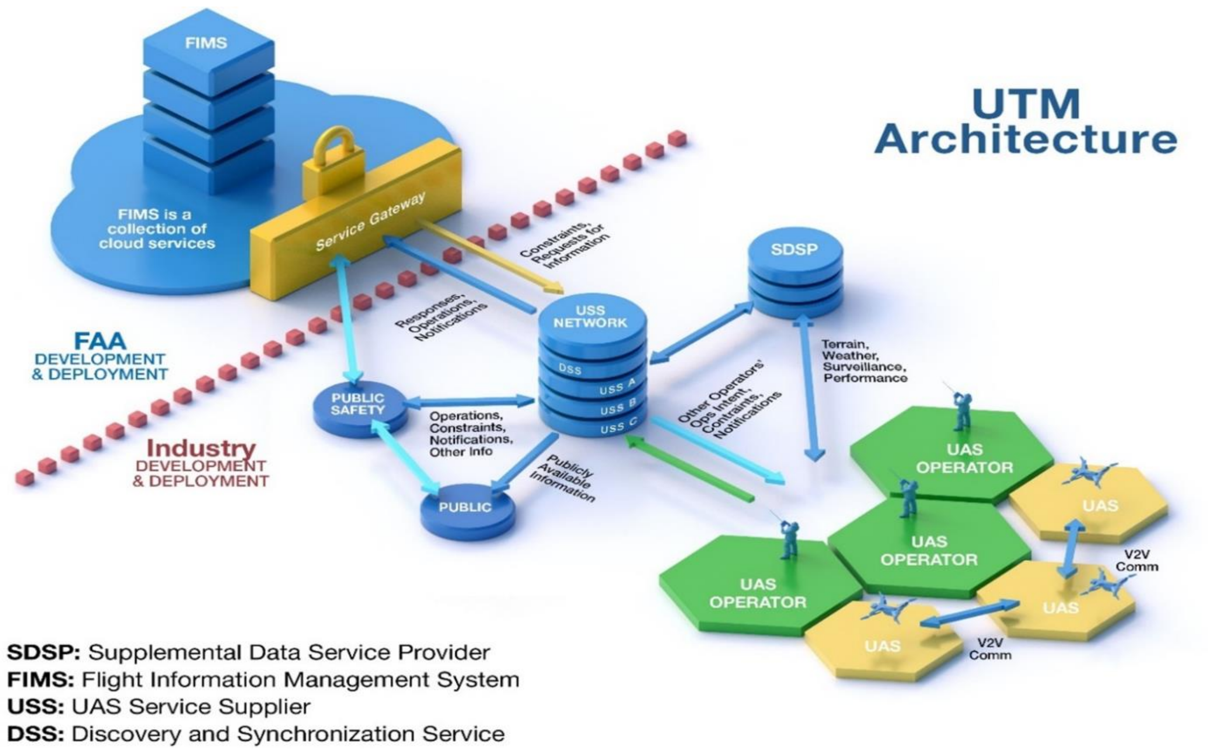

Figure 1: UTM High-Level Architecture

1.2 Scope

This document provides a report of UFT test and evaluation results. The document uses the following structure.

- Section 2 includes an overview of UFT, which details demonstrated capabilities, key elements that were a focus of UFT activities, test sites/supporting participants, and test site operating environments.
- Section 3 provides a summary of the execution of UFT activities including the test and data collection approach, entity onboarding, checkouts, shakedown tests, and final showcase activities.
- Section 4 provides details across the various demonstrated capabilities, which includes relevant data and analysis and observations.
- Section 5 provides a conclusion for UFT and discusses the next steps as they relate to UTM implementation.

2 UTM Field Test (UFT) Overview

UFT was established as an important component in continuing the collaboration between FAA, NASA, and industry as they mature UTM concepts, services, and standards. In July 2022, the FAA selected two FAA UAS test sites to partner with for UFT development, testing, and evaluation activities.

- Virginia Tech (VT), Mid Atlantic Aviation Partnership (MAAP) with the Texas A&M University-Corpus Christi's Lone Star UAS Center of Excellence and Innovation (LSUASC)
- New York UAS Test Site (NYUASTS)

In collaboration with NASA, the selected FAA UAS test sites, industry stakeholders, and public safety stakeholders, the FAA conducted live flights to support industry in validating standards and evaluating the maturation of UTM services. The UFT project aimed to:

- Advance capabilities proposed by standards including strategic coordination in complex environments.
- Test enhancements to UTM functionalities (e.g., data correlation).
- Develop and test updated security management for information exchanges between the FAA, industry, and authorized entities.
- Explore concept elements such as authorized historical data queries.
- Inform policy development to enable routine UTM operations.

Observations from UFT are used to inform and support many areas, including but not limited to informing policy developing, maturing UTM standards and technologies, advancing UTM capabilities, and informing best practices for secure UTM information exchanges.

2.1 Key Elements of UFT

This section provides background information on key UTM elements that are a focus of UFT and are discussed throughout this report.

2.1.1 UFT Architecture

Figure 2 is the high-level architecture that was used during UFT activities.

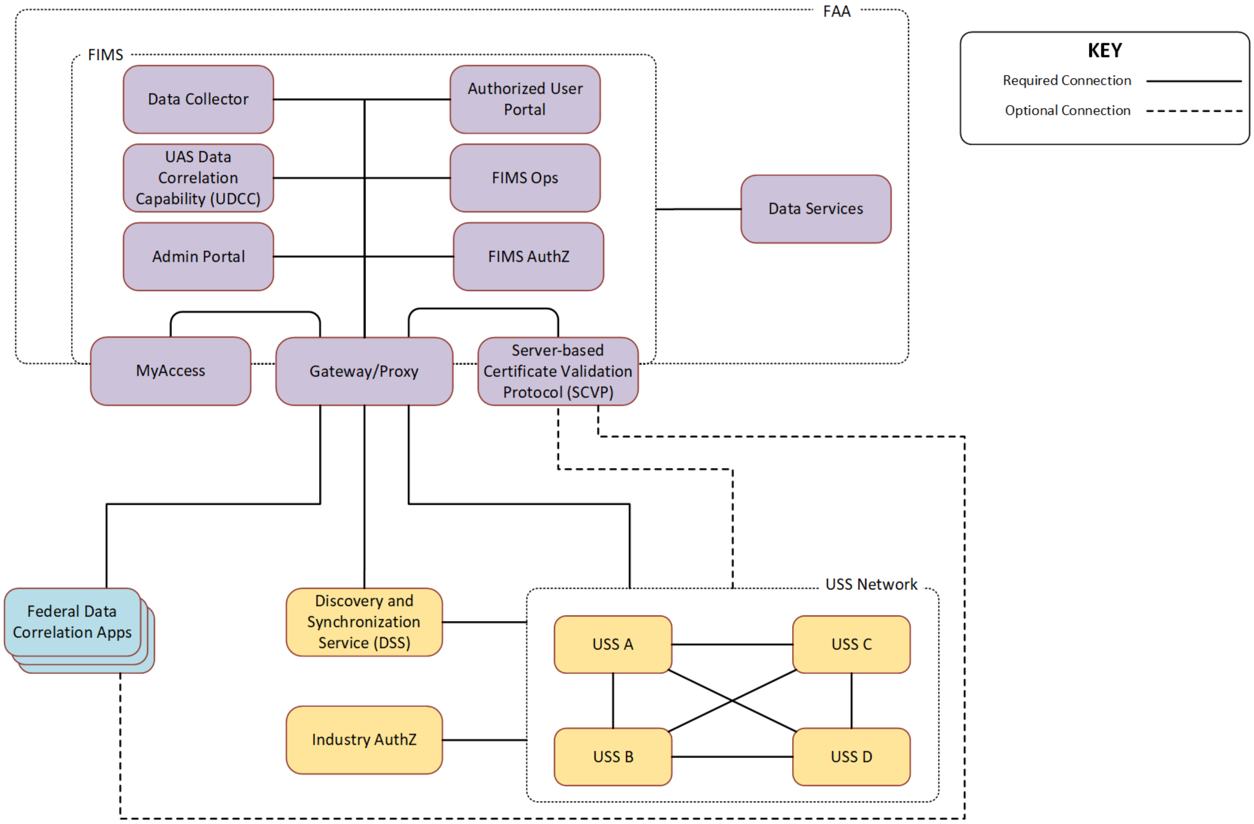

Figure 2: UFT High-Level Architecture

2.1.2 UAS Service Supplier (USS)

A USS is an entity that assists UAS operators with meeting UTM operational requirements that enable safe and efficient use of airspace. A USS may provide three main functions:

- Act as a communications bridge between federated UTM actors to support operators' abilities to meet the regulatory and operational requirements for UAS operations.
- Provide the operator with information about planned operations in and around a volume of airspace so that operators can safely and efficiently conduct their mission.
- Archive for the operator their operations data in historical databases as appropriate for analytics, regulatory, and operator accountability purposes.

In general, these key functions allow for a network of USSs to provide cooperative management of low-altitude operations without direct FAA involvement. The following terms are defined within the context of USSs.

- **USS Network:** The amalgamation of USSs connected to each other, exchanging information on behalf of subscribed operators. USSs share operational intent data, airspace constraint information, and other relevant details across the network to ensure shared situational awareness for UTM participants.

- **Discovery and Synchronization Service (DSS):** DSS is utilized by USSs to facilitate automated data exchanges between one another within the USS network. This capability allows USSs to identify one another and exchange relevant information when USSs are in the same geographical service area.

The ASTM F3548-21 Standard Specification for UTM USS Interoperability [2] details the requirements and Application Programming Interfaces (APIs) used to exchange data within the USS network and with the DSS.

2.1.3 Flight Information Management System (FIMS)

The Flight Information Management System (FIMS) is the FAA's interface for data exchange between FAA systems and UTM participants. FIMS enables the exchange of relevant data between the FAA and the USS network. FIMS also provides a means for approved FAA stakeholders to query for limited data on UTM operations.

The FAA FIMS prototype was implemented by the FAA Next Generation Air Transportation System (NextGen) Integration and Evaluation Capability (NIEC) lab at William J. Hughes Technical Center (WJHTC). The FIMS prototype consists of the following key components.

- **FIMS Authorization Server (AuthZ):** An OAuth 2.0 compliant authorization server. OAuth 2.0 is an authorization framework for delegated access to APIs used to protect UTM APIs from unauthorized access. For UFT FIMS, AuthZ provided authorization services for data correlation and historical query APIs.
- **UAS Data Correlation Capability (UDCC):** A prototype data correlation capability to support authorized queries for information held by the FAA that correlates to information received from broadcast remote Identification (ID).
- **FIMS Authorized User Portal:** A prototype web-based user interface accessible to authorized FAA users that provides the ability to submit data correlation or historical queries.
- **FIMS Admin Portal:** A prototype web-based user interface used to provide FIMS administrators access to tools to administer FIMS (e.g., manage USS roles and scopes used by FIMS AuthZ). For the purposes of test and demonstrations like UFT, the admin portal provides visualizations for operational intent and constraints for awareness of UTM activities.
- **Historical Query:** A future concept capability that was prototyped and tested during UFT. Historical query allows the FAA to obtain on-demand access to USS-held data. USS-held data may include operational intent, Unmanned Aircraft (UA) position info, or constraints.
- **Data Collector:** A service accessible via an API used to ingest data specific to testing, validation, and demonstration activities that support analysis and metric generation. The data collector primarily supported data collection that is identified as the FAA's responsibility.

2.1.4 Additional Industry Services

An area that UFT explored was industry taking on responsibilities that had been managed, for demonstration purposes, by government entities in previous demonstration and test activities. The two key areas where UFT explored this concept were the UTM authorization server and the checkout process for USSs.

2.1.4.1 Industry Managed USS Test Harness

In UFT, industry participants proposed using a test suite for industry checkouts—specifically, one developed by the Linux Foundation's InterUSS platform. This test suite is intended to enable a USS to validate that it is in alignment with standards, such as the ASTM USS Interoperability Standard. The test suite allows each USS to test against this test suite independently and the test suite can also be executed with a group of partners to test interoperability.

2.1.4.2 Industry Authorization Server

The authorization server in UTM serves an important function for securing interactions via the issuance and management of OAuth 2.0 access tokens to entities in UTM. The industry-hosted authorization server supported USS-USS data exchanges per the ASTM USS Interoperability standard.

2.1.5 Message Security

One of the core objectives of UFT was to develop, test, and evaluate approaches to secure exchanges in the UTM ecosystem. UFT evaluated a series of security objectives that are important to the UTM ecosystem, specifically authorization, authentication, data integrity, non-repudiation, and confidentiality. The sections below introduce the security objectives along with a high-level description of the relevant UFT testing and evaluation activities.

2.1.5.1 Authorization

The federated nature of the UTM ecosystem necessitates that there be Identity Access Management (IAM) mechanisms in place to ensure that the systems and users acting with UTM have the appropriate permissions, or authorization, to exchange messages. The OAuth 2.0 framework is an appropriate approach to achieve the authorization of system-to-system communications by using a trusted authorization server that issues access tokens to the systems (i.e., USSs and FIMS) in UTM. The use of OAuth allows for the application of role-based access controls for the USSs exchanging data in the UTM ecosystem. Testing in UFT evaluated the potential for industry-driven services to fill this role, including an industry hosted authorization server. The implications of an industry-hosted authorization server are explored further in Section 4.8.

2.1.5.2 Authentication, Data Integrity, and Non-Repudiation

UTM data exchanges serve critical operational functions, so it is vital that they can be ensured to have information security protections. Since these exchanges occur over the public internet, it is important to layer several security approaches to achieve an adequate level of security. For point-to-point security, UFT data exchanges required the use of Transport Layer Security (TLS). On top of TLS, these exchanges should apply security to the messages themselves, to maintain information integrity beyond just a point-to-point connection. The application of digital signatures to the Hypertext Transfer Protocol (HTTP) communications in the UTM ecosystem provides a cryptographic mechanism to ensure data integrity and non-repudiation to prevent an entity from denying having sent a message.[3] If the signatures are linked to a trusted Public Key Infrastructure (PKI), then the exchange also has the proper authentication.

2.1.5.3 Confidentiality

The UTM ecosystem may contain sensitive data of national security, privacy, or proprietary nature. Like the needs for point-to-point security for data integrity and authentication, the use of the TLS protocol provides point-to-point confidentiality protections for UTM data exchanges. For certain data exchanges, it might be necessary to apply additional confidentiality protections at the message level. Tests conducted in UFT examined the application of message-level encryption to certain sensitive data exchanges between the FAA and UTM industry participants, specifically for data correlation queries by authorized users for FAA-held data. It should be noted that UFT testing did not include actual sensitive data and used simulated sensitive datasets.

