NASA/TM–20250002630

BVLOS UAS Cargo Delivery Simulation

A DoD-Sponsored Operational Evaluation with NASA and Project ULTRA

Cynthia A. Wolter
San Jose State University Foundation

Louise K. Morgan Ruszkowski
Amentum Services, Inc.

Abhay R. Borade
NASA Ames Research Center

Madison T. Goodyear
San Jose State University Foundation

March 2025

NASA STI Program…in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA scientific and technical information (STI) program plays a key part in helping NASA maintain this important role.

The NASA STI program operates under the auspices of the Agency Chief Information Officer. It collects, organizes, provides for archiving, and disseminates NASA's STI. The NASA STI program provides access to the NTRS Registered and its public interface, the NASA Technical Reports Server, thus providing one of the largest collections of aeronautical and space science STI in the world. Results are published in both non-NASA channels and by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or co-sponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services also include creating custom thesauri, building customized databases, and organizing and publishing research results.

For more information about the NASA STI program, see the following:

- Access the NASA STI program home page at http://www.sti.nasa.gov

NASA/TM—20250002630

BVLOS UAS Cargo Delivery Simulation
A DoD-Sponsored Operational Evaluation with NASA and Project ULTRA

Cynthia A. Wolter
San Jose State University Foundation

Louise K. Morgan Ruszkowski
Amentum Services, Inc.

Abhay R. Borade
NASA Ames Research Center

Madison T. Goodyear
San Jose State University Foundation

National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, California

March 2025

Acknowledgements

The NASA FUSE team would like to extend their thanks to colleagues that assisted with the 2024 Cavalier mission simulation. The success of this effort is shared with:

> Paul Liu, the Lead Systems Engineer; Jeffrey Homola, the Concepts and Development Lead; Erik Larson and Latha Balijepalle of the Airspace Operations Laboratory (AOL) in the Human Systems Integration Division at NASA Ames Research Center; Jinn-hwei Cheng, Sherry Jurcak, and the Aviation Systems Division Software Operations team at NASA Ames Research Center for their contributions to system deployment, testing, and troubleshooting; and the FREDDIE team from the Aviation Systems Division at NASA Ames Research Center for leading software development and providing expert advice.

The NASA FUSE team would also like to thank the Department of Defense, the CLUE team, and the Northern Plains UAS Test Site along with their subcontractors. Your partnership is greatly valued.

Available from:

NASA STI Program / Mail Stop 050
NASA Langley Research Center
Hampton, VA 23681-2199

Table of Contents

List of Figures and Tables

Acronyms and Definitions

AAM	Advanced Air Mobility
AFRL	Air Force Research Laboratory
AOL	Airspace Operations Lab
ASIS	AirSpace Integration System
ATC	air traffic control
BVLOS	beyond visual line of sight
CFR	Code of Federal Regulations
CLUE	Collaborative Low-Altitude UAS Integrated Effort
COA	Certificate of Waiver or Authorization
COP	common operating picture
CSFS	Cavalier Space Force Station
C-UAS	Counter Unmanned Aircraft Systems
DoD	Department of Defense
DSS	Discovery and Synchronization Service
ETM	Upper Class E Traffic Management
FAA	Federal Aviation Administration
FIMS	Flight Information Management System
FUSE	Federal USS Synthesis Effort
FUSS	Federal UAS Service Supplier
GFAFB	Grand Forks Air Force Base
KRDR	GFAFB airport
LOA	Letter of Agreement
MACS	Multi Aircraft Control System
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NESS	NASA ETM Service Supplier
NPSU	NASA Provider of Services to AAM
NPUASTS	Northern Plains UAS Test Site
NTAP	Near Term Approval Process (FAA)
NUSS	NASA UAS Service Supplier
OUSD-A&S	Office of the Under Secretary of Defense - Acquisition and Sustainment
RTB	Return to Base
RTL	Return to Launch
SDSP	Supplemental Data Service Provider
UAS	Uncrewed Aircraft Systems
ULTRA	UAS Logistics, Traffic, Research, and Autonomy
USS	UAS Service Supplier
UTM	UAS Traffic Management
UVR	UAS Volume Reservation

BVLOS UAS Cargo Delivery Simulation

A DoD-Sponsored Operational Evaluation with NASA and Project ULTRA

Cynthia A. Wolter[1], Louise K. Morgan Ruszkowski[2],
Abhay R. Borade[3], Madison T. Goodyear[1]

1 Introduction and Background

Since 2017, the National Aeronautics and Space Administration (NASA) and the Department of Defense (DoD) have collaborated to perform a series of simulations and live flight tests in support of developing a system to support federal Uncrewed Aircraft Systems (UAS) missions [1-10]. Beginning with understanding how the DoD would utilize UAS Service Suppliers (USS) to participate within UAS Traffic Management (UTM), to then supporting UTM, Advanced Air Mobility (AAM), and Upper Class E Traffic Management (ETM) operations, the 2023 flight test evaluated the Federal USS Synthesis Effort (FUSE) ecosystem and its ability to combine UTM, AAM, and ETM missions into a single common operating environment (Figure 1) [11]. The 2024 operational evaluation simulation takes the concept further by simulating the support of long-range beyond visual line of sight (BVLOS) large uncrewed air cargo missions in the National Airspace System (NAS).

