UAS Traffic Management (UTM) Technical Capability Level 3 (TCL3) Flight Demonstration: Concept Tests and Results

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***Abstract*—Over the course of three months in 2018, NASA, in collaboration with the six FAA UAS Test Sites and industry partners, conducted its Technical Capability Level 3 (TCL3) flight testing as part of its UAS Traffic Management (UTM) research. A set of five tests were developed to address elements of the UTM concept that involved Beyond Visual Line of Sight landings, Contingency Management, development of a Public Portal for UTM information, Sustained Operations, and Unauthorized Airspace Entry/Exit. Each of the tests were successfully performed and unique insights were gained in each of the testing areas.**

Keywords—NASA, FAA UAS Test Sites, UTM, TCL3

I. Introduction

NASA has been engaged in research focused on enabling the commercial application of small Unmanned Aircraft Systems (UAS) that is safe, scalable, equitable, and efficient. This effort falls under the UAS Traffic Management (UTM) project, which has taken the approach of defining operating environments according to their relative risks and complexity in order to scope the research into distinct Technical Capability Levels (TCL). This approach resulted in the definition of four TCLs that encompass UTM environments ranging from low density, rural operations as part of TCL1 to the high density, urban operations envisioned in TCL4 [1]. Since 2015, live flight demonstrations have been conducted as part of each TCL that highlighted the key elements of the respective capability level in terms of the concept, reference technologies, and procedures [2-5]. The TCL3 demonstration consisted of tests that were grouped according to the focus areas of the joint FAA and NASA Research Transition Team: Data Exchange Working Group (DWG), Sense and Avoid (SAA), Communications and Navigation (C&N), and the Concepts and Use Cases Working Group (CWG) [6].

The CWG is focused on the collaborative development of the UTM concept between NASA and the FAA. The tests included in TCL3 as part of the CWG -referred to as the CON tests- were intended to explore specific elements in order to inform the refinement of the UTM concept as it relates to TCL3 and the envisioned environment. This paper will describe the tests conducted as part of the CWG contribution to TCL3 and report on the results and lessons learned from those tests. For a broader overview of the overall testing, refer to [7].

II. Test Overviews

In the spring of 2018, overall TCL3 testing was conducted at six FAA UAS Test Sites. The CON tests were conducted at 5 of the 6 test sites with involvement from multiple industry partners and technologies. A total of 5 tests were constructed based on areas of focus to advance the further development of the UTM concept. The tests described below were all performed at different test sites in different combinations, which provided the opportunity for a broader understanding and assessment of the concept elements.

A. *CON 1: Beyond Visual Line-of-Sight Landing*

CON 1 focused on the performance of operations that involved landings and subsequent take-offs while Beyond Visual Line-of-Sight (BVLOS). The objective for CON 1 was to test the operation planning, procedures, and the technology needed to enable a BVLOS landing, take-off, and return to base in a variety of live environments. This test built upon previous TCL testing where BVLOS operations were conducted but landings and takeoffs while BVLOS were not required nor a focal point. The ability for operators to perform the full sequence of maneuvers covered in CON 1 while connected to a USS and exchanging data is considered an enabler for safe BVLOS operations with shared awareness available to other airspace entrants mediated by the UTM ecosystem.

B. *CON 2: Contingency Management*

The performance of CON 2 was intended to provide an understanding of the procedures and information exchanges needed in handling contingency situations within a UTM environment. The tests involved operations in which an emergency situation was injected into the scenario that necessitated the activation and announcement of a prepared contingency. As part of TCL3, changes were made to the UTM Application Programming Interface (API) that provided operators the ability to include contingency plan information with their operation submissions for reference to pre-defined plans (e.g., loiter points, landing areas). New messages were also implemented to allow operators to communicate the initiation and cancellation of contingency plan procedures to other airspace users via their supporting USS for awareness and subsequent assessment in determining required actions.

C. CON 3: UTM Public Portal

The focus of CON 3 was on the development of a browser or app-based interface for a member of the general public to access appropriate UTM information. This test provided an opportunity to explore different approaches to the development and display of UTM information and to gain insight into considerations from the public, industry, and public safety organizations on what information should be available regarding the operation of UAS in public settings.