2.2 UFT Partners and FAA Support

As noted in Section 2.2, UTM operations are primarily managed by a federated set of actors, including UAS operators and the USSs that support them. Given this, it was critical that UTM test and evaluation activities included a diverse set of stakeholders to ensure the envisioned capabilities address the varied sets of needs and interests. UFT focused on this need and brought together various FAA stakeholders, NASA, industry service providers, UAS operators, and public safety stakeholders to support use cases within the integrated test environment.

2.2.1 Test Site Partners

Table 1 provides overviews of the industry partners and other participating stakeholders who worked with MAAP and NYUASTS in UFT. The test site oversaw project management for activities executed at their sites; provided infrastructure/services to support USS and UAS operator activities; coordinated with the NIEC lab to provide the integrated test environment; and provided additional support to the FAA, partners, and other stakeholders as needed.

Table 1: Test Site Partners

Partner	UFT Role
MAAP in Partnership with LSUASC	
MAAP	Project Management, Operator, Visual Observer, UAS Platforms
LSUASC	Operator, Visual Observer, UAS Platforms
ANRA Technologies	USS, Operator, Remote ID Devices and Receiver, Data Correlation Client
Collins Aerospace	USS
OneSky	USS
Wing	Operator, DSS Provider, Industry AuthZ Provider
Raytheon Technologies	Radar Supplemental Data Service Provider (SDSP)
Streamline Designs	Operator, Visual Observer, UAS Platforms

Partner	UFT Role
AirspaceLink	Constraint Manager
Virginia FIX	Constraint Provider
NYUASTS	
NUAIR	Project and Flight Operations Management, Operator, Ground Crews, Visual Observers, UAS Platforms
ANRA Technologies	USS, Remote ID Receiver, Data Correlation Client
AX Enterprize	USS, Remote ID Devices and Receiver, Operator, UAS platforms, Data Correlation Client
CAL Analytics	USS
OneSky	USS
Oneida County Sheriff's Department	Public Safety, Operator
Oneida Indian Nation Police Department	Public Safety, Operator

USSs provided technologies and services to support live and simulated flights of UA, integrating them into the test environment and ensuring they conformed to applicable standards and project requirements. Public safety operated UAS, used constraint services in simulated public safety conditions, and used broadcast remote ID data to initiate queries to the FAA's prototype data correlation capability. Other partners supported in various ways including, providing SDSP capabilities, operating UAS, constraint management, and others.

2.2.2 NextGen Integration and Evaluation Capability (NIEC) Lab

The FAA NIEC lab provided infrastructure, technologies, and applicable support to enable an integrated test environment for the test sites and their partners. Activities included, but were not limited to, software development, alignment to ASTM standards, development of the FAA's UFT message security requirements, provision of FIMS components described in Section 2.1.3, connecting USSs into FIMS infrastructure, and conducting USS checkout processes for data correlation and historical query. More information on the NIEC can be found in [3].

2.2.3 NASA

As part of the Onboarding and Checkout phase of UFT and in collaboration with the FAA, NASA hosted an Industry Day. As UFT progressed, NASA participated in the scoping discussions as the technical scope of the project was being coordinated across the project's stakeholders. In the later stages of testing, they provided simulated operations in order to add complexity to the use cases. This effort was integral in achieving the desired complexity as laid out in the test approach. NASA was also responsible for creating a message security extension to InterUSS test suite, which validated USS compliance with the UFT message security requirements. Additionally, throughout the development and execution of UFT, NASA played an advisory role.

2.3 Operating Environments

This section provides details on the operating environments used by NYUASTS and MAAP to execute the use cases and scenarios for UFT.

2.3.1 New York UAS Test Site (NYUASTS)

The NYUASTS is a FAA-designated UAS test site located at a towered airport, surrounded by Class D airspace, and supported by the Low Altitude Authorization and Notification Capability (LAANC). NYUASTS defined two 15-square-mile operating areas for UFT activities. One area encompassed the Griffiss International Airport area (labeled: North) and the other is around the Oriskany flight area (labeled: South) as shown in Figure 3.

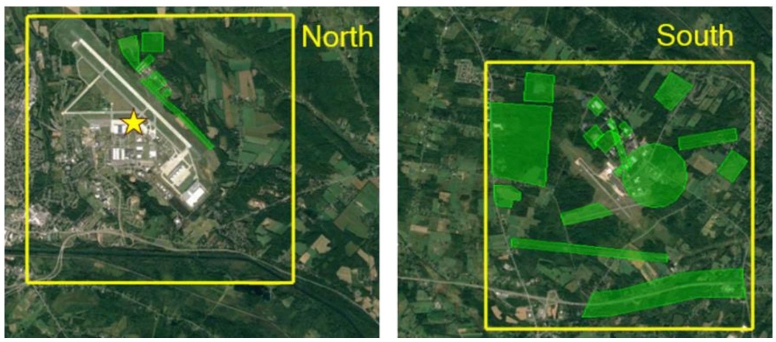

Figure 3: NYUASTS Operating Areas

2.3.2 Mid Atlantic Aviation Partnership (MAAP)

For UFT, MAAP supported three different operating environments as shown in Figure 4.

- **Virginia Tech's Kentland Farms:** The Kentland Farm Agricultural Research Center is owned by Virginia Tech and contains the Kentland Experimental Aerial Systems (KEAS) lab. Kentland Farm is 1,800 acres in size, bordered on the South and West by the New River, and 2.6 miles corner-to-corner. The airspace over Kentland Farm is Class G from surface to 700 feet AGL.
- **Uptown Christiansburg, VA:** Christiansburg Huckleberry Park is in Uptown Christiansburg. In addition, Wing delivery flights are performed around this test area.
- **Corpus Christi, TX:** Cole Park in Corpus Christi was used to conduct flights by LSUASC.

Figure 4: MAAP Operating Environments (MAAP shown on left, LSUASC shown on right)

3 UFT Execution

From summer 2022 to early spring 2023, MAAP and NYUASTS worked with their partners, the FAA, and NASA to integrate their systems into the test network, test USS services functionality and interoperability, define test cards and data collection approaches, and execute flight tests to prepare for final showcase events. UFT was executed in a hybrid environment, through the use of online collaboration software and simulated flights where appropriate, to help foster the collaborative virtual environment to prepare for major test events (e.g., shakedowns and showcases). This section describes these key activities conducted through stages of UFT.

3.1 Test Approach

UFT testing was conducted using live flights at all operating environments, while supplementing with simulated operations where desired complexity may not have been capable with live flights only. Complexity was a key element of UFT testing and is described in Section 3.1.1. Additionally, to create representation of the real world, the UFT approach was designed to minimize scripting to the greatest appropriate extent possible. The approach aimed for participants to gain situational awareness and make decisions on planning and replanning using UTM services as events happened, instead of following a plan that was defined in advance.

UFT participants and stakeholders were integrated and tested through a series of stages as shown in Figure 5. At each stage, issues were identified, tracked, and solutions were developed and tested as the project progressed to the next stage.

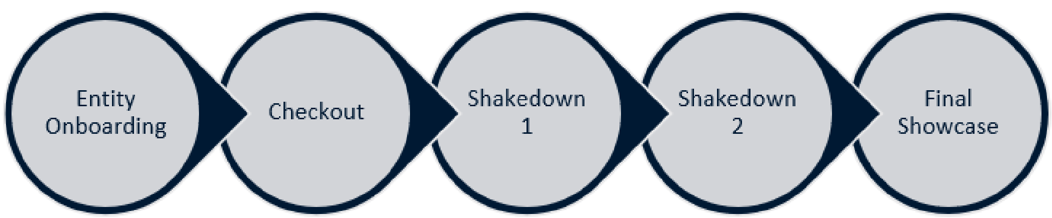

Figure 5: UFT Test Approach Stages

3.1.1 Complexity

For UFT activities, operational complexity was characterized through multiple perspectives, including the following.

- **Number of Interactions:** The number of interactions can be categorized by instances where one or more operations conflict with one another or constraints, driving the need for coordination, deconfliction, and other actions/activities.
- **Types of Interactions:** The types of interactions are categorized as the interactions between flights with varying types of operations as well as constraints.
- **Operational Tempo:** Operational tempo is categorized as the number of flights planned and flown in an operational area within a given time window. Lower or higher operational tempo may have varying impacts on operational complexity.

- **Operating Environment:** Operating environment includes the environment that operations are occurring within and the changes that may occur within that environment for various reasons. UFT aimed to test and evaluate capabilities and standards in operating environments of varying complexity to discover how effective the UTM services are as the level of complexity changes.

3.2 Data Collection Approach

A Data Management Plan (DMP) was developed and agreed upon by UFT participants to support data collection for UFT. Data collection identified in the DMP is for UFT analysis only and does not imply any future FAA auditing needs. The DMP provided the Measures of Effectiveness (MOEs), detailed a collection of metrics to be generated in support of the MOEs, and the use of surveys to capture non-quantitative feedback from participants. Metric generation responsibility was split between the FAA and test sites based upon their involvement in the relevant capability. For the FAA, the metrics focused on additional capabilities beyond the ASTM standard and used APIs to collect the data. For the test site, metrics focused on data relevant to testing the ASTM USS Interoperability Standard, the mechanisms for data collection and metric generation were left to the test sites to decide on the most effective approach to presenting this information. This enabled the test sites to explore mechanisms they were familiar with and deemed appropriate.

Data collection mechanisms were developed, tested, and matured during the phases of UFT from Shakedown 1 to final showcase. All data collection mechanisms were fully functioning by final showcase week. Data was also collected during the shakedown events, but due to the nature of the testing during these events, the analysis and visualizations in the section below do not include data from the shakedowns. However, this analysis occurring throughout the shakedowns yielded useful insights and lessons learned that helped to inform stakeholders as UFT progressed and were considered as part of observations.

3.2.1 Measures of Effectiveness (MOEs)

For UFT, MOEs were developed to determine if the services, systems, and technologies demonstrated during the associated activities were able to satisfactorily support operations conducted in the test environments. The capabilities identified in Section 2 were used to develop the MOEs listed in Table 2.

Table 2: UFT MOEs

Label	Description
UFT-MOE-1	**Industry services supporting UTM** effectively support UAS operations staying safely separated.
UFT-MOE-2	UFT activities successfully test **planning and coordination** in operating environments of varying complexity.
UFT-MOE-3	UFT participants validate the use of **elevated priority operations**.

Label	Description
UFT-MOE-4	UFT activities successfully test **data correlation service** enhancements providing authorized users additional information related to UAS.
UFT-MOE-5	UFT participants successfully test **secure information exchange** using required **IAM** and **message security** capabilities.

To support the MOEs, a set of metrics were defined to provide data analysis in the areas of complexity, priority operations, constraints, data correlation, and cybersecurity. In addition, surveys and whitepapers were also created to support MOEs. Surveys were completed by various UFT participants at various phases of the project. More information on the analysis and results of the metrics and survey are provided throughout Section 4 and its subsections.

3.3 Entity Onboarding

Entity onboarding was the initial execution phase of the UFT project and was used to get all partners integrated into the project. The entity onboarding phase consisted of a set of procedures and forms completed by UFT partners. The list below provides a summary of activities conducted during entity onboarding.

- Test sites provided contact information for partners to onboard to the project collaboration tools, Slack (online communication) and Redmine (information exchange and project management).
- USSs completed the entity onboarding form detailing which UTM roles/service they will support.
- USSs used a DocuSign process to obtain International Aviation Trust Framework (IATF) certificates from the FAA's prototype Certificate Authority (CA).
- USSs provided details on partner use of the FAA's Server Based Certificate Validation Protocol (SCVP) web service, which is used for validation of certificates.

3.4 Checkout

For an activity such as UFT, one of the critical elements that helps to facilitate efficient, streamlined, and secure integration into the UTM ecosystem is the checkout process. Checkout processes test the capabilities of each of the actors involved in the activity and verify that each meets a certain level of functionality. Checkout processes also help to verify interoperability across all participants. For UFT, automated testing was used for USS functionality per the ASTM USS Interoperability Standard and manual tests were used to test additional capabilities such as data correlation and historical query. NYUASTS automated checkouts were conducted December 2022 through January 2023. For MAAP, automated checkouts were conducted January through February 2023. The manual test for data correlation and historical query capabilities was conducted February through March 2023 as partners implementations matured.

3.4.1 Industry Led Checkout

In UFT, industry participants proposed that industry take on the responsibility of USS API checkouts, specifically using the open source InterUSS automated test suite [5]. These tests were used by USSs to validate alignment with the ASTM USS Interoperability Standard. The tests were independently executed by each USS participating in UFT. NASA developed an extension to also validate USSs' implementation of message signing. Section 4.10 further expands the observations from the use of the InterUSS test suite.

3.4.2 FAA Led Checkout

Manual tests were used to checkout data correlation and historical query capabilities. These tests were performed between the NIEC lab and each entity providing data correlation and historical query capabilities.

3.5 Shakedowns

The operational testing of UFT capabilities in the integrated test environment was conducted through shakedown activities. These activities tested end-to-end systems through the operational use cases. During the shakedown activities, UFT partners were able to exercise their vehicles and systems to test the various standards, concepts, and operational requirements. In many cases, this was the first validation of updated standards that were tested across different industry partners in a live environment, revealing several challenges previously unknown to the UTM community. The shakedown tests allowed partners to identify and resolve challenges and ensure the success of the final showcase.

Challenges identified and overcome during shakedowns included the following.

- USS services checkout for services functions and interoperability
- USS FAA message signing checkout
- Message signing implementations
- Prioritization handling
- USS conformance monitoring
- USS support for inflight rerouting

The scenarios used during the shakedowns are outlined in Appendix A.1.

3.5.1 Shakedown 1

3.5.1.1 NYUASTS

From January 23–27, 2023, NYUASTS UFT Shakedown 1 was executed in Rome, NY at the NYUASTS. This event was a live-fly exercise utilizing both BVLOS and Visual Line of Sight (VLOS) operations. Additionally, simulated flights were used to supplement complexity.

Deconfliction was handled for all operators through an assigned USS. A total of 76 operations were conducted during Shakedown 1.

This event followed an approach where complexity was gradually added throughout the testing. This approach allowed for issues to be identified and corrected during the phase of reduced complexity. Each day of testing focused on a limited number of scenarios to provide depth to issue identification and correction.