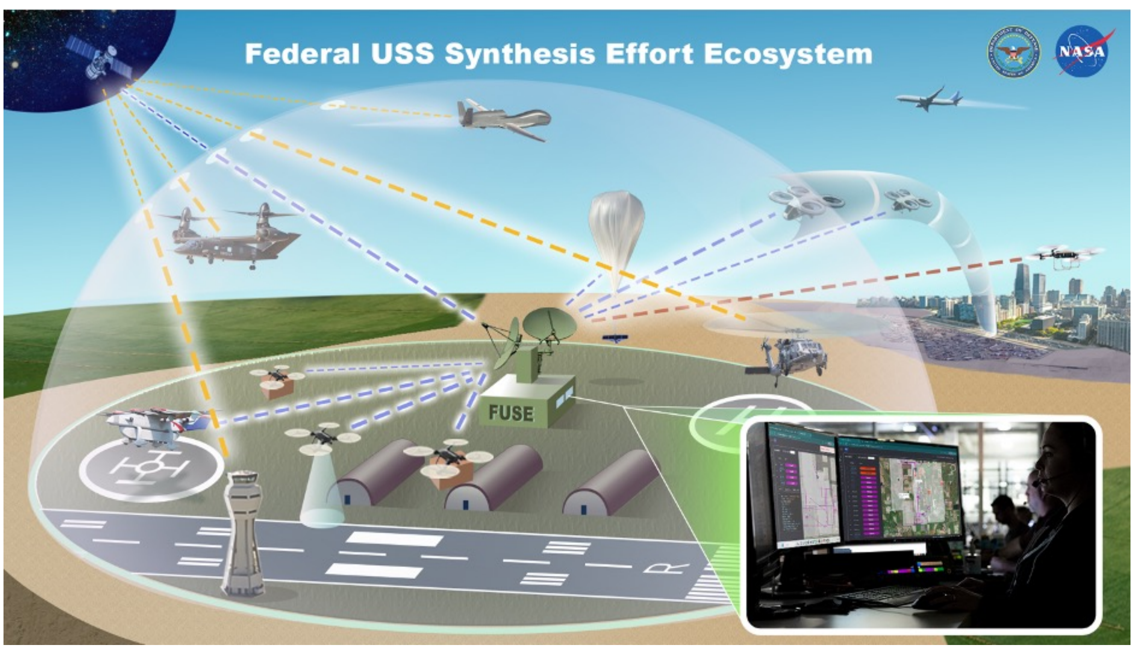

Figure 1. The Federal USS Synthesis Effort Ecosystem.

[1] San Jose State University.
[2] Amentum Services, Inc.
[3] NASA Ames Research Center

Currently existing UAS flight system implementations often require a Federal Aviation Administration (FAA) Certificate of Waiver or Authorization (COA), thus posing the challenge of missions being repeatable. Operators request stand-alone, one-off waivers and specific approvals for each flight circumstance. In addition to those limitations, there are additional risk mitigations that must be accomplished to conduct flight missions. These mitigations usually involve conformance monitoring and externally deployed ground-based sensor installations. As many DoD flights will have to transit through the NAS, they will also be subjected to FAA rules that apply to the respective airspace.

The FUSE ecosystem is intended to support routine repeatable UAS operations by addressing the above issues and expanding instances in the NAS. The 2024 simulation served as a preliminary bridge between previous flight tests and future efforts by evaluating the functionality required for a Federal USS to routinely support BVLOS UTM operations. This simulation focused on supporting large cargo delivery missions between Cavalier Space Force Station and Grand Forks Air Force Base (the Cavalier Mission) and informed further developments to elements of the ecosystem, including complementary tools and interfaces. The Cavalier Mission contributes to the larger Project ULTRA (UAS Logistics, Traffic, Research, and Autonomy), which was established to enhance the military's capability for UAS cargo delivery operations. The simulated Cavalier Mission will be repeated as a live flight as part of the operational evaluation of 2025.

A critical element to support repeatability is the exploration of the FAA's Near Term Approval Process (NTAP) [12]. The NTAP allows UAS service suppliers and operators to each obtain a Letter of Agreement (LOA) to conduct BVLOS operations prior to Parts 108 and 146 rules being published. NASA plans to navigate a NASA-developed Federal USS for the DoD through the NTAP.

2. The FUSE Ecosystem

The FUSE system architecture enables the NASA UAS Service Supplier (NUSS), the NASA Provider of Services to AAM (NPSU), and the NASA ETM Service Supplier (NESS) to manage their Discovery and Synchronization Service (DSS) subscription, Flight Information Management System (FIMS) authorization, and communication with participating service providers within the corresponding domains of UTM, AAM, and ETM. The FUSE XTMClient is a user interface component introduced to collect and aggregate information from the NUSS, NPSU, and NESS and display that information to users to support improved situational awareness. By combining these ecosystems, flight operators, air traffic control (ATC) personnel, and Counter UAS (C-UAS) participants can interact directly. Although the ecosystem retains the ability to also support AAM and ETM operations, only the UTM portion of the architecture was utilized for the 2024 Cavalier Mission (Figure 2). For a more in-depth description of these systems, please refer to the FUSE 2023 Flight Test Report [11].