D. CON 4: Multiple Operations for Long Durations

CON 4 consisted of a long duration scenario in which multiple interacting operations were conducted under various use cases and missions. The performance of CON 4 served as a platform for the demonstration and assessment of the ability to safely plan and conduct multiple operations in the same airspace with a sustained operational tempo. The duration of each CON 4 test was intended to last at least two hours.

E. CON 5: Unauthorized Airspace Entry/Exit

For the CON 5 tests, operators intentionally flew their vehicles out of its Operation Volume and towards controlled or otherwise unauthorized airspace in order to evaluate the procedures, interactions, and information exchanges needed in cases where a vehicle is near or within unauthorized airspace. New UTM messages were added to alert operators to their proximity to and breach of existing airspace class boundaries as well as dynamic and/or static airspace structures currently referred to as UAS Volume Reservations.

III. Test Performance

The CON tests were assigned to the test sites according to a number of considerations. Fig. 1 shows the final distribution of tests per site where broad coverage was achieved for each test to be performed in at least three instances. The testing window for the CON tests opened with CON 5 in North Dakota on March 22, 2018 and closed on May 25, 2018 in Alaska with CON 5 as well.

Test	Alaska	Nevada	New York	N Dakota	Texas	Virginia
CON1						
CON2						
CON3						
CON4						
CON5						

Fig. 1. Distribution of CON tests across TCL3 test sites

Across the five test sites, a total of 16 different types of vehicles were flown in support of the CON tests. The complement of vehicles consisted of a mix of multi-rotor, fixed wing, and hybrid configurations with varying levels of sensor equipage and capabilities. The configuration of ground control stations for those vehicles, display presentations, and operator interactions with the UTM system were not prescribed. Rather, the operational test requirements were prescribed (e.g., safe flight operations while connected to a USS and exchanging data) and the topics of information display and operator interactions were approached as research areas that were addressed by the human factors team out in the field. Refer to [8] for their overall TCL3 report.

TCL3 testing further incorporated the UTM architecture built upon the previous tests in TCL1 and TCL2 and initially defined in the concept of operations [1]. Seven distinct UAS Service Suppliers (USS) supported operations that participated in the CON tests. Each USS was connected to the USS Data Collector (UDC), which recorded all of the UTM data shared by each USS regarding operations, positions, messages, and airspace constraints. These data were also complemented by data received post-flight through the established data management plan, which consisted of, for example, data direct from the vehicles, architectural and process/procedural definitions, and off-nominal reports. Additionally, subjective data and observations were collected at each of the test sites by human factors researchers related to operator interactions and approaches to UTM integration as well as feedback on areas of the UTM concept as experienced through the tests.

Following the conclusion of the testing, an effort was undertaken to verify the data and arrive at a final set of operations and associated elements to use as a reference in performing subsequent analyses. The following results are based on the outcome of that effort complemented by debrief transcriptions, human factors results, and the final reports provided by each of the test sites.

IV. Results

A. CON 1: Beyond Visual Line-of-Sight Landing

For the CON 1 tests, the objective was to conduct operations in which the vehicle flew beyond visual line-of-sight (BVLOS) from the pilot in command, landed at least once while BVLOS, and returned to launch point. Throughout the entire operation, the vehicle was connected to a USS, which provided strategic deconfliction prior to flight and conformance monitoring primarily while in flight.

Three test sites performed CON 1, each with different environments and range capabilities. One of the participating test sites, for example, operated from an airport. At this site, the vehicle was remotely launched from inside a hangar. While inside the hangar, the vehicle used positioning data from optical flow sensors for navigation while in transit and transitioned to GPS once outside. The other sites used open fields and farmland within the confines of the test range for their missions.