3.5.1.2 MAAP

The first shakedown at MAAP was a simulated event January 30–February 3, 2023, in which major test points were conducted remotely. A test director located at MAAP oversaw the test and managed the screen share and telephone conference line that served as the primary communication method between all participants. Slack was used as a secondary communication method. All USSs called into the conference line to assist in the testing.

ANRA, Collins, and Streamline Design flights teams utilized Software-in-the-Loop (SITL) simulators for their aircraft. MAAP utilized a combination of Hardware-in-the-Loop (HITL) and SITL simulators. For the UAS, HITL and SITL simulation was used as a stand-in for actual flights.

3.5.2 Shakedown 2

3.5.2.1 NYUASTS

NYUASTS UFT Shakedown 2 was executed in Rome, NY at the NYUASTS March 6–10, 2023. Like the previous shakedown, it mixed simulated and live operations and used an approach of increasing complexity over time. Through this shakedown activity, a subset of scenarios and capabilities were identified to be run during the final showcase. The later days of the shakedown were used to further test this subset of scenarios and capabilities in preparation from their use in the final showcase.

All activities planned for testing were performed during the shakedown. The planned capabilities for this more mature shakedown included UAS flights and telemetry submission, NASA scenario integration, SCVP, priority operational intent submission, dynamic replanning, operator notification, constraint submission, conformance monitoring, remote ID, data correlation queries, DMP data collection, historical query, and metrics collection. Dynamic rerouting around injected constraints was a primary focus of the week's testing and the efforts helped to identify mature capabilities as well as identify issues, which were solved prior to showcase execution. A total of 335 operations were conducted during Shakedown 2.

3.5.2.2 MAAP

MAAP's second shakedown was conducted March 20–22, 2023, and March 29–31, 2023, at Kentland Farms near Blacksburg, VA and in Corpus Christi, TX. All use cases and major test points were validated via live and simulated flights, with a total of 73 flights and a total of 8.4 flight hours. Testing included iterations of scenarios which exercised all the needed interactions for each use case.

A key success of this shakedown was identifying and working through a challenge with historical query. The remaining challenges identified were related to SDSP integration, InterUSS checkouts, and remote ID information over the UTM network. Despite not affecting core UFT objectives, they were identified and addressed during the shakedown testing. By the end of Shakedown 2, the UTM functionality required for the showcase was in place and working as expected. A total of 65 operations were conducted during Shakedown 2.

3.6 Final Showcase

The final showcase events were executed in spring 2023 at the respective test sites. The NYUASTS showcase was held on April 5, 2023, and focused its messaging on highly technical information targeted to working-level participants. An Oneida County's executive delivered pre-recorded opening remarks.

The MAAP showcase was an executive-level event held on April 19, 2023, and split between the Kentland Farms location in Blacksburg, VA and the Wing Nest in Christiansburg, VA. An opening statement from the FAA Administrator was shared to open the event. FAA's Office of Communications, as well as local media—including NBC, CBS, and Fox affiliates—were present at the second location to interview the ANG Assistant Administrator and MAAP Test Site Director.

Both events included demonstrations of multiple use cases. They also featured panels and Question and Answer (Q&A) opportunities between the FAA, test site personnel, and industry partners. Accompanying scenario videos were developed in a narrative style to support the event speakers and translate complex technology for a varied audience. Table 3 and Table 4 show all use cases and scenarios used during showcase activities. The scenarios tested during shakedown activities were modified and curated to present the appropriate capabilities based on the showcase audience and timeframe available.

Table 3: NYUASTS Showcase Scenarios

Scenario	Goals
Strategic Deconfliction of UTM Operations	• Demonstrated UTM operational intent submission, constraint submission, prioritization, strategic conflict detection, conformance monitoring, broadcast remote ID transmission/receipt and data correlation.
UTM Services Supporting Dynamic Replanning	• Highlighted operation deconfliction (without priority), advisory constraints, and conformance monitoring • The second phase focused on dynamic replanning
UTM Operations in Environments of Varying Complexity	• Demonstration of operation complexity • Included Operation prioritization and in-route replanning (rerouting) was demonstrated as well

Table 4: MAAP Showcase Scenarios

Scenario	Goals
UTM Operations in Environments of Varying Complexity	• Evaluate cooperative traffic management and various means of strategic conflict resolution based on the ASTM USS Interoperability Standard • Test how standards, technologies, and capabilities support mixed UAS operations in complex environments • Evaluate UTM services, such as strategic deconfliction, for criticality in supporting BVLOS operations in complex environments to inform evolving regulatory framework and future service qualification
Public Safety UTM Operations in Environments of Varying Complexity	• Test cooperative operating practices for resolving conflicts • Evaluate interoperability of having higher priority operations in the vicinity of with lower priority operations • Inform approaches for service qualification

Public Safety Queries Due to Concern of UAS Operations	• Test the FAA's data correlation service
	• Evaluate functionalities associated with:
	  ○ IAM
	  ○ Data and service access per user or entity permissions
	  ○ Message security
	• Obtain feedback from stakeholders on tested data correlation capabilities
	• Demonstrate use of the FAA's historical data query capability using location-based query parameters
	• Obtain feedback from stakeholders on data correlation
	• Obtain data on the implementation of message signing

During final showcase week activities, a total of 197 operations were flown at the NYUASTS test environment in Rome, NY. At MAAP's testing locations, a total of 147 operations were flown. Figure 6 provides a breakdown of the operations supported by the USSs across each test site.

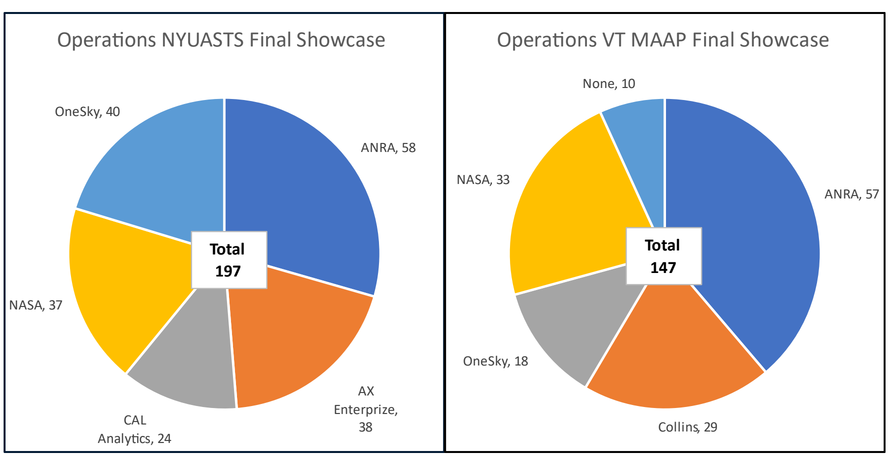

Figure 6: Operations Flown During Final Showcase Activities

4 Demonstrated Capabilities

This section provides an analysis and summary of data collected during UFT activities. Unless otherwise stated, metrics provided for analysis are based on data collected during final showcase week activities.

Table 5 shows how the demonstrated capabilities discussed in the following subsections map to the MOEs described in Section 3.2.1. The table also highlights if data collection for the demonstrated capability was done by the test site or the FAA.

Table 5: Demonstrated Capability to MOE Mapping

Demonstrated Capability	Section	MOE	Collected By
Operational Complexity	4.1	UFT-MOE-1, UFT-MOE-2, UFT-MOE-3	Test Site
Strategic Deconfliction	4.3	UFT-MOE-1, UFT-MOE-2	Test Site
Priority Operations	4.3	UFT-MOE-3	Test Site
Conformance Monitoring	4.4	UFT-MOE-1, UFT-MOE-2	Test Site
Constraint Management and Processing	4.5	UFT-MOE-1	Test Site
Data Correlation	4.6	UFT-MOE-4	FAA
Historical Query	4.7	UFT-MOE-1	FAA
Authorization Servers	4.8	UFT-MOE-5	N/A
Message Security	4.9	UFT-MOE-5	FAA

4.1 Operational Complexity

As described in Section 3.1.1, complexity was a key element of the UFT test approach. The goal was to provide environments of varying complexity to test the effectiveness of UTM services as operational complexity changes. Table 6 highlights the data collection metrics to show varying operational complexity.

Table 6: Operational Complexity Metrics

Metric ID	Metric Title	Description	Supported MOE
COMP-06	Tempo/density of operations	How many operations, (live and simulated), are occurring within an operating area over time?	UFT-MOE-2
COMP-07	Tempo/density of operations by state	How many operational intents are within an operating area are in each operational intent state (Accepted, Activated, Nonconforming, Contingent) over time?	UFT-MOE-2

4.1.1 Analysis

4.1.1.1 NYUASTS

NYUASTS captured operational tempo/density (COMP-06) in both the North and South operating areas. Figure 7 shows the operational density for the north and south operating areas. In the North, the maximum density was 11 operations; in the South, it was 18 operations.

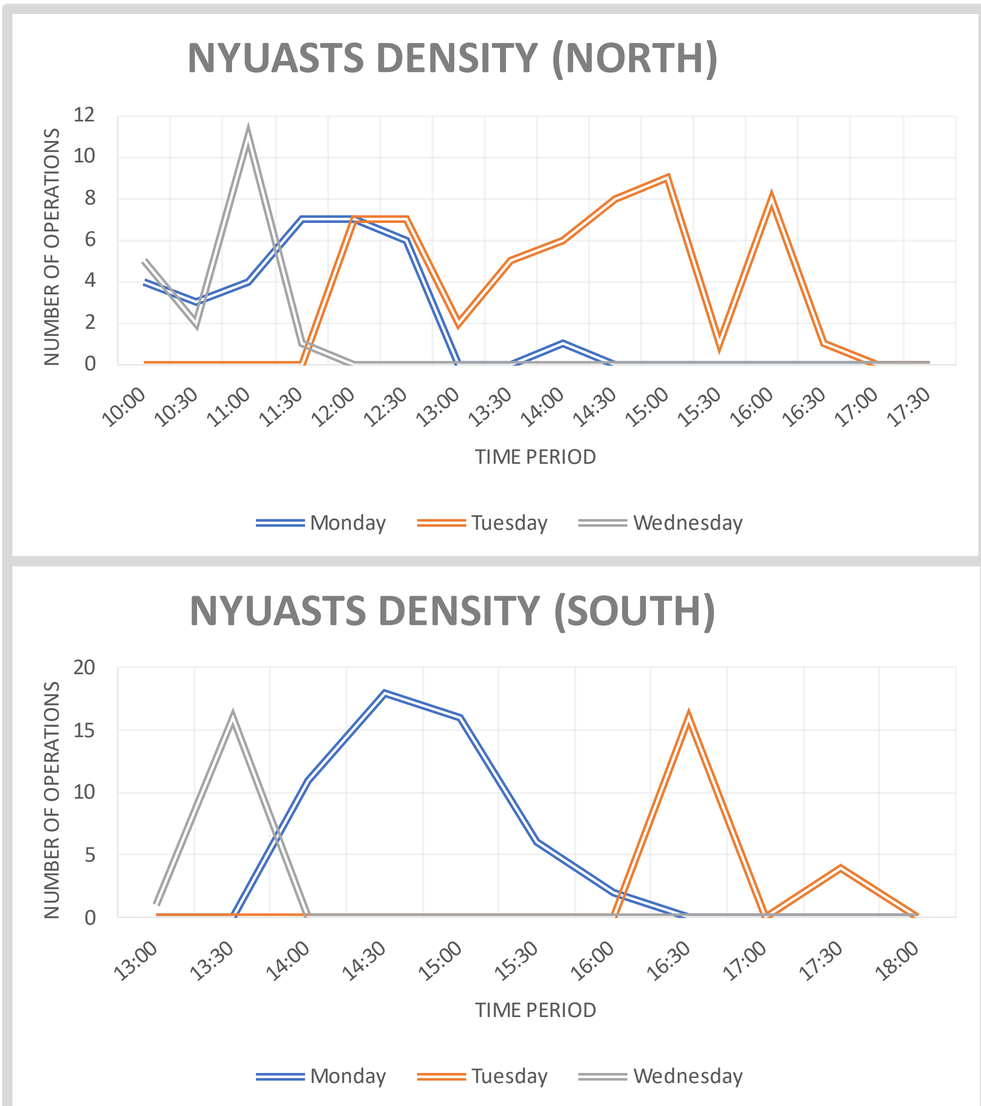

Figure 7: NYUASTS Operational Density

NYUASTS also captured tempo/density by operational intent state (COMP-07). The analysis is broken down by day and shown in Figure 8.

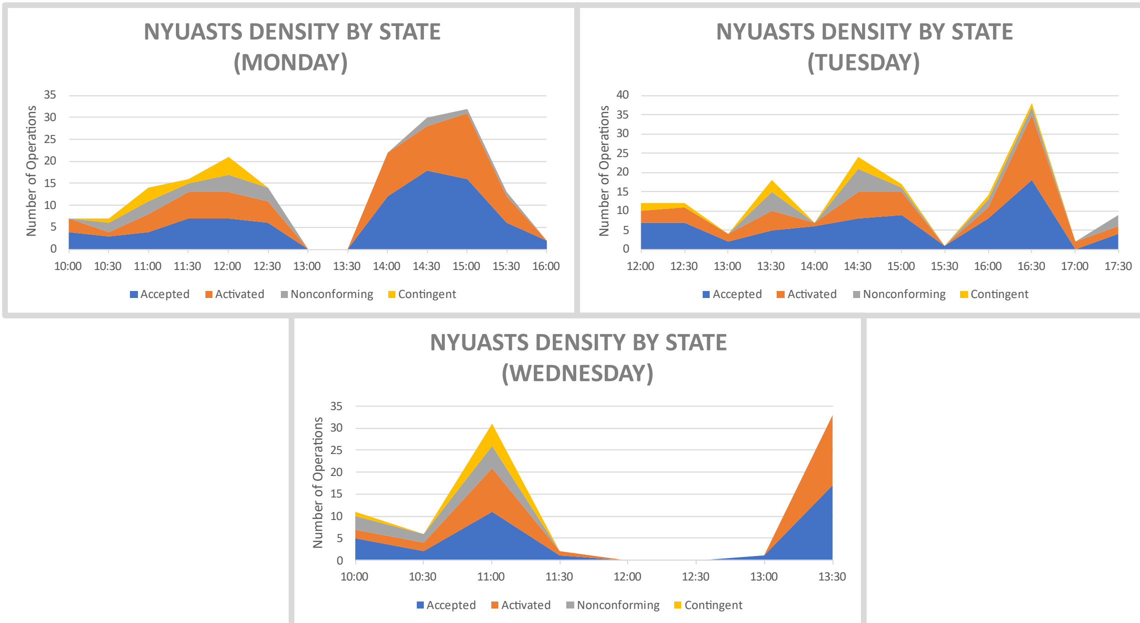

Figure 8: NYUASTS Density by State

4.1.1.2 MAAP

MAAP calculated density of operations (COMP-06) across multiple runs of four use cases. Some uses cases were excluded from data capture since density was not a focus. Density was calculated using the method described in Appendix D. A maximum density of 6 UA was reached in both the 0.2-square-mile and 0.4-square-mile areas. Figure 9 provides visualizations of the maximum operational densities achieved per use case.