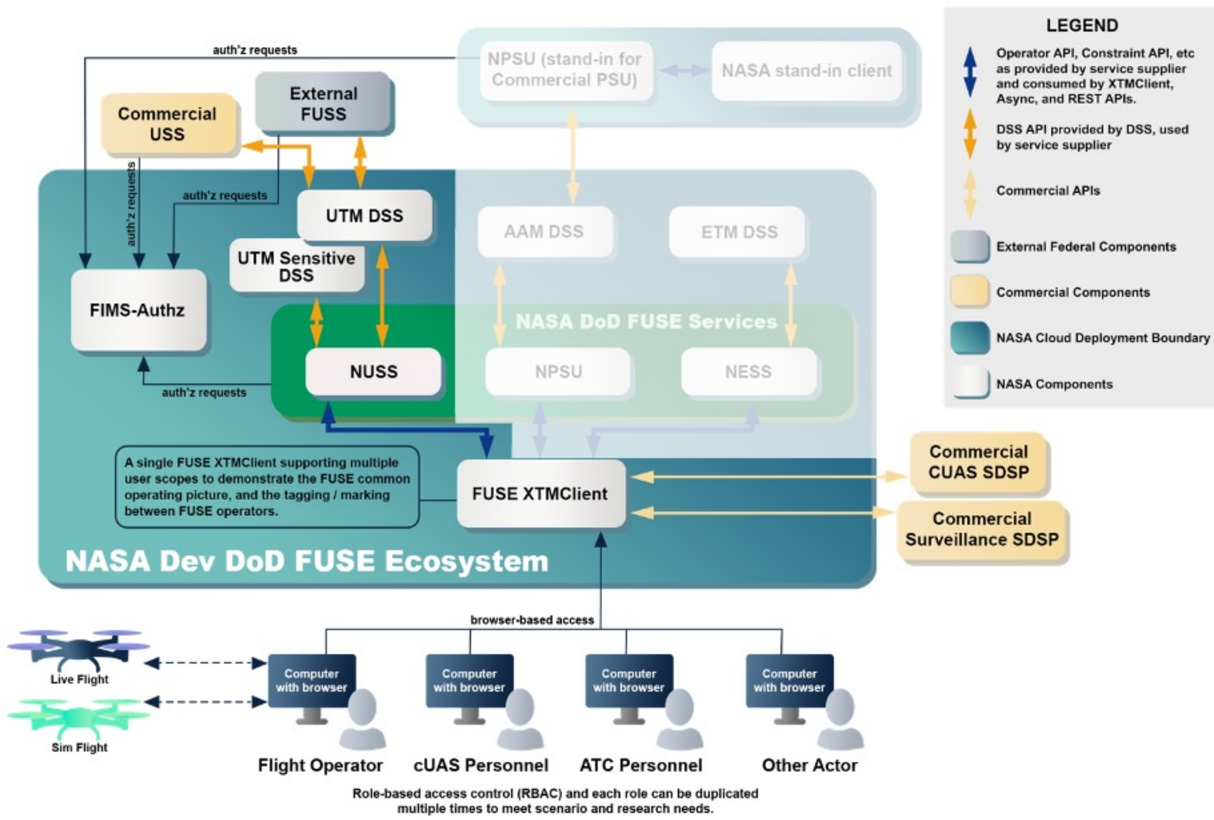

Figure 2. FUSE system architecture.

3. Roles and Responsibilities

3.1. Department of Defense

The DoD, specifically the Office of the Under Secretary of Defense - Acquisition and Sustainment (OUSD-A&S), was the primary sponsor of this effort. The FUSE efforts are all guided by the objective to achieve the use cases as defined by and relevant to the DoD.

3.2 National Aeronautics and Space Administration

NASA's primary responsibility was to contribute a Federal USS (FUSS) instance in support of the Cavalier Mission. The NASA team held a series of additional roles for the current simulation, including jointly defining scenarios with the test site, acting as flight operators by submitting Federal UTM operations in three scenarios, and reacting to both disclosed and undisclosed scenario events. NASA was responsible for a variety of software during the simulation, including the XTMClient which served as a user interface for the NASA FUSS. The operations team ran their missions using NASA's Multi Aircraft Control System (MACS) simulation software. Finally, a human factors researcher observed the test, recording data on interactions and noting recommendations for USS functionality, improvements, and future research.

3.3 GrandSKY and Northern Plains UAS Test Site

GrandSKY, in conjunction with Northern Plains UAS Test Site (NPUASTS), acted as the lead for Project ULTRA's Cavalier Mission and directed the scenarios, initiating scripted (disclosed) events, and by acting as a stand-in for ATC actions during the simulations. In addition, they also devised and directed Simulyze to insert unscripted (undisclosed) amendments to the scenarios in real-time to dynamically interact with the NASA and/or Collaborative Low-Altitude UAS Integrated Effort (CLUE) operations.

3.4 Simulyze

Simulyze played the roles of a Commercial USS, a Public Safety USS, and a Supplemental Data Service Provider (SDSP) to the FUSE ecosystem. They submitted seven pre-planned operations to occupy the airspace and interact with NASA and CLUE missions. As the Public Safety USS, they also submitted UAS Volume Reservations (UVRs) and non-participating (sensor-detected) operations to interact with NASA and CLUE missions.

3.5 Air Force Research Laboratory

The CLUE team from the Air Force Research Laboratory (AFRL) provided another Federal USS prototype to support simulated operations. The CLUE team submitted Federal UTM operations in three scenarios during the simulation and reacted to both disclosed and undisclosed scenario events.

4 Simulation Demonstration

The 2024 simulated Cavalier Mission was conducted on July 16th and 17th, 2024 (Figure 3). The simulation consisted of five scripted scenarios that were designed to investigate the feasibility of conducting repeatability long-range UAS cargo missions, demonstrate current FUSE capabilities, and perform a preliminary assessment of future use cases. To do so, NPUASTS and NASA first developed scenarios together with the primary goal to meet the demonstration requirements. To achieve the secondary objective, NPUASTS prepared a series of amendments to the scenarios, introducing contingencies for the NASA and CLUE teams to react to without prior notice. The timing of these scenario amendments was chosen so as not to interfere with achieving the simulation's primary objective.

Figure 3. The Airspace Operations Laboratory (AOL) during the FUSE 2024 simulation.

As stated on the shared test cards, the simulation objective was to perform simulated Federal UAS delivery missions flying from the Grand Forks Air Force Base (GFAFB) airport (KRDR) to the Cavalier Space Force Station (CSFS) (Figure 4). These missions were to deconflict/interact with various commercial volumes participating in the AirSpace Integration System (ASIS). Messaging and information sharing was based on an extended UTM structure.