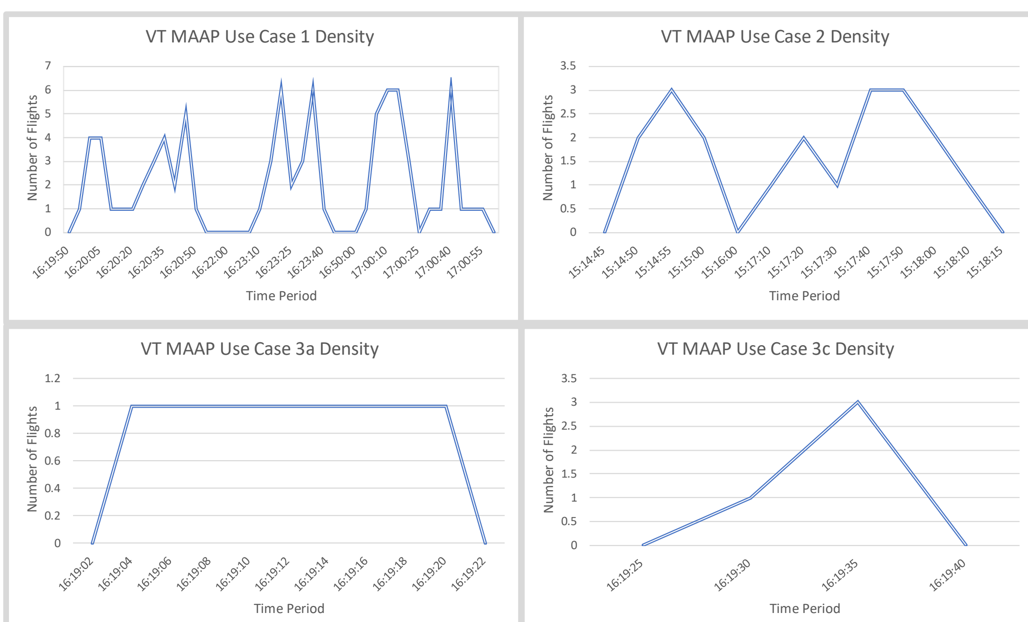

Figure 9: MAAP Tempo/Density by Use Case

MAAP also captured tempo/density by operational intent state (COMP-07). The analysis is broken down by day and shown in Figure 10.

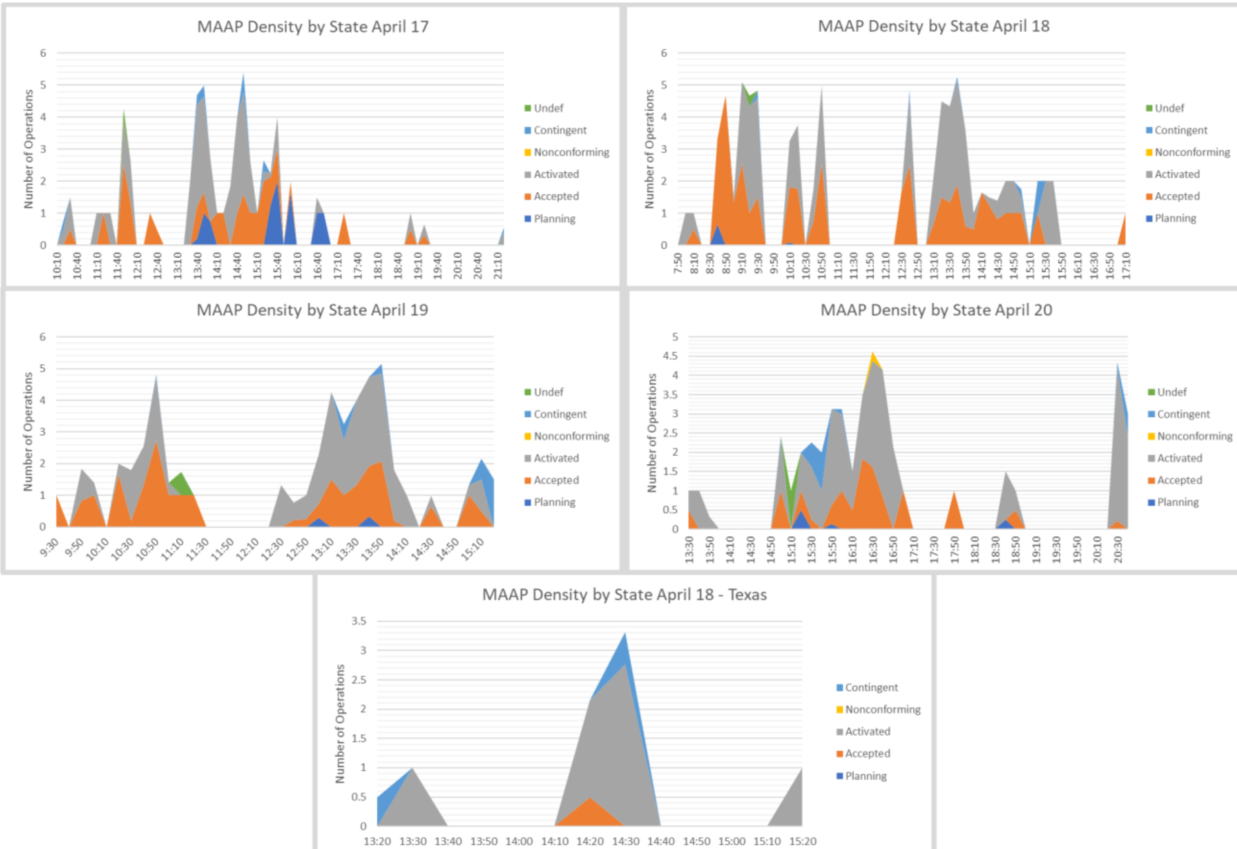

Figure 10: MAAP Density by State

4.2 Strategic Deconfliction

Strategic deconfliction is a service consisting of the arrangement, negotiation, and prioritization of intended operational volumes, routes, or trajectories of UAS operations to minimize the likelihood of airborne conflicts between operations. Strategic deconfliction is specifically highlighted in the FAA UTM Concept of Operations (ConOps) v2.0 [6] as one of the key capabilities that UAS operators use to maintain separation from one another and from constraints (e.g., obstacles, weather, airspace constraints), in a cooperative traffic management ecosystem such as UTM. The ASTM USS Interoperability Standard uses the USS role for strategic coordination to support strategic deconfliction. Strategic coordination is comprised of two services: 1) Strategic Conflict Detection, which determines if an operational intent conflicts with other operations intents, and 2) Aggregate Operational Intent Conformation Monitoring, which monitors an operator's aggregate conformance with operational intents over time.

For UFT, all USSs utilized the ASTM USS Interoperability Standard. This standard provided the framework for deconflicting operations with strategic conflict detection but leaves the approach to strategic conflict resolution open for the individual USS to decide. Strategic conflict resolution is the process of resolving conflicts through the modification of operational intents. Although there is no absolute time threshold, strategic conflict resolution requires sufficient time before the conflict to generate, coordinate, and implement the modification to the operational intent. Figure 11 shows an example of the deconfliction used, showing multiple operations from various USSs successfully deconflicted without any overlaps.

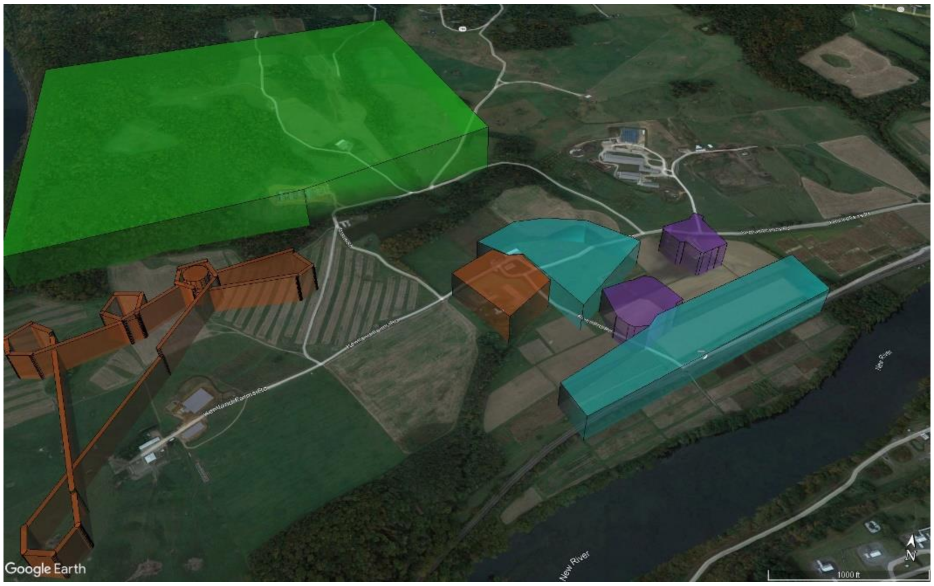

Figure 11: Display of Strategically Deconflicted Operations

Table 7 highlights the key data collection metrics to assess strategic deconfliction and supporting services/technologies.

Table 7: Strategic Deconfliction Metrics

Metric ID	Metric Title	Description	Supported MOE
COMP-02	Attempts for accepted operation	• How many attempts were needed by the operator/Remote Pilot in Command (RPIC) to obtain an accepted operation? • Categorize by operator/RPIC and USS (min, max, average, 95th percentile).	UFT-MOE-2
COMP-03	Operational replan causes	• Number and percentage of replans by cause (e.g., environmental, priority operation, constraints, etc.). • Replans occur after an operational intent is at least in an Accepted state.	UFT-MOE-2
COMP-04	Operational replan per operational area	• How many replans occur within an operational area.	UFT-MOE-2
COMP-05	Operational replan stage	• Number and percentage of replans occurring pre-flight vs. in-flight.	UFT-MOE-2

4.2.1 Analysis

4.2.1.1 NYUASTS

For flight activities, on average, UAS operators were able to achieve an accepted operation on their initial attempt at planning (COMP-02), as shown in Table 8. This signifies that the USSs were successful in supplying the UAS operators with enough situational awareness information during the planning phase to effectively plan around existing operational intents and constraints.

Table 8: NYUASTS Attempts for Accepted Operation

USS	Min	Max	Average
ANRA	1	2	1
AX	1	3	2
CAL	1	2	1
OneSky	1	2	1

There are situations that may cause operations to be replanned after they are accepted. For UFT, the two main causes of replans were constraints or higher priority operations (COMP-03), which could occur both pre-flight and in-flight (COMP-05) and can be categorized by operating area (COMP-04). These are highlighted by the metrics shown in Figure 12.

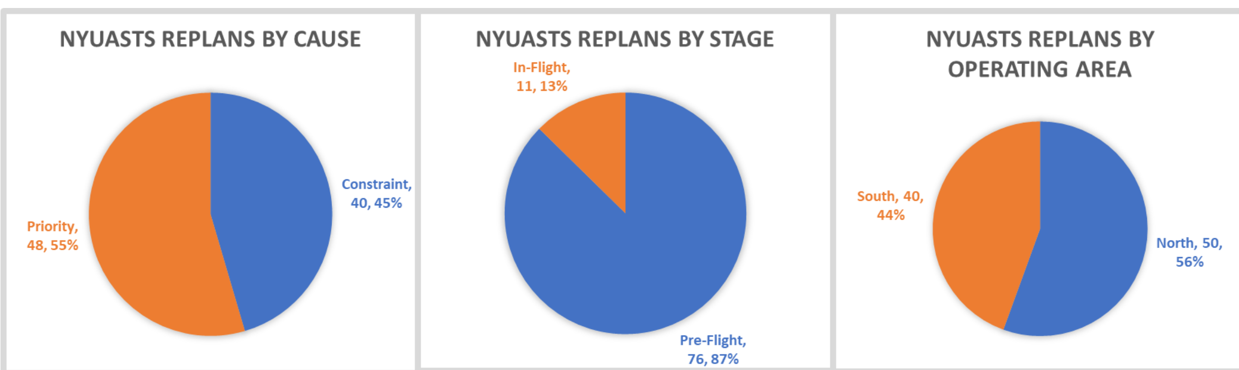

Figure 12: NYUASTS Replans by Cause and Stage

4.2.1.2 MAAP

For flight activities, on average, UAS operators were able to achieve an accepted operation on the first attempt at planning (COMP-02), as shown in Table 9. This was aided by the approach that allowed operators/RPICs to see all other operations in the USSs user interfaces.

Table 9: MAAP Attempts for Accepted Operation

USS	Min	Max	Average	95th Percentile
ANRA	1	6	1	1.75
Collins	1	1	1	1.00
OneSky	1	2	1	1.00

For UFT, the two main causes of replans were constraints or higher priority operations (COMP-03), which could occur both pre-flight and in-flight (COMP-05) and are highlighted in Figure 13. In total there were 10 replans at MAAP and 9 of them fell within the 0.2-square-mile and 0.4-square-mile operating areas (COMP-04) and are highlighted in the heatmap in Figure 14.

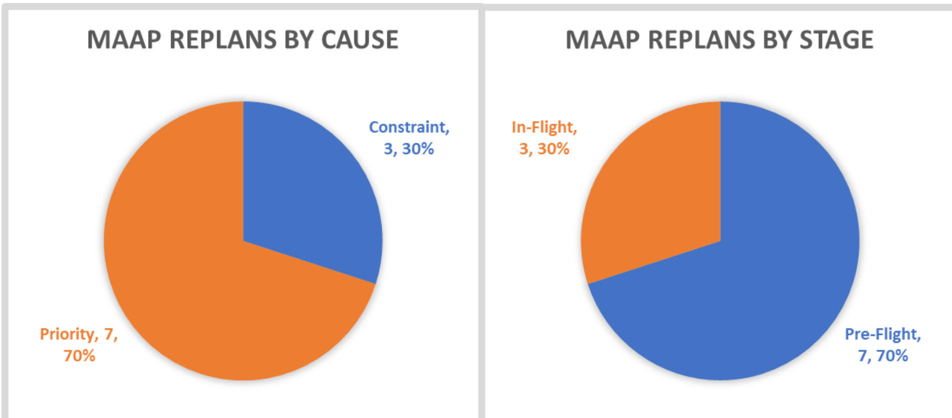

Figure 13: MAAP Operational Intent Replans

Figure 14: MAAP Operational Intent Replan Heatmap

4.2.2 Observations

Table 10 contains strategic deconfliction related observations compiled from the test sites and UFT participants.

Table 10: Strategic Deconfliction Observations

Area	Observations
Planning Attempts	• The level of information provided to the operators (e.g., showing all existing operational intents to the operator) allowed most operations to be accepted on the first attempt. • While the information sharing was successful, UFT identified an opportunity to increase resilience in the UTM data exchanges and improve the presentation of information to the operators.
Automation	• UFT identified potential limitations to manual deconfliction by operators when the operational complexity continues to increase or deconfliction becomes more complicated. • Automated solutions could reduce the burden on the pilot and add efficiency to the airspace. Any automated solution should balance the need for safety, operational efficiency, and privacy of users. • Feedback from participants showed that a means of negotiation between USSs is important as operational complexity increases. • Further USS and Ground Control Station (GCS) integration could be beneficial for improving operator awareness during operations.
In-Flight Replans	• Some USSs supported full in-flight replanning and avoided the need to land the UA before they were able to replan. • Support for in-flight replans could be beneficial as USS software continues to mature.
COPs	• The addition of COPs and best practices for reasonable time to deconflict, volume buffers, common resolution approaches would benefit the consistency and efficiency of strategic conflict resolution.

4.3 Priority Operations

Strategic conflict detection, per the ASTM USS Interoperability Standard, assumes certain regulations are established by the regulator in relation to operation priority. These regulations include the identification of priorities of operations and whether conflicts/overlaps are allowed within the same priority level. For traditional aviation, the FAA has existing rules in place, which dictate when and where a certain flight may have priority over another. For the UTM environment, the ASTM standard includes the concept of prioritization for small UAS operations, signified by a priority integer in the operational intent without a specific structure or scheme. UFT explored the technical approach to exchange prioritization data based on capabilities identified in the ASTM standard. Any concepts implemented by UFT in this area should be viewed strictly from a research perspective and not misinterpreted as any regulatory or policy decision having been made by the FAA. For UFT, conflicts/overlap was not allowed within the same priority level, the first-planned operation was given priority over subsequent operations.

The standard puts the prioritization scheme, priority levels, and attributes that characterize them at the discretion of the regulator. Nonetheless, a lower priority operation must be planned not to conflict with a higher priority operation [2]. At the time of UFT, the FAA has not determined a formal prioritization scheme, so a generic numbering scheme was used. The generic priority structure used integer numbers (e.g., between 0 to 40 with an increment of 10). The higher the integer indicates the higher the priority. The scheme in UFT was solely intended to test the concept and technology but should not be interpreted as any type of decision from the agency on this topic. Table 11 highlights the key data collection metrics to assess priority operations and supporting services/technologies.

Table 11: Priority Operations Metrics

Metric ID	Metric Title	Description	Supported MOE
PC-01	Elevated priority conflicts detected	• Percentage/number of elevated priority operations causing conflicts. • Number of elevated priority operations planned vs. number of conflicts detected.	UFT-MOE-3
PC-02	Replan time due to higher priority operation conflict	• How long does it take for an operator/RPIC to replan its operation (accepted or later state) due to a priority operation conflict? • Categorize pre-flight vs. in-flight (min, max, average, 95th percentile).	UFT-MOE-3
PC-03	Replan attempts due to higher priority operation conflict	• How many attempts does it take for an operator to successfully replan due to a higher priority operation conflict?	UFT-MOE-3

4.3.1 Analysis

4.3.1.1 NYUASTS

During UFT activities at NYUASTS, priority operations were tested with all four USSs: ANRA, AX Enterprize, CAL Analytics, and OneSky. Priority operations were tested by submitting lower priority operations into the UTM ecosystem first, then submitting higher priority operations, which required lower priority operations to be replanned. 101 elevated priority operations were filed across the four USSs. 98 operations were impacted by the elevated priority operations. Table 12 shows the number of elevated priority operations created by the USSs and the number of conflicts that were detected because of the elevated priority operations (PC-01).

Table 12: Priority Ops Created vs. Conflicts Detected

USS	# Priority Ops	# of Conflicts Detected
ANRA	27	23
AX Enterprize	44	38
CAL Analytics	10	10
OneSky	20	27

Several replans were done due to elevated priority operations. The replans occurred both pre-flight and in-flight with CAL Analytics and AX Enterprize supporting the in-flight replans. All replans were accepted on the first attempt (PC-03). Time to replan metrics (PC-02) are provided in Table 13. Challenges with data collection and the human factors associated with planning resulted in a wide range of values for the time it took to replan operational intents. These times should not be interpreted as the typical amount of time for a UTM system to replan.

Table 13: Replan Time Due to Higher Priority Operation

Time to Replan in Seconds	
Min	9.44
Max	410
Average	74.07
95^{th} Percentile	168.75

4.3.1.2 MAAP

For MAAP, 16 elevated priority operations were filed via the OneSky and Collins USSs. 30 operations were impacted by elevated priority operations. 70% of the elevated priority operations conflicted with other operations. Table 14 shows the number of elevated priority operations created by the two USSs and the number of conflicts that were detected because of the elevated priority operations (PC-01).

Table 14: Priority Ops Created vs. Conflicts Detected

USS	# Elevated Priority Ops	# of Conflicts Detected
Collins	12	24
OneSky	4	6

Seven replans were done due to elevated priority operations. Two of the seven occurred in-flight. Due to limitations in some USSs software, the in-flight replan required the operator to the land the aircraft before replanning, which greatly increased the total replan time. All replans were accepted on the first attempt (PC-03). This sample size is small, but the time to replan metrics (PC-02) are provided in Table 15.

Table 15: Replan Time Due to Higher Priority Operation

Time to Replan in Seconds	
Min	60
Max	720
Average	162
95^{th} Percentile	540

4.3.2 Observations

Table 16 contains priority operations related observations compiled from the test sites and UFT participants.

Table 16: Priority Operations Observations

Area	Observations
Priority Scheme	• The generic priority numbering scheme used during UFT was successful in testing priority operations per the ASTM USS Interoperability Standard. • Stakeholders noted there were several possible priority schemes that could not be supported by the ASTM standard. ○ As a result of UFT, industry stakeholders have begun evaluating updated approaches for evaluating conflicts based on priority. An improved approach would support more complex scenarios (such as operations of same priority but with different regulatory requirements in terms of UTM participation). • A formal prioritization scheme could be created and accepted by all parties involved within UTM. • Standards and other documentation would need to be updated to support the formal prioritization scheme as needed and for interoperability.
Off-nominal vs. Higher Priority Operation	• UFT participants identified a gap needing further development and guidance in the standard when an elevated priority operation conflicts with a lower priority off-nominal (nonconforming or contingent) operation.
COPs	• The addition of COPs and best practices for reasonable time for a lower priority operation to replan due to conflict with a higher priority operation, both pre-flight and in-flight, would provide guidance and support determination on strategic vs. tactical actions.

4.4 Conformance Monitoring

The FAA's UTM ConOps v2.0 defines conformance monitoring as a service that provides real-time alerting of non-conformance with intended operation volume/trajectory to an operator or another airspace user [6]. The ASTM USS Interoperability Standard supports this capability through the Conformance Monitoring for Situational Awareness (CMSA) role. CMSA is a USS role and service that determines whether a UA is in conformance with its operational intent on behalf of the operator or accepts self-reported conformance data from the UAS or operator. The service also initiates the sharing of situational awareness data with relevant USSs when nonconforming or contingent situations occur. The standard defines conformance as a situation where a UA is flying according to its activated operational intent.

The ASTM USS Interoperability Standard prescribes that non-coordinated off-nominal volumes be added to the operational intent when it goes nonconforming and contingent. The standard does not define how the non-coordinated volumes are calculated, so USSs have taken varying approaches. Some USSs used circular volumes while other used rectangular volumes. Figure 15 shows the varying approaches to off-nominal volumes at NYUASTS.

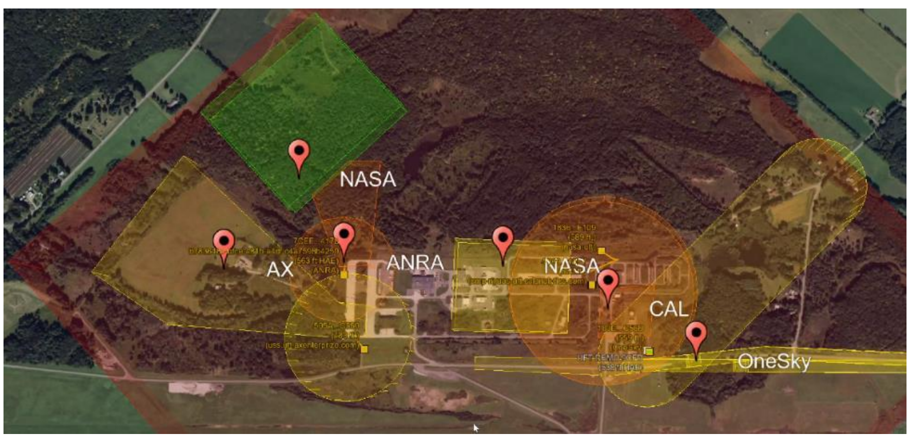

Figure 15: Non-Coordinated Off-Nominal Volumes

Table 17 highlights the key data collection metrics to assess aspects of conformance monitoring and supporting services/technologies.

Table 17: Conformance Monitoring Metrics

Metric ID	Metric Title	Description	Supported MOE
COMP-08	Off-nominal operations	How many operations transition to an off-nominal state (nonconforming or contingent)? • Total number • Percentage of operations • Number expected (due to scenario execution) vs. actual • By operating area	UFT-MOE-2

Metric ID	Metric Title	Description	Supported MOE
COMP-09	Latency in sharing off-nominal operations	What is the latency between when a USS transitions an operation to a nonconforming or contingent state and when relevant USSs are notified? (min, max, average, 95th percentile)	UFT-MOE-1

4.4.1 Analysis

4.4.1.1 NYUASTS

For NYUASTS, flight test activities during showcase week were analyzed for off-nominals. Overall, 39% of operations went off-nominal but 34% of the operations were planned to be off-nominal. This shows that only about 5% of operations went off-nominal unexpectedly. This could be a potential indicator for the effectiveness of the operational intent volumes being created, and the ability of the UA to stay inside the volumes 95% of the time when operators have proper awareness and USS implementation a functioning consistently. Table 18 shows the breakdown of off-nominals per day (COMP-08). Table 19 shows the latency statistics for long it takes a USS to notify other USSs when an operation goes off-nominal (COMP-09). The 4.488 second 95th percentile calculation is within the 5 second notification requirement from the ASTM USS Interoperability standard. There are some outlier numbers that drive the Max to be outstandingly high. This could be due to data collection challenges or other network latencies at times.

Table 18: NYUASTS Off-Nominal Operations

Date	# Operations	Total Off-Nominal	Planned Off-Nominal	Unplanned Off-Nominal
3-Apr	32	14 (44%)	11 (34%)	3 (10%)
4-Apr	54	19 (35%)	18 (33%)	1 (2%)
5-Apr	19	8 (42%)	7 (37%)	1 (5%)
Weekly Total	105	41 (39%)	36 (34%)	5 (5%)

Table 19: NYUASTS Latency Sharing Off-Nominal Operations

Latency in Seconds	
Min	0.005
Max	272
Average	1.092
95th Percentile	4.488

4.4.1.2 MAAP

For MAAP, flight test activities during Shakedown 2 and showcase flights at both the Virginia and Texas locations were analyzed. Overall, 20% of operations went off-nominal but only 6% of the operations were planned to be off-nominal. The unplanned off-nominals were usually due to aircraft accidentally leaving the planned operation, exceeding the time bounds of the operation, or USS software failure. The reasoning for the high number of off-nominals highlight the importance of operator training, how additional USS interface capabilities may aid operators in maintaining conformance with their Four-Dimensional (4D) bounds, and the importance of mature USS implementations to help limit failures. Analysis showed that USSs were able to notify other USSs of an off-nominal operation within 7 seconds 95% of the time. Table 20 shows the breakdown of off-nominal per use case (COMP-08). Table 21 shows the latency statistics for how long it takes a USS to notify other USSs when an operation goes off-nominal (COMP-09). The 7.333 second 95th percentile is above the 5 second notification requirement from the ASTM USS Interoperability standard. There are several outlier numbers that drive the 95th percentile to be above the standard specification. This could be due to data collection challenges or other network latencies at times.

Table 20: MAAP Off-Nominal Operations

Use Case	# Operations	Total Off-Nominal	Planned Off-Nominal	Unplanned Off-Nominal
UFT-1	94	21 (22%)	9 (10%)	12 (12%)
UFT-2	69	6 (9%)	1 (1%)	5 (8%)
UFT-3a	8	3 (38%)	2 (25%)	1 (13%)
UFT-3b	17	6 (35%)	3 (18%)	3 (18%)
UFT-3c	3	3 (100%)	1 (33%)	2 (66%)
General Testing	64	11 (17%)	0 (0%)	11 (17%)
Grand Total	**255**	**50 (20%)**	**16 (6%)**	**34 (14%)**

Table 21: MAAP Latency Sharing Off-Nominal Operations

Latency in Seconds	
Min	0
Max	84
Average	2.145
95th Percentile	7.333

4.4.2 Observations

Table 22 contains conformance monitoring related observations compiled from the test sites and UFT participants.

Table 22: Conformance Monitoring Observations

Area	Observations

USS User Interfaces	• Conformance monitoring as implemented per the ASTM USS Interoperability Standard was successful and worked as expected.
	• Through test site feedback, it was identified that improvements to USS interfaces could aid operator/RPIC overall situational awareness. Noted areas identified for improvement include:
	  • Make operation start and end times clear.
	  • Improvements in notifications and warnings sent to the pilot (e.g., notification when approaching operational intent boundary).
	  • Improvements in human factors associated with alerting operator/RPIC to ensure off-nominal information is not missed (e.g., notifications being prominent and having audible notifications).

Off-Nominal Volumes	• USSs successfully shared off-nominal volumes to other relevant USSs when operations went nonconforming and contingent. • USSs had varying approaches to how the off-nominal volumes are created and displayed. Evaluation of a consistent approach to the creation of off-nominal volumes in the ASTM standard may be beneficial.
Standards Compliance	• As some latency times were above the identified values in the ASTM USS Interoperability standard, further maturation and testing of USS software could be done to ensure compliance to the standard specification.