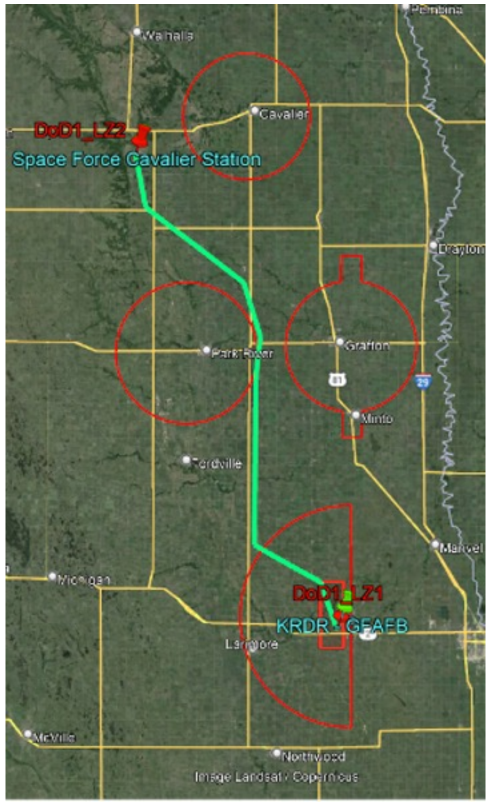

Figure 4. Simulation location and primary flight route in North Dakota.

4.1 Scenarios

Five scenarios were completed over two days from July 16th to July 17th, 2024. On the first day, the CLUE team participated without NASA operations, completing Scenario 1 and Scenario 2 as guided by NPUASTS and with additional previously undisclosed operations injected by Simulyze. The corresponding results from these runs will be included in a separate report as NASA participation was only required on this day to troubleshoot issues with the FUSE ecosystem if any occurred.

The remaining scenarios were completed with NASA-submitted operations on day 2 of the evaluation. Scenario 3 and Scenario 4 saw the NASA team participating without CLUE, as guided by NPUASTS, and with additional undisclosed operations injected by Simulyze. The evaluation concluded with Scenario 5, with both NASA and CLUE participating in a more congested environment. The events for Scenarios 3, 4, and 5 are detailed below and include the steps as known by the NASA and CLUE teams beforehand, in addition to any previously undisclosed amendments or contingencies that were made known to the NASA and CLUE teams in real-time.

4.1.1 Scenario 3

Scenario 3 included one delivery mission using a Federal USS (XTM1) that was simulated by NASA, traveling from GFAFB to Cavalier Space Force Station. While en route, nearby operations were submitted by Simulyze as either pre-planned to deconflict with XTM1, or with the need to replan to deconflict in space and/or time. The objective of these initial conflicting Simulyze missions was to demonstrate pre-launch operation replanning and resubmitting. Further into the scenario, a UVR was placed over a portion of the XTM1 route, prompting the operator to initiate actions to deconflict XTM1 from the UVR. To add realism to the evaluation, the XTM1 operators were not aware of the potential location and timing of the UVR, thus requiring the XTM1 operator to promptly devise and execute a plan to exit the UVR. In the first run of this scenario, XTM1 was nearing the far edge of the UVR at the time the UVR was dropped into the simulated environment (Figure 5). While this demonstrated an occasion where an operator may choose to continue along the planned path, a subsequent run demonstrated dynamic replanning by the XTM1 operator.

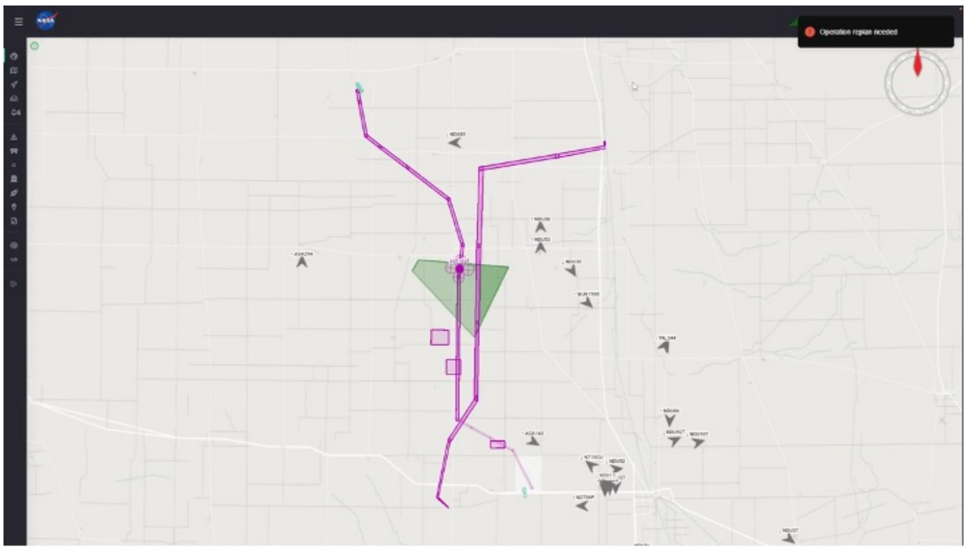

Figure 5. A UVR drops over XTM1.

4.1.1.1 Scenario 3 events (Note that pre-disclosed events are shown in bold)

- **Federal delivery mission (XTM1) submitted from GFAFB to Cavalier Space Force Station.**
- **Commercial Honeyford (Ultra2) submits operation pre-planned to deconflict with Federal delivery mission (XTM1).**
- **CHS Ag delivery (Ultra3) submission conflicts with Federal delivery mission (XTM1). Ultra3 resubmits with a time-based deconfliction, choosing an activation time that is past the end time for the intersecting XTM1 volume segment.**
- **Meteodrone operations submitted near KRDR and Cavalier Space Force Station.**
- **Inkster (Ultra4) operation submitted, deconflicted with Federal delivery mission (XTM1).**
- **Search mission (Ultra5) submitted, deconflicted with Federal delivery mission (XTM1).**
- **Commercial Lidar mission (Ultra1) submission conflicts with Federal delivery mission (XTM1). Ultra1 resubmits with a location-based deconfliction.**

• Undisclosed operations submitted in the area of XTM1, to the south of the UVR, and appear on the XTMClient, deconflicted by time, vertical, or lateral separation.