4.5 Constraint Management and Processing

An airspace constraint is defined as an impact to the capacity of an airspace resource used by airspace operators, defined with temporal and geographically specified information. An airspace constraint may restrict access to airspace for operations or may be advisory in nature. They can be associated with activities, events, or situations occurring in the air, on the ground, or both. The FAA maintains authority of the creation of any constraints in the National Airspace System (NAS), which includes those necessary to support safe UTM operations. While the UFT demonstrated capabilities related to the creation, dissemination, and processing of constraints, it should be recognized that airspace constraints in UTM are subject to the authority of the FAA.

The ASTM USS Interoperability Standard defines a constraint as “one or more 4D volumes that inform USSs, UAS personnel, operators automation systems, or other stakeholders, or combinations thereof, about specific geographically and time-limited airspace information. A constraint may restrict access to airspace for some or all operations, or it may be informational.”

The standard defines two roles to support constraints, constraint management and constraint processing. Constraint management is a USS service and role that supports authorized constraint providers in the creation, modification, and deletion of constraints. A USS with the constraint management role also handles the information sharing for created, modified, or deleted constraints. Constraint processing is a USS service and role that enables the USS to ingest constraint information and relay it to the UAS personnel, operator's automation systems, and/or other stakeholders for applicable operations.

During UFT, constraints were published using a simplistic, binary classification of "Advisory" or "Restrictive." Advisory constraints are used to relay any geographical specific information to the operator that may assist with their situational awareness or planning. Restrictive constraints represent airspace that may not be open to all operators. Table 23 highlights the key data collection metrics to assess constraint management, processing, and supporting services/technologies.

Table 23: Constraint Metrics

Metric ID	Metric Title	Description	Supported MOE
PC-04	Constraint conflicts detected	• Percentage/number of constraints causing conflicts • Number of constraints created vs. ingested vs. number of conflicts detected.	UFT-MOE-1
PC-05	Replan attempts due to constraint conflict	• How many attempts does it take for an operator to successfully replan due to a constraint conflict	UFT-MOE-1
PC-06	Replan time due to constraint conflict	• How long does it take for an operator/RPIC to replan its operation (accepted or later state) due to a constraint conflict? • Categorize pre-flight vs. in-flight (min, max, average, 95^{th} percentile)	UFT-MOE-1
PC-07	Latency in operator notifications	• The latency from when a USS knows about a conflict and when the operator is notified. Categorize operational intent, constraint, priority operation (min, max, average, 95^{th} percentile).	UFT-MOE-1

4.5.1 Analysis

4.5.1.1 NYUASTS

For NYUASTS final showcase week activities, a total of 86 advisory constraints were injected to support use cases and drive dynamic replanning. Table 24 highlights the number of constraints what was ingested by each USS (PC-04). Since constraint sharing and ingestion is dependent upon if a USS is supporting operations in the area and time of the constraint, it is feasible that a USS may not ingest all 86 constraints. As one USS reported ingestion of more than 86 constraints, further evaluation and testing of USS implementations would be beneficial in ensuring consistent situational awareness and deconfliction.

Table 24: NYUASTS Constraints Ingested

	ANRA	AX Enterprize	CAL Analytics	OneSky
Constraints Ingested	23	41	44	111

Operators took one or two attempts on average to successfully replan due to a constraint (PC-05). The time to replan metrics are provided in Table 25 (PC-06).

Table 25: NYUASTS Replan Time Due to Constraints

Time to Replan in Seconds	
Min	0
Max	360
Average	111.6
95th Percentile	137.4

In addition to the time to replan an operation, the latency in the notification to the operator of the conflict (PC-07) was also captured. The notification occurred within 6 seconds 95% of the time as shown in Table 26.

Table 26: NYUASTS Conflict Notification to Operator

Latency in Operator Notification in Seconds	
Min	0.005
Max	20.290
Average	0.772
95th Percentile	6.006

4.5.1.2 MAAP

AirspaceLink and ANRA fulfilled the constraint management role for MAAP. ANRA, Collins, and OneSky fulfilled the constraint processing role. AirspaceLink was their own constraint provider, and the VA Fix was the constrain provider for ANRA. AirspaceLink as a constraint manager only highlights how providers can choose which USS roles from the ASTM standard they want to provide. The constraint processing USSs provide constraint displays to operators, providing awareness of constraints to the operators. Figure 16 shows the constraint displays of the constraint processing USSs.

Figure 16: USS Constraint Displays

During UFT Shakedown 2 and final showcase week activities at MAAP, 29 constraints were filed. 36 operations were impacted by constraints. 52% of the constraints caused conflicts with at least one operation. Both advisory and restrictive constraints were submitted. Table 27 shows the number of advisory and restrictive constraints created by each of the two providers, AirspaceLink and ANRA, and the number of conflicts that were caused because of the constraints (PC-04).

Table 27: Constraints Created vs. Conflicts Caused

Provider/Manager	# Advisory Constraints	# Restrictive Constraints	# of Conflicts Caused
AirspaceLink	15	12	36
VA Fix/ANRA	1	1	0

Although there were 36 conflicts caused due to constraints, only three replans were done. All replans were successful on the first attempt (PC-05). One of the three replans occurred in-flight. The in-flight replan required the operator to land the aircraft before replanning, which greatly increased the total replan time. This sample size is small, but the time to replan metrics are provided in Table 28 (PC-06).

Table 28: Replan Time Due to Constraints

Time to Replan in Seconds	
Min	60
Max	348
Average	156
95th Percentile	318

In addition to the time to replan an operation, the latency in the notification to the operator of the conflict (PC-07) was also captured. The notification occurred within 53 seconds 95% of the time as shown in Table 29.

Table 29: MAAP Conflict Notification to Operator

Latency in Operator Notification in Seconds	
Min	0.006
Max	364.868
Average	11.253
95th Percentile	53.262

4.5.2 Observations

Table 30 contains constraint management related observations compiled from the test sites and UFT participants.

Table 30: Constraint Management Observations

Area	Observations
Constraint Display	• Constraint displays could benefit from additional human factors in relation to alerting and notification to make constraints more prominent and clearer to the operator. Some limitations seen in UFT include: ○ Some constraint displays showed constraints but required the user to determine any conflicts. ○ Some constraint displays showed notifications but required a map refresh to show the constraint on the map.
Constraint Management	• The inclusion of relevant local data that may impact the safety of UAS operations or other events, conditions, facilities, or emergencies taking place at the local level would be beneficial for safe, scalable, BVLOS operations.

Area	Observations

Constraint Types	• UFT explored the use of the Type element within the Constraint object in the ASTM Standard to signify restrictive or advisory constraints.
	• Further maturation may be needed to the standard and APIs to provide additional constraint details beyond what can easily be displayed in the Type element.
	  ○ Development of data models and classification schemas to communicate relevant constraint information to enable operators or their automation to respond appropriately.
	  ○ Support for conditional constraints that may apply to some operations and not others.
	    ▪ This may be contingent on multiple factors including aircraft certification, equipage, operation type, or manual whitelisting by relevant local, state, or national authorities.

4.6 Data Correlation

The UAS data correlation prototype was successfully tested during UFT and provided an API that allowed authorized entities to query for FAA-held data based upon a defined set of input parameters. The UFT testing focused on correlating the serial number of a UA to FAA-held data. This input parameter was chosen due to language in the FAA's remote ID rule stating that "correlating the serial number or session ID with the registration database will be limited to the FAA and can be made available to authorized law enforcement and national security personnel upon request" [7]. For the prototype, FAA-held data contained mocked data for UAS Registrations and Airspace Authorizations.

The FAA and industry partners created user interfaces that integrated with the UAS data correlation API. The user interfaces required users to log in and be authorized to submit correlation queries. User identity information was also sent with API requests, allowing the correlation service to also verify identity of users and their authorization to access certain FAA-held data. The FAA provided prototypes for a mobile application and web application for data correlation (Figure 17). At MAAP, ANRA, Collins, and OneSky implemented web-based user interfaces requiring the serial number to be input manually. At NYUASTS, AX Enterprize integrated data correlation into its broadcast remote ID application (Figure 18) and ANRA provided a web-based user interface (Figure 19). The FAA created a prototype mobile application and web-based interface.

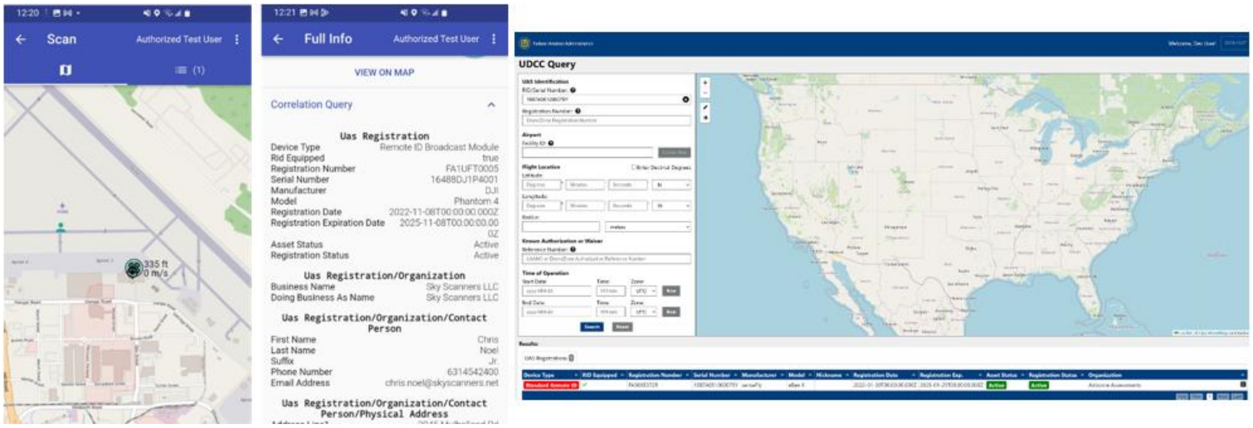

Figure 17: FAA Data Correlation User Interfaces

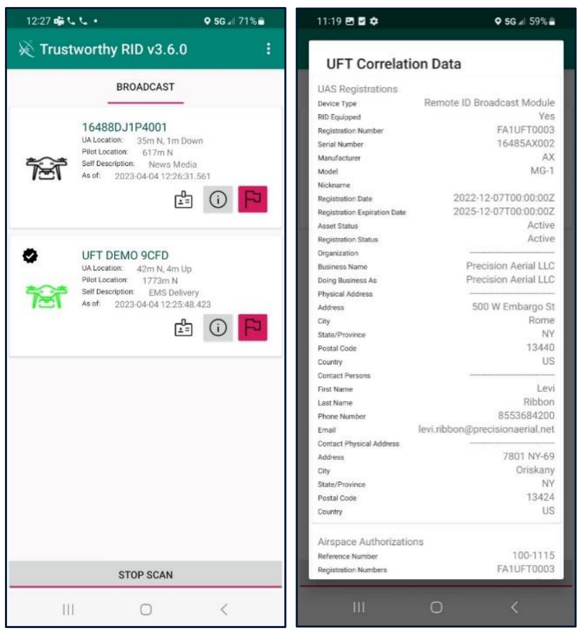

Figure 18: AX Enterprize Remote ID App with Data Correlation

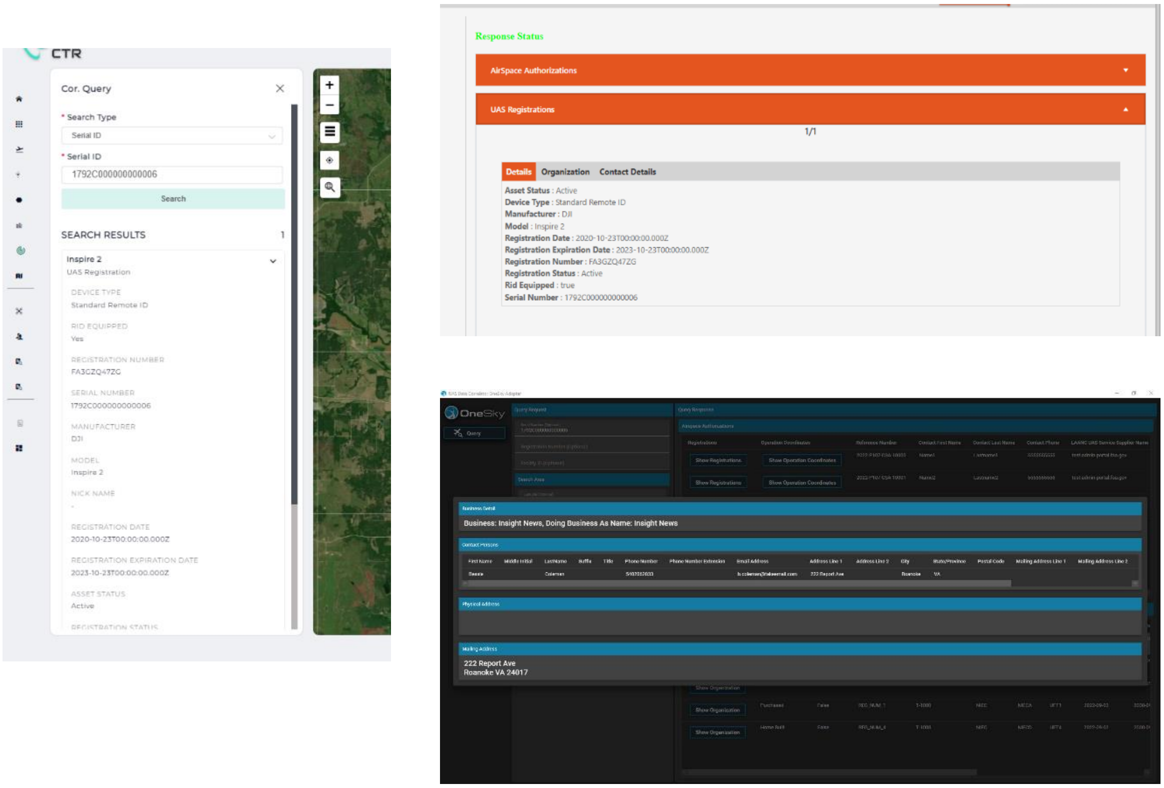

Figure 19: ANRA, Collins, and OneSky Data Correlation Displays

Table 31 highlights the key data collection metrics to assess data correlation and supporting services/technologies.

Table 31: Data Correlation Metrics

Metric ID	Metric Title	Description	Supported MOE
DC-01	Data correlation error rate	• How often did a data correlation query return an error? -Total - Percentage of queries with errors	UFT-MOE-4
DC-02	Data correlation latency	• Latency of data correlation queries. Min, max, average, 95th percentile, grouped by user group.	UFT-MOE-4
DC-03	Data correlation response size	• What is the size of data correlation responses? Min, max, average, 95th percentile, grouped by user group (e.g., authorization levels).	UFT-MOE-4

4.6.1 Analysis

The data correlation error rate continually decreased during UFT flight activities as implementations matured and issues were fixed. For the final showcase, the error rate was down to 4% from the 56% percent experienced in Shakedown 1 (DC-01). The data correlation response size steadily increased between UFT flight activities as additional mock data was added to support test execution (DC-03). The amount of time (latency) that it took to process a data correlation request varied between UFT flight activities (DC-02). The two major factors in latency were the error rate and the response size. The average latency increased from Shakedown 1 to 2 as the response size grew and the error rate remained relatively high compared to the showcase error rate. During the final showcase, the low error rate allowed the average latency to decrease, even with the increase in response size. Figure 20 shows charts to highlight the data correlation error rate, response size, and latency based on the data collected during UFT.

Figure 20: Data Correlation Metrics

4.6.2 Observations

Table 32 contains data correlation related observations compiled from the test sites and UFT participants.

Table 32: Data Correlation Observations

Area	Observations
Overall	• The data correlation prototype and client applications were successfully demonstrated during UFT. • As most client applications were developed during UFT, the consistent downtrend in error rate shows that testing and collaboration was a key factor to success.
User Interfaces	• Some of the user interfaces from UFT partners required manual input of the UA serial number. It would be more streamlined to integrate the data correlation features into the remote ID display applications.
Authorization	• A USS or other third-party entity developing a user interface for the data correlation API should strictly enforce access based on the permissions of the end user to ensure any FAA-held data is appropriately protected.
Remote ID Modules	• A system to correlate remote ID modules to specific aircraft may be needed to address modules used for multiple aircraft. One option would be to assign module serial numbers to an individual and not an aircraft.

4.7 Historical Query

The FAA's UTM ConOps states that the FAA will have on-demand access to UTM operational information when needed [6]. Historical query is a prototyped capability that allows the FAA to obtain on-demand access to USS-held data. For UFT, the prototype aligns with the USSLogSet data structure available in the API that supports the ASTM USS Interoperability Standard. The prototype allows authorized FAA users to make requests to an API endpoint supported by each USS. USSs respond with operational data based on the input parameters provided in the request. For UFT, the input parameters included an area of interest (polygon or circle) and a date and time range of interest. Figure 21 shows the prototype historical query user interface. While this approach allowed UFT to evaluate the use of an API to support the testing of FAA queries for data from the USS network, the FAA has yet to identify the specific requirements for data needs and retention within the USS network.

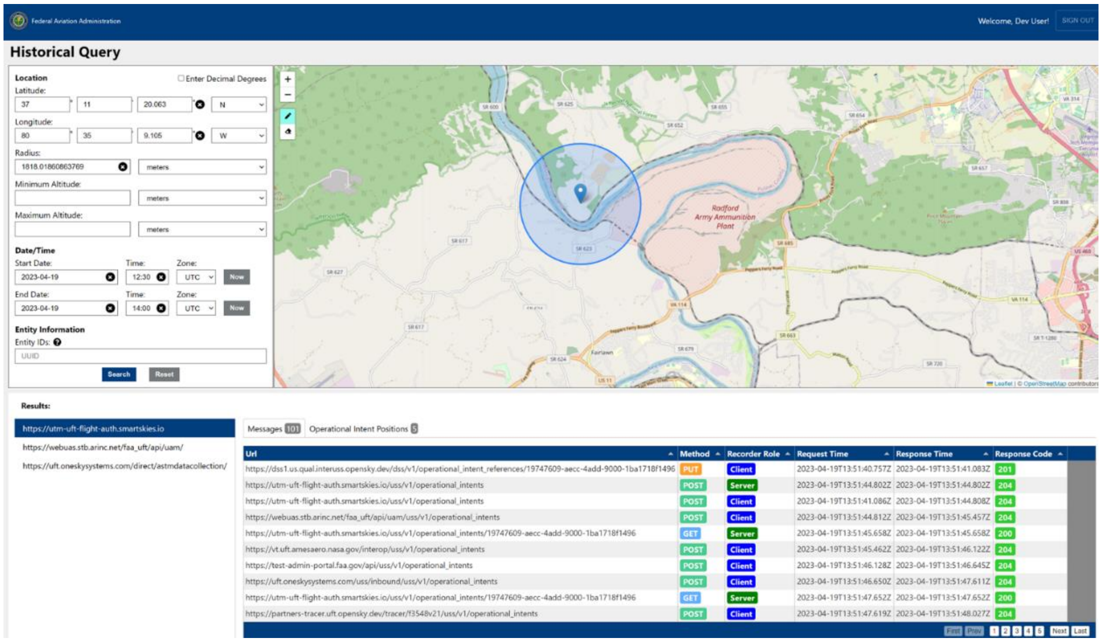

Figure 21: Historical Query User Interface

4.7.1 Analysis

Most USSs implemented historical query capabilities, but a significant portion of the implementation occurred between Shakedown 2 and final showcase activities. As such, data collection for historical query was only available for a portion of the final showcase activities. A total of 46 historical query requests were captured for data collection once capabilities were fully implemented. 48% of the requests had errors, indicating the need for additional testing and potential software updates. On average, the size of historical query responses was 1.8 megabytes. Table 33 highlights the metrics calculated from the historical query data collected.

Table 33: Historical Query Metrics

Historical Query Metrics	
Min Response Size	29 Bytes
Max Response Size	12.9 Megabytes
Average Response Size	1.8 Megabytes
95th Percentile Response Size	8.1 Megabytes
Request Error Rate	48%

Since historical query responses are textual, 1.8 megabytes would include a significant amount of content. While historical query and data correlation return different types of data, the difference of a 20-kilobyte data correlation response and a 1.8-megabyte historical query response are several orders of magnitude different. This is indicative that historical query responses could be reduced. The structure of the response data would need to be further analyzed to ensure only information of interest is returned and in an easily digestible format. Historical query requests took an average of 4 seconds to complete, and the requests were completed within 11 seconds 95% of the time.

4.7.2 Observations

Table 34 contains historical query related observations compiled from the test sites and UFT participants.

Table 34: Historical Query Observations

Area	Observations
Requirements	• Data requirements need to be determined (e.g., retention time, data types) to support historical query and other audit needs.
Standard Usage	• The use of standard data fields and structures within the ASTM USS Interoperability Standard was a positive step toward promoting effective and efficient incident investigations. • An unlimited, on-demand endpoint for historical UTM data, as used in UFT, may not be applicable in an operational environment
Data Format	• Use of the USSLogSet proved usability of existing data structures for historical query responses. • USSLogSet may contain more information than the FAA is concerned with and may present challenges in extracting the needed information. (e.g., operational intents, positions, etc.). • The USSLogSet requires a significant amount of message parsing to sort through extra information, as made evident by the average response being 1.8 megabytes in size.
USS Determination	• UFT identified a gap in determining which USSs were active in an area at a given time, which forces the FAA to query every USS which is inefficient and not scalable. ○ The cause of this gap was identified as the DSS not storing historical information and no alternative solutions exists. ○ A solution to this gap could be beneficial to the maturation of historical query.

4.8 Authorization Servers

UFT tested an implementation of the ecosystem which implemented two authorization servers: one supporting USS-USS interactions and one that secured the endpoints associated with FAA query functionalities (i.e., correlation, historical query). The use of multiple authorization servers was successful, with partners able to integrate with the necessary authorization servers based on their role in UFT. The design of the two authorization servers in UFT was significantly different, with FIMS-AuthZ using a design similar to previous UFT activities and the industry authorization server relying on a commercial provider for the authorization functionality. While there were no issues caused by this implementation, it is worth noting that if a multiple authorization server design was needed in future operations it would be ideal for the implementations to be similar. Similarity would reduce the potential interoperability challenges facing participants that have to connect to two different authorization servers. Also, NASA experienced IT policy challenges when connecting to the industry authorization server, and similar issues could be encountered by other federal agencies if there is a need for them to connect to an industry authorization server. Lastly, for the testing activities in UFT it was acceptable for a single UTM entity to host the authorization server. However, a neutral party should be considered in the hosting of the authorization server to avoid the potential conflict of interest if the host is also a USS managing operations.

4.8.1 Observations

Table 35 contains authorization server related observations compiled from the test sites and UFT participants.

Table 35: Authorization Servers Observations

Area	Observations
Industry Management of USS Authorization	• The industry authorization server was able to effectively support the communications needs in the USS network without causing any issues.
Multi-Authorization Server Approach	• USSs were able to obtain tokens from different authorization servers for secured queries (i.e., correlation, historical query) and USS network communications. • If future UTM activities use multiple authorization servers, aligning the approach for the authorization servers could be beneficial to prevent any potential interoperability issues. • NASA connectivity to industry authorization server presented certain policy challenges which should be considered if an industry authorization server is used in any future UTM activities. • The FAA and industry should consider the importance of a neutral party hosting the authorization server for future activities.

4.9 Message Security

The security controls implemented in UFT focused on securing UTM data exchanges through message security protections and IAM. The elements in these security areas include the application of message signatures, the encryption of data in correlation queries. The metrics were self-reported by each of the USSs and FIMS and provided to the FAA through an API provided either by the NIEC or via spreadsheet.

Table 36: Cybersecurity Metrics

Metric ID	Metric Title	Description	Supported MOE
CY-01	Overall signed message percentage	• The overall percentage of messages were signed.	UFT-MOE-5
CY-02	Message signing validation error frequency	• Percentage of messages signed which return an error in the validation process	UFT-MOE-5
CY-03[1]	Acceptance of invalid message (signature)	• Percentage of messages accepted by the received when the signature did not pass validation	UFT-MOE-5
CY-04	Acceptance of invalid message (token)	• Percentage of messages accepted by the received when the token did not pass validation	UFT-MOE-5
CY-05	Latency of encryption vs. non-encryption	• Latency of request responses due to encryption vs. non-encryption. Min, max, average, 95th percentile	UFT-MOE-5
CY-06	Number of issued tokens (identity vs. access)	• Total number of issued token - Identity tokens - Access tokens	UFT-MOE-5
CY-07	Latency of MyAccess authentication	• The length of the MyAccess authentication process Min, max, average, 95th percentile	UFT-MOE-5

4.9.1 Analysis

A key element of the security controls evaluated in UFT was an approach to message signatures based on a draft Internet Engineering Task Force (IETF) specification [7]. To capture the signature data, the API used two different fields, *has_signature* and *valid_signature*. The *has_signature* field identified that a certain message contains a signature, whereas the *valid_signature* verified that a signature was able to be validated. Data collection by the industry participants occurred in Shakedown 2 and showcase events, and therefore most of the issues relating to message signing had been identified and addressed. ***Of the messages that were required by UFT to be signed, 99% contained a digital signature***, capturing the CY-01 metric, which focused on the percentage of signed messages in UFT. To capture metric CY-02, the message signing validation error frequency, the percentage of messages with a false value for the *valid_signature* field indicated

[1] CY-03 and CY-04 were envisioned to include an UFT participant actively sending bad data to test whether USSs were accepting messages with improper security. The final technical scope of UFT did not include this activity and CY-03 and CY-04 were not captured within the project.

the error frequency. Since most of the message signing issues were identified and resolved by the time data collection had taken place, **less than 0*.1% of the messages that contained a signature did not validate***. These results indicate that by the time of the showcase, the UFT partners had a successful implementation of the UFT message signing approach to ensure message security of UFT exchanges.

There were two types of tokens used in UFT, access tokens used for USS authorization and identity tokens used to verify that data correlation users had been authenticated. Access tokens were issued by both the industry authorization server for exchanges using the ASTM USS Interoperability Standard and by the FIMS authorization server for historical query and data correlation. Throughout the duration of UFT, the FIMS authorization server issued 356 access tokens, with 64 during Shakedown 1, 207 during Shakedown 2, and 85 during the final showcase, which captured metric CY-06.

Data collection for encryption focused on data exchanges involving the data correlation application. With the results of the data correlation queries potentially becoming significant in terms of the size of the returned data, it was of interest to determine whether encryption would cause any performance issues for data correlation communications. Metric CY-05 focuses on this encryption latency and was captured through an experiment which ran correlation queries under two different experimental conditions, with encryption on and off, for a total of 100 tests per condition. The experiment measured the time from the initialization of the correlation request to the time when the correlation request was completed. The payloads that were encrypted for the experiment spanned several different sized messages, ranging from 5 to 20 kilobytes, which were general estimates for an average UTM message exchange.

The results of the correlation encryption experiment are shown in Figure 22. Most notably, there is not a significant difference in the amount of time for correlation responses to be generated between the two experimental conditions. While there are several response times with encryption on that are higher than any other sample, these were for moderately sized messages, which is indicative that the encryption process itself is not responsible for the increased response time., There is no correlation between response body size and response time. The results indicate that application layer encryption is likely not contributing significantly to message latency and potentially networking elements are responsible for the latency of these correlation responses.

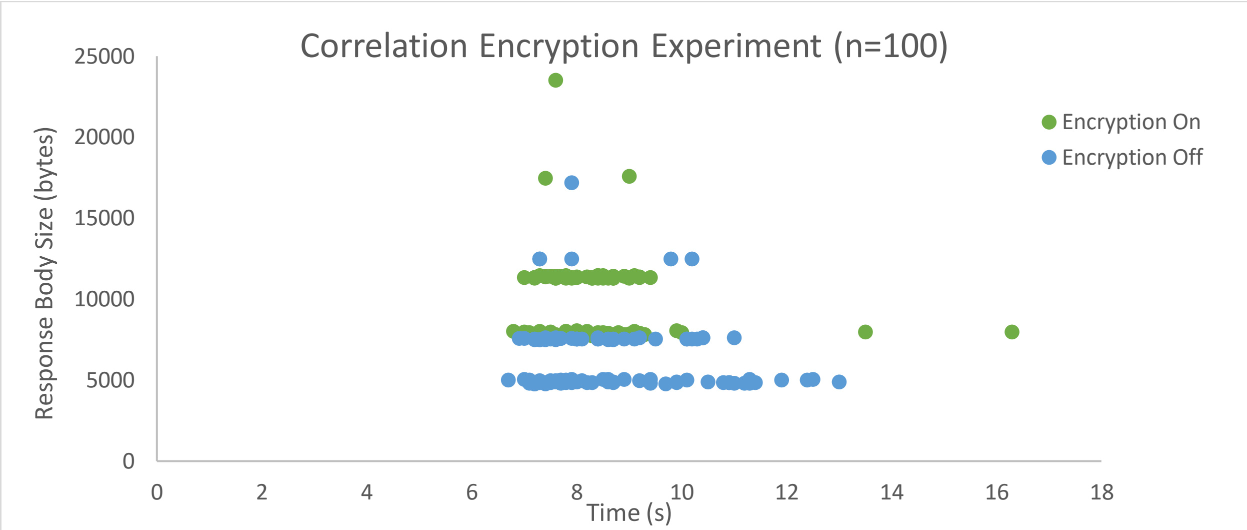

Figure 22: Comparing the Timing of Correlation Queries with Encryption Both On and Off

4.9.2 Observations

Table 37 contains message security related observations compiled from the test sites and UFT participants.