• Local fire department deploys a UVR with an undisclosed location and activation time.

• **Ultra1 Return to Launch (RTL) due to UVR.**

• XTM1 conflicts with the UVR and continues to destination.

• XTM1 must either adjust their speed to exit the area while remaining within the volume's time window or must dynamically replan, adjusting their route and volumes to deconflict with and exit the UVR before it transitions to an active state.

4.1.2 Scenario 4

Scenario 4 added complexity to the previous by including two NASA-simulated delivery missions using a Federal USS, the first traveling northward from GFAFB to Cavalier Space Force Station (XTM1) and the second traveling westward from GFAFB (XTM2). While en route, nearby operations were submitted by Simulyze as either pre-planned to deconflict with XTM1, or with the need to replan to deconflict in space and/or time. The objective of these initial conflicting Simulyze missions was to demonstrate pre-launch operation replanning and resubmitting. As with the previous scenario, a UVR was placed over XTM1 with unknown timing and location, as were the locations of surrounding nearby operations that could influence operator decision making. This required the XTM1 operator to promptly devise and execute a plan to exit the UVR while also remaining clear of the previously undisclosed nearby operations (Figure 6). XTM2 was included so that the operator had to monitor one mission while dynamically replanning another.

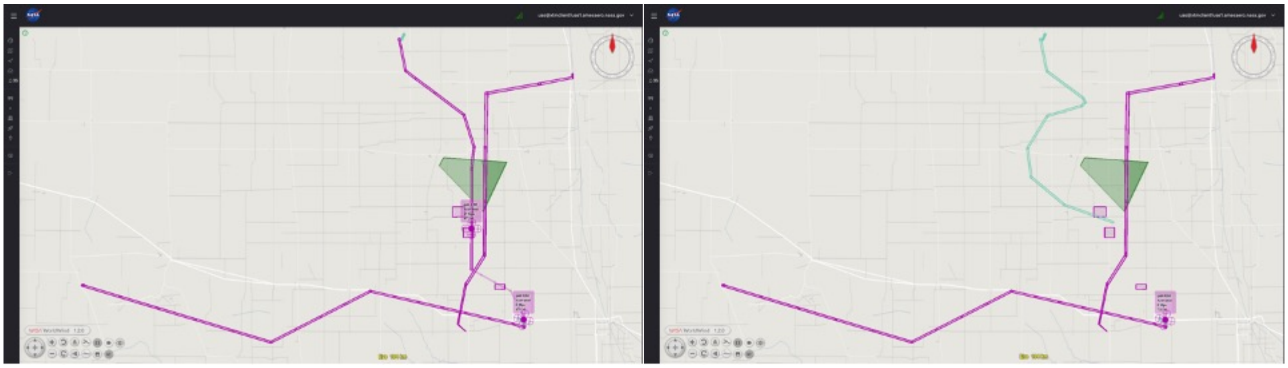

Figure 6. Before (left) and after (right) of XTM1's route when replanning due to a UVR.

An unintended event produced positive data for the evaluation when NPUASTS experienced Wi-Fi connectivity issues mid-run, requiring them to briefly pause their test direction. To allow for this delay, the test director instructed XTM1 to hover for a brief time, which affected the mission as it continued, resulting in time-outs where brief periods of non-conforming states occurred when approaching the far edge of each remaining volume segment (Figure 7).

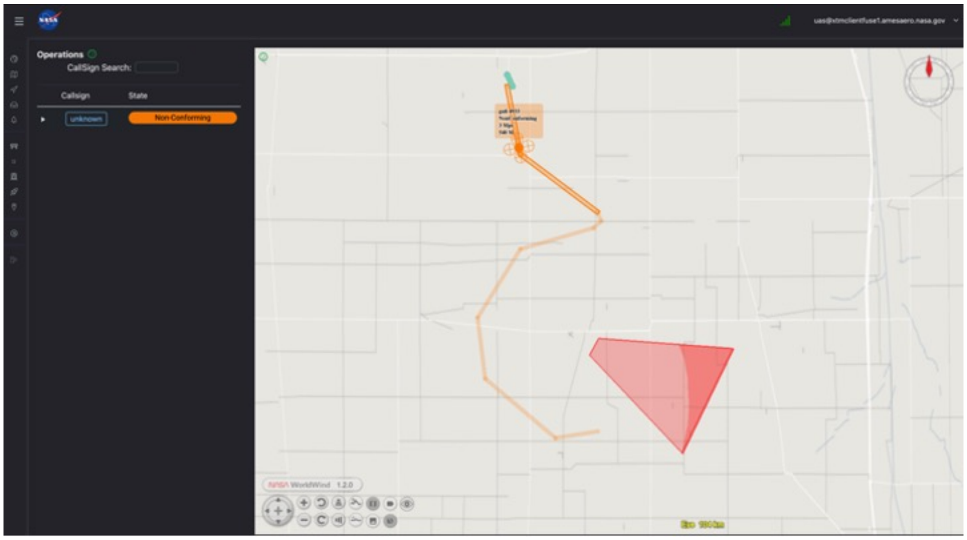

Figure 7. XTM1 in a non-conforming state due to extended hover.