Table 37: Message Security Observations

Area	Observations
Message Signing	• The message signing approach used by UFT participants is a significant improvement over previous UTM activities, as a single signing approach can be used across all messages in the ASTM USS Interoperability Standard. • The message signing requirements developed by UFT partners were developed for the research and development needs of UFT and would need to be revisited to meet the needs of an operational system. • The extension of the InterUSS test suite to meet the needs of message signing showed automated checkouts to be an effective way to validate USS capabilities.
Secured Queries	• UFT highlighted that for the size range of 5–20 kilobytes, there was no statistically significant difference in the latency of an encrypted message compared with an unencrypted message. • For correlation applications, each application provided an identity token to the FAA’s correlation service, which successfully applied the permissions of the user to the query results. • This federated identity concept would be useful for future correlation applications but requires policies and agreements in place to enact operationally.

4.10 Test Harness

To ensure USSs were ready to interoperate with each other, each USS executed the tests contained within the InterUSS test suite [5]. The test suite tests a subset of the requirements in the ASTM USS Interoperability standard, with a focus on operational intent and strategic conflict detection. NASA added a new set of tests to the test suite to validate message signing requirements used in UFT.

While the use of the InterUSS test suite was a step towards automated test to verify a USS is compliant with the ASTM USS Interoperability standard and ready to interoperate with other USS, the limitations seen in UFT highlight the need for further maturation. More information on the limitations is provided in the observations section.

4.10.1 Observations

Table 38 contains message security related observations compiled from the test sites and UFT participants.

Table 38: Test Harness Observations

Area	Observations
Test Coverage	• The InterUSS test suite only tests a subset of the requirements in the ASTM USS Interoperability standard. • To be a sufficient test harness, the test suite should cover 100% of all appropriate requirements in the standard.
Extensibility	• NASA successfully extended the test suite and added tests for the message signing requirements. • Some users identified difficulties in executing the message signing tests, as the tests required a different setup. • Further guidance and best practices, focused on the creation of extensions, could help ensure tests can be executed in consistent manner.
Interoperability	• While individual USS testing of the harness is a reasonable approach at first, group testing to further validate the interoperability amongst multiple USSs may be beneficial.

5 Conclusion

Through the activities that occurred in UFT, the FAA, NASA, and industry partners were able to demonstrate the effectiveness of UTM standards in enabling deconflicted small UAS operations. The testing evaluated various elements of the USS Interoperability Standard from ASTM, including strategic conflict detection, conformance monitoring, constraint management and processing, and priority operations. In addition, UFT evaluated several areas beyond the standard including data queries (i.e., UAS data correlation, historical query), and security capabilities such as message signing. UFT also evaluated several industry capabilities (i.e., authorization server, checkout harness) that had in previous demonstrations been performed by government (e.g., NASA, FAA). Some of the specific observations and potential next steps are described in the subsections below.

5.1 Summary of Observations

The testing and evaluation of UTM capabilities during UFT helped to showcase a number of key UTM capabilities. Section 4 of this report presented each of the various capabilities demonstrated throughout the project. UTM participants identified several observations based on the experiences of UTM services supporting operations throughout the course of the UFT project. Several high-level observations are presented below.

- UFT validated that the ASTM standard should support strategic deconfliction and conformance monitoring among multiple USSs and operators.
- The level of information provided to the operators (e.g., showing all existing operational intents to the operator) allowed most operations to be accepted on the first attempt.
- Further maturation of operator-to-USS interfaces/displays would result in increased awareness and efficiency for UTM operations in the NAS.
- Tested initial development of industry-managed shared services to support future UTM operations beyond UFT, such as an industry-hosted authorization server and test harness.
- Advanced security capabilities are critical to protect UTM data exchanges.
- The automated testing was shown to be effective for USS capability checkout and is expected to help streamline service qualifications.
- New query capabilities have been tested to enable future UTM data exchanges, such as the historical query.
- UFT identified areas where industry needs to reach consensus on aspects of UTM implementation. With this consensus, industry can bring these areas to the FAA who will need to concur on certain aspects of UTM. Such areas include the establishment of COPs across the USS network, the specific implementation of an Authorization Server, and the definition of off-nominal volumes.
- UFT identified areas in the standards that are presented as gaps in implementation (e.g., availability arbitration, aggregated operational intent conformance monitoring, and in-flight strategic conflict mitigations). This will be part of continued maturity of USS technology as well as development for agreed up on cooperative operating practices ensure interoperability and quality of services.

5.2 Next Steps

Over the past decade, the FAA, NASA, and industry partners have performed a variety of research activities to advance the capabilities of the UTM ecosystem. These activities have helped to support the development of the industry, from the growth of service suppliers to the development of critical standards such as the ASTM USS Interoperability Standard. The activities of UFT provide valuable insights as the FAA and other stakeholders look to begin to consider the implementation of UTM capabilities to support the safety cases for real-world small UAS operations. The objectives of UFT to represent actual UAS operations with the highest possible fidelity should ensure that the observations from UFT would be useful for implementation. In addition, the industry-managed elements of UFT, such as the checkout test harness, demonstrate that it may be possible for industry to manage certain elements of future implementation. As UTM transitions towards implementation, Industry could evaluate important governance issues, such as service quality, and ensure agreement on the approach to meet the FAA requirements on safety, security, and privacy. While UFT validated the standard in a controlled environment, further maturation of UTM services will require evaluation through real-world operations.

Appendix A Scenarios

This appendix gives an overview of the scenarios used during shakedown testing. Throughout testing, scenarios were modified as necessary to accommodate readiness.

Appendix A.1 Shakedown Scenarios

Table 39: Shakedown Scenarios

Name	Summary
UTM Operations in Environments of Varying Complexity	• Explores planning and execution in environments of varying complexity (e.g., numbers and types of interactions, operational tempo, and environment, etc.) • Operation planning, off-nominals, constraints, etc. • Mixed operations including over people and at night
Public Safety UTM Operations in Environments of Varying Complexity	• Explores planning and execution of public safety operations in complex environments, including priority operations • Information sharing, operator notifications, operation replans/reroutes
Public Safety Queries Due to Concern of UAS Operation	• Explores data correlation using remote ID received and serial ID • Explores various levels of user data access for data correlation queries
Future Concept Elements: Post-Incident Investigation Involving UAS	• Explores data correlation using location-based query parameters and other capabilities to aid post-incident investigations • Explores queries for historical UTM information

Appendix B UFT Aircraft

Four distinct UAS platforms were used by NYUASTS and nine were used by MAAP, with a total of 12 platforms used throughout UFT. Table 40 lists all platforms used and associated test site.

Table 40: UFT Aircraft

Platform	Test Site
S1000	NYUASTS
F450	NYUASTS
HX8	NYUASTS
Phantom 4	NYUASTS and MAAP
SenseFly eBee X	MAAP
DJI Mini Pro 3	MAAP
Tarot 680 Pro	MAAP
FT Guardian	MAAP
SD-hxlO	MAAP
DJI Mavic Pro	MAAP
Free Fly Astro	MAAP
Volatus Fixar 007	MAAP

Appendix C UAS Test Site's Partner USS Summaries

Appendix C.1 ANRA

Developer of a cloud-based drone operational platform designed to support commercial entities for launching and managing commercial drone operations. The company's platform offers flight planning, airspace management, data analytics, compliance, drone management, resource management and maintenance information in a singular platform, enabling drone operators and service providers to have access to the command and control for one or multiple uncrewed aerial vehicle operations at any given time.

Appendix C.2 AX Enterprize

AX Enterprize provides expertise in UTM, payload design/deployment, and integrating UAS into the NAS. The company has substantiative experience with providing systems integration (UTM, Air Traffic Management [ATM], platforms, sensors, communications, and weather), command and control, dynamic mission planning/replanning, and data management. AX Enterprize also designed, built, and maintains the FAA-designated NYUASTS Operations and Data Management Center at Griffiss International Airport in Rome, NY.

Appendix C.3 CAL Analytics

CAL Analytics is a small business focusing on the development of aviation and autonomous systems. Located in Dayton, OH and founded in 2010, CAL Analytics has expertise in navigation systems, remote sensing, signal analysis, and information fusion. Their mission is to provide agile and rigorous R&D to bring new technologies to the world.

Appendix C.4 Collins Aerospace

Collins Aerospace, a unit of Raytheon Technologies Corp., is a leader in technologically advanced and intelligent solutions for the global aerospace and defense industry. Created in 2018 by bringing together UTC Aerospace Systems and Rockwell Collins, Collins Aerospace has the capabilities, comprehensive portfolio, and expertise to solve customers' toughest challenges and to meet the demands of a rapidly evolving global market.

Appendix C.5 OneSky

OneSky develops and produces air traffic awareness systems to "safely and efficiently open the sky to all flying objects, as a universal and connected medium for businesses." OneSky's enterprise-ready, software platforms use proven, industry-leading analytics to support safe, compliant, and efficient UAS flights BVLOS and integrated within the same airspace as other crewed and uncrewed aircraft. Leveraging 30 years of validated modeling, simulation and 4D visualization software from Analytical Graphics, Inc. (AGI), OneSky places powerful predictive and real-time capabilities into the hands of platform and payload manufacturers, commercial UAS operators and air navigation service providers.

Appendix C.6 Wing

Wing is an on-demand drone delivery service that can deliver food, medicine, or other items within minutes. The company has developed a UTM platform to support coordination between drones operating at low altitudes. Wing's approach to UTM is grounded in their experience as an operator. They have been heavily invested in building UTM technology, including supporting standards development, and contributing to research that will support the air traffic management ecosystem of the future.

Appendix D Method for Calculating UAS Operational Density

The density of operations during the UFT testing for MAAP was calculated using the method outlined by NASA for the TCL4 efforts [9]. This analysis utilizes the telemetry logged by each UA to calculate the number of aircraft within a specified area around the geometric median. For this analysis a circular area was chosen, and the analysis was performed for an area of 0.2 square miles and 0.4 square miles.

The following provides the general methodology applied for UFT to determine operational density during flight activities.

1. **Import Telemetry** – Import all telemetry files for a given use case iteration and convert into a uniform format.
2. **Combine Telemetry** – Telemetry from each flight during the use case is then combined into a single data frame with a matching time index. This is so the position of each aircraft can be determined for each time step. The time step used during this analysis is 10 seconds. There are also a few data filtering steps necessary. This includes filtering out any portion of the telemetry log that is not during the flight (aircraft on the ground).
3. **Calculate the Geometric Median** – Per the method developed by NASA, the geometric median is used to determine the operational density. For this analysis, the median latitude and longitude of all active aircraft is found. Simply taking the median of the latitude and longitude values will result in errors if the distance between the points is great, however for the short distances between the aircraft during testing this error is not significant (this assumes a flat earth).
4. **Calculate the Distance from the Geometric Median** – Now that the location of each aircraft and the geometric median is known for each time step, the distance from the median for each aircraft is calculated.
5. **Determine Density** – Lastly, the density is found for each timestamp by counting the number of aircraft within a certain distance of the median. For this analysis the areas assessed were 0.2 square miles and 0.4 square miles, which is a radius of 393 meters and 556 meters, respectively.

Appendix E References

[1] FAA, Uncrewed Aircraft Systems (UAS) Traffic Management (UTM) Pilot Program (UPP) Phase 2 Final Report. July 29, 2021. Retrieved from: https://www.faa.gov/sites/faa.gov/files/uas/research_development/traffic_management/utm_pilot_program/FY20_UPP2_Final_Report.pdf

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Appendix F Acronyms

All acronyms used throughout the document are provided in Table 41.

Table 41: Acronyms

Acronym	Definition
4D	Four-Dimensional
AGI	Analytical Graphics, Inc.
AGL	Above Ground Level
ANG	FAA Office of NextGen
API	Application Programming Interface
ASTM	American Society for Testing and Materials (Known as ASTM International)
ATM	Air Traffic Management
BVLOS	Beyond Visual Line of Sight
CA	Certificate Authority
CMSA	Conformance Monitoring for Situational Awareness
DMP	Data Management Plan
DSS	Discovery and Synchronization Service
FAA	Federal Aviation Administration
FIMS	Flight Information Management System
GCS	Ground Control Station
HITL	Hardware-in-the-Loop
HTTP	Hypertext Transfer Protocol
IAM	Identity Access Management
IATF	International Aviation Trust Framework
ID	Identification
IETF	Internet Engineering Task Force
KEAS	Kentland Experimental Aerial Systems
LAANC	Low Altitude Authorization and Notification Capability
LSUASC	Texas A&M University-Corpus Christi's Lone Star UAS Center of Excellence
MAAP	Mid-Atlantic Aviation Partnership
MOE	Measure of Effectiveness
NAS	National Airspace System
NASA	National Aeronautics and Space Administration

Acronym	Definition
NIEC	NextGen Integration and Evaluation Capability Lab
NY	New York
NYUASTS	New York UAS Test Site
OH	Ohio
PKI	Public Key Infrastructure
Q&A	Questions and Answers
RPIC	Remote Pilot in Command
RTT	Research Transition Team
SCVP	Server Based Certificate Verification Protocol
SD	Streamline Designs
SDSP	Supplemental Data Service Provider
SITL	Software-in-the-Loop
TCL	Technical Level Capability
TX	Texas
UA	Unmanned Aircraft
UAS	Unmanned Aircraft Systems
UDCC	UAS Data Correlation Capability
UFT	UTM Field Test
UPP	UTM Pilot Program
USS	UAS Service Supplier
UTM	UAS Traffic Management
VA	Virginia
VLOS	Visual Line of Sight
VT	Virginia Tech
WJHTC	William J. Hughes Technical Center