4.1.2.1 Scenario 4 events (Note that pre-disclosed events are shown in bold)

- Inkster (Ultra4) mission submitted and appears to intersect with future XTM1, but is deconflicted by time and/or altitude.
- **Meteodrone operations submitted near KRDR and Cavalier Space Force Station.**
- Commercial Honeyford (Ultra2) operation submitted and appears to intersect with future XTM1 but is deconflicted by time and/or altitude.
- **Federal delivery mission (XTM1) submitted from GFAFB to Cavalier Space Force Station.**
- CHS Ag delivery (Ultra3) operation submitted, deconflicted by time and/or altitude with XTM1's intersecting volume segment.
- Commercial Lidar mission (Ultra1) submitted, deconflicted by time and/or altitude with XTM1's intersecting volume segment.
- **Federal delivery mission (XTM2) submitted westward from GFAFB.**
- Commercial Lidar mission (Ultra1) submitted, deconflicted with Federal delivery mission (XTM1).
- Local fire department deploys a UVR over XTM1, Ultra1, and Ultra3.
- Ultra1 RTL before UVR is activated.
- Ultra3 initiates a Return to Base (RTB) due to UVR.
- XTM1 conflicts with UVR and must either adjust their speed to exit the area while remaining within the volume's time window or must dynamically replan, adjusting their route and volumes to deconflict with and exit the UVR before it transitions to an active state. Chosen deconfliction method must also remain clear of undisclosed operational volumes.
- *Run 1 Only* Test director instructed XTM1 to hover while Wi-Fi issues were being mitigated. Delay caused XTM1 to time-out of volume segment, resulting in brief periods of non-conforming states when approaching the far edge of each remaining volume segment.

4.1.3 Scenario 5

The final scenario in this concept evaluation further explored possible future research by introducing two simulated CLUE delivery missions operating in the vicinity of two simulated NASA delivery missions. The NASA missions (XTM1 & XTM2) utilized a Federal USS, while a commercial USS was used for the CLUE missions (CLUE1 & CLUE2). The XTM1 and CLUE1 missions were both to travel from GFAFB to Cavalier Space Force Station and had volumes that were originally submitted with identical lateral boundaries but were separated vertically by 70m (Figure 8). As the delay between launching these operations was only three minutes, this created a situation later in the scenario where the two teams of flight operators were exposed to nearly the same conditions when the need to respond to undisclosed events arose.

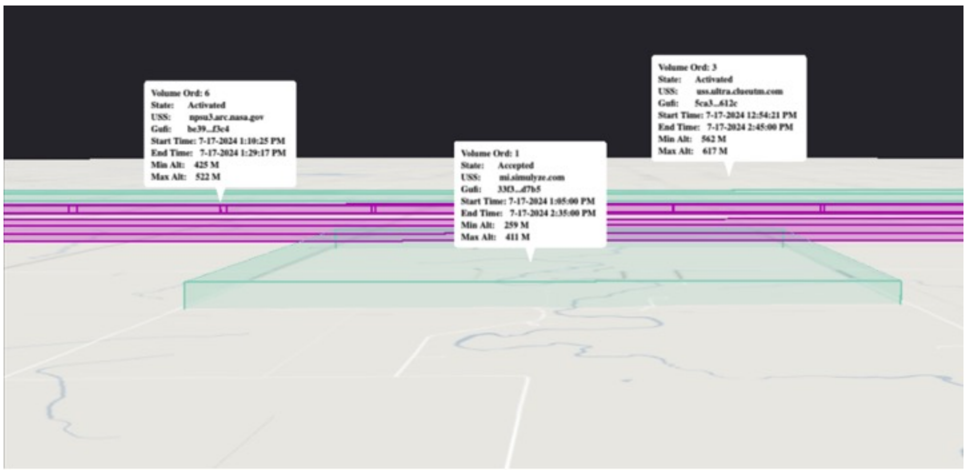

Figure 8. Side-view of XTM1 and CLUE1's active (magenta) volumes with 40m vertical separation.

When the UVR was dropped into this scenario but was not yet active, XTM1 was approaching the area from the south and CLUE1 had submitted and was active but had not yet launched (Figure 9, center magenta line on the left image). To avoid the UVR and Ultra3, the XTM1 and CLUE1 operators both replanned those routes to instead travel westward and northward (cyan line and magenta line to the right of the UVR, respectively). The modified XTM1 route did not originally fully extend back to the launch location due to operator workload while replanning mid-flight, and the operator intended to complete the replan once the urgency of avoiding the UVR had passed. Although this omission could be attributed to the user or the technology, it should be noted that supporting systems should assist avoiding this outcome when dynamically replanning mid-flight, especially if demand on the operator is consumed by multiple missions.

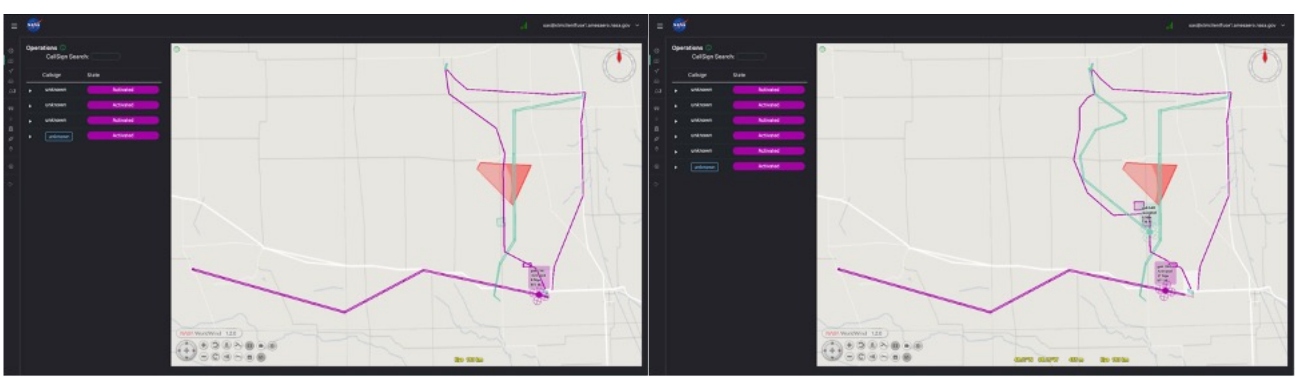

Figure 9. Before (left) and after (right) of XTM1 and CLUE1's routes when replanning due to a UVR.

After the UVR and towards the end of the scenario, multiple simulated non-participating operations were launched with the intent to provoke tactical avoidance actions from the XTM and CLUE operators (Figure 10). One of these operations circled continuously ahead of CLUE1, so the operator hovered until they thought it necessary to replan their remaining volumes. Another operation prompted XTM2 to hover, however, this delay caused XTM2 to transition to a non-conforming and then contingent state as the volume segments expired. Both these, and the examples above illustrate the need to further investigate the possible hazards and solutions associated with dynamically replanning a route while mid-flight in a congested and high-workload environment.

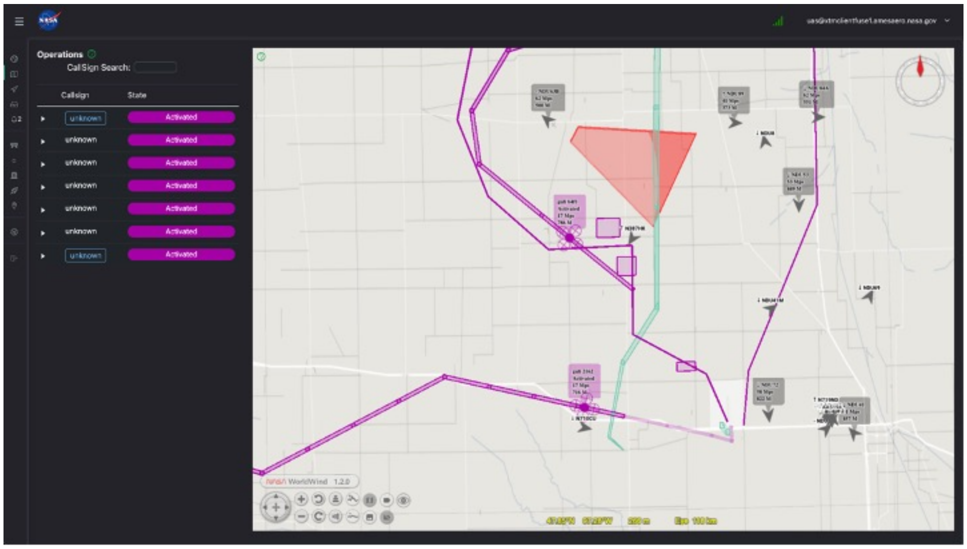

Figure 10. Non-cooperative operations inserted to prompt tactical avoidance by NASA and CLUE operators.

4.1.3.1 Scenario 5 events (Note that pre-disclosed events are shown in bold)

- **Meteodrone operations submitted near KRDR and Cavalier Space Force Station.**
- **Commercial delivery mission (CLUE1) submitted from GFAFB to Cavalier Space Force Station.**
- Commercial Honeyford (Ultra2) operation submitted, deconflicted by time and/or altitude with CLUE1. It appears to intersect with future XTM1, but is deconflicted by time and/or altitude.
- **Federal delivery mission (XTM1) submitted from GFAFB to Cavalier Space Force Station (note: planned 400’ difference in disclosed altitude from CLUE1).**
- XTM1 has the same lateral volume boundaries as CLUE1, but they are vertically deconflicted by 40m.
- CHS Ag delivery (Ultra3) submission conflicts with Federal and commercial delivery missions (XTM1 and CLUE1). Ultra3 resubmits with a time-based deconfliction, choosing an activation time that is past the end time for the intersecting XTM1 and CLUE1 volume segments.
- Commercial Lidar mission (Ultra1) submitted, deconflicted by time and/or altitude with XTM1 and CLUE1 intersecting volume segments.
- Inkster mission (Ultra4) submitted, deconflicted with XTM1 and CLUE1.
- ULTRA2 cancels and resubmits operation at a higher altitude.

- Local fire department deploys a UVR that conflicts with XTM1, CLUE1, Ultra1, and Ultra3.
- **CLUE2 and XTM2 operations submitted and do not conflict with UVR.**
- **Federal delivery mission (XTM2) submitted westward from GFAFB.**
- **Commercial delivery mission (CLUE2) submitted northward from GFAFB to Laramie and then westward to Cavalier Space force Station.**
- The XTM1 and CLUE1 routes conflict with the UVR and must either adjust their speed to exit the area while remaining within the volume's time window or must dynamically replan, adjusting their routes and volumes to deconflict with and exit the UVR before it transitions to an active state. Chosen deconfliction methods must also remain clear of other nearby operational volumes.
- Search mission (Ultra5) submitted, deconflicted with other operations.
- Non-cooperative operations launch and intentionally interfere with remaining XTM and CLUE operations, prompting tactical avoidance maneuvers from the XTM and CLUE operators.

5. Results

The 2024 simulated Cavalier Mission demonstrated the ability of the FUSE system to support large cargo delivery missions from GFAFB to Cavalier Space Force Station by conducting simulated instances of future live test missions. Current capabilities, including a USS navigating the FAA's NTAP, were tested and exposed opportunities to further refine NASA tools utilized in the FUSE ecosystem to support the DoD mission. Within the scenarios, flight operators were able to simulate dynamic replanning of operations while in flight and view their own and other operations via the FUSE ecosystem and XTMClient. This is a foundational step toward 2025 where the Cavalier Mission will be conducted with a live vehicle.

Inserting unpredictable events into the simulations served to illuminate research avenues regarding potential increased operator workload, inefficiencies, or associated hazards while calculating and executing appropriate responses to UVRs or conflicting operations. The UVR and non-participating aircraft events revealed potential technology and user challenges regarding the types of responses or deconfliction methods researchers might want to investigate in future live flight tests and evaluations. The types of resolutions chosen should be noted in conjunction with operator workload, the operation's state, and the surrounding airspace conditions. Tracking the successfulness of the resolutions and gathering data on the kinds of supportive automation available or desired could lead to increased efficiencies when dynamically replanning in the future. To perform those investigations, the following research questions were identified as the most apparent candidates based on the events of this simulation:

- What action(s) do operators choose when responding to a UVR event (e.g., speed, altitude, and/or heading changes)?
- How much time do operators need to replan their operation mid-flight?
- What information is needed for operators to successfully replan while remaining both safe and efficient?
- What factors are considered when replanning an operation?
- How does having to maintain awareness of another operation during a UVR affect the operator's response choice (and workload)?

- Does the presence of other operations change the operator's response choice (including accounting for operations with unknown volume or trajectory modifications that are also impacted by the UVR)?
- Is there a relationship between volume configuration methods (e.g., a few long volumes vs. many short volumes) and operator workload or success during dynamic replans?
- Are potential delays considered when creating operational volumes, such as additional time buffers for each segment?
- Does the benefit of keeping the UVR activation time undisclosed/flexible surpass the advantages of it being disclosed to flight operators?
- Would knowing the UVR activation time change the response action(s) chosen by operators?
- Should the current airspace complexity be a consideration for UVR activation times?
- What is the relationship between successful replanning and the number of operations concurrently replanning due to a UVR?
- What actions(s) should an operator take if they cannot successfully replan before a UVR is activated?
- What are operators' perceived thresholds for risk tolerance that, when reached, would require a replan rather than a speed adjustment?
- What tools and/or automation would be helpful for operators to complete effective and efficient operation replans mid-flight?

6. Conclusion

The current operational evaluation of the FUSE concept supported the continued development of the FUSE ecosystem towards future flight tests. Additionally, through the exploratory methods of the simulation, research questions were identified for potential inclusion in future live flights and simulations.

One of the most notable features of the FUSE ecosystem is its repeatability. With no geographic constraints, the FUSE ecosystem can be utilized anywhere. NASA initiated the concept development, advocated for development of the prototype systems, and partnered with the DoD to integrate and test the ecosystem for its applications. The FUSE ecosystem will enable the DoD to conduct routine BVLOS operations, connecting both operators and service providers. The DoD is already implementing Federal USS prototypes at some of its facilities [13]. The implementation of a Federal USS alongside a common operating picture (COP) provides operators with improved situational awareness and the ability to conduct scalable and repeatable missions.

Moving forward, NASA intends to obtain a LOA from the FAA after going through the NTAP. This will allow the NASA version of the DoD Federal USS to support routine BVLOS operations, helping bridge the gap between current operational rules and future rulemaking (e.g., Parts 108 and 146). NASA, the DoD, GrandSKY and its partners plan to conduct the Cavalier Mission with a live cargo UAS in the summer of 2025.

References

1. Borade, A., Homola, J., Rios, J., and Wolter, C., (2022) Federal Unmanned Aircraft Systems Traffic Management – Concept and Joint Evaluation with the Department of Defense, NASA Technical Memorandum, NASA/TM-20220004794, October 2022.

2. Rios, J., Smith, I., Venkatesen, P., Homola, J., Johnson, M., and Jung, J. (2019) Baseline requirements for providing USS services within the UAS Traffic Management System, NASA Technical Memorandum, NASA/TM-2019-220376.

3. Rios, J., Smith, I., and Venkatesen, P. (2019) UAS Service Supplier Framework for Authentication and Authorization. NASA Technical Memorandum, NASA/TM–2019–220364.

4. Kopardekar, P., Rios, J., Prevot, T., Johnson, M., Jung, J., and Robinson, J. (2016) Unmanned Aircraft System Traffic Management (UTM) Concept of Operations, 16th AIAA Aviation Technology, Integration, and Operations Conference, Washington, D.C., 13–17 June 2016.

5. AX Enterprize, (2023) Collaborative Low-Altitude UAS Integration Effort (CLUE III) – NASA FUSE North Dakota Test Event Final Report, 29 August 2023.

6. ASTM International. Standard Specification for UAS Traffic Management (UTM) UAS Service Supplier (USS) Interoperability, ASTM F38.02 WK63418 Working Group. https://www.astm.org/f3548-21.html [retrieved on May 28, 2024].

7. The Linux Foundation. (2022) InterUSS Platform. https://interussplatform.org/ [retrieved on May 28, 2024].

8. The Linux Foundation. (2022) DSS Github Repository. https://github.com/interuss/dss [retrieved on May 28, 2024].

9. Hardt, D. (2012) The OAuth 2.0 Authorization Framework. RFC 6749, DOI 10.17487/RFC6749, October 2012, https://www.rfc-editor.org/info/rfc6749 [retrieved on May 28, 2024].

10. Code of Federal Regulations. (2024) 14 CFR Part 107 - Small Unmanned Aircraft Systems (May 23, 2024) https://www.ecfr.gov/current/title-14/chapter-I/subchapter-F/part-107 [retrieved on May 28, 2024].

11. Borade, A., Wolter, C., Morgan Ruszkowski, L., Homola, J., Liu, P., Rios, J., Goodyear, M., Jurcak, S., and Larson, R. (2024) Federal USS Synthesis Effort: 2023 Flight Test Report, A NASA and Department of Defense Joint Evaluation of Multi-Domain Airspace Integration, NASA Technical Memorandum, NASA/TM-20240012300.

12. Federal Aviation Administration, (2023). Unmanned Aircraft Systems Traffic Management (UTM) Implementation Plan. https://www.faa.gov/sites/faa.gov/files/PL_115-254_Sec376_UAS_Traffic_Management.pdf [retrieved on October 25, 2024]

13. United States Senator for North Dakota John Hoeven. (05.28.24). Hoeven's Project ULTRA Launches Effort to Use Unmanned Aircraft to Deliver Military Cargo [Press Release]. https://www.hoeven.senate.gov/news/news-releases/hoevens-project-ultra-launches-effort-to-use-unmanned-aircraft-to-deliver-military-cargo