Fig. 2 provides a representative example of a CON 1 mission reconstructed from position data sent to the vehicle's supporting USS. In this example, the vehicle was launched from a hillside parking lot then proceeded to transit out into an open field before making a sharp turn to head toward a small forest down range that was BVLOS from the pilot. The vehicle overflew an outcropping of the forest and performed its landing behind the trees before returning to launch. In the provided example, the vehicle flew a total enroute distance of 5,888 ft with the landing point located 2,654 ft from the launch point. Fig.3 provides another example of a long distance BVLOS flight conducted over farmland. In this example, rather than landing, the vehicles performed package deliveries at pre-defined drop points at the furthest extents of the route. The accuracy of delivery drops were assessed in lieu of landing accuracy as done at the other test sites. The flight represented in Fig. 3 involved a total enroute distance flown of 12,059 ft with a maximum distance from the launch point of 5,943 feet.

Fig. 2. BVLOS landing behind trees at a distance of 2,654 ft from launch point

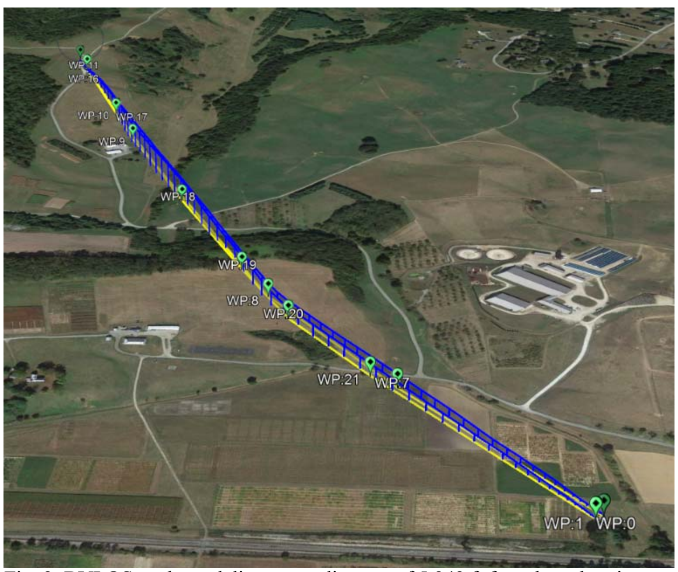

Fig. 3. BVLOS package delivery at a distance of 5,943 ft from launch point

Conducting BVLOS landings and package deliveries highlighted the importance of continuous and reliable telemetry data as well as the benefits of redundancies in Command and Control (C2) and navigation systems. Connectivity to a supporting USS throughout BVLOS operations was maintained across CON 1 operations, which was critical for the shared awareness of those operations within the UTM environment. Landings and deliveries were measure for their accuracy for select flights within the CON 1 test. For landings, there was a range of accuracies from 6 inches to 30 inches offset from the target point with issues impacting navigation accuracy theorized as the contributor to the variability. The accuracy of package deliveries were assessed by examining the location of individual packages relative to a circular drop zone with a 5 ft radius. All packages were successfully delivered within the defined zone.

B. *CON 2: Contingency Management*

The CON 2 test was designed to exercise the procedures and information exchanges involved in managing contingency situations while conducting operations as part of UTM. The impetus for this test in further developing the concept was the need for alerting airspace users via the UTM architecture of emergency situations and intent information so that others are aware of the situation and have the opportunity to react accordingly. To enable this capability, a number of additions were made to the UTM API to support the initial approach to contingency management within UTM.

At the planning stages, new fields in the Operation model allowed operators to include, as part of their operation submission, contingency plan information as pre-defined options to invoke while in flight. Items within the contingency plan included additional information such as the contingency cause (e.g., loss of C2, security incident, or conflict situation), contingency response (e.g., loiter or return to base), and related location information such as contingency point with associated position and relevant altitudes of loiter points. Contingency volumes, similar to operation volumes, were also definable and meant to be updated in real time in order to provide the operator with the ability to quickly update their volume to accommodate a contingency situation while maintaining conformance and communicating situation and intent to other airspace users. Multiple instances of contingency plan information were able to be defined and associated with each operation volume segment in order to provide adequate coverage for contingencies throughout the planned mission.

As part of the CON 2 tests, the participating test sites developed scenarios in which a simulated emergency or distress situation was injected as a test event. In response to the event, the vehicle operator was expected to communicate the initiation of a given contingency plan to the supporting USS, which would subsequently be communicated to other operations supported by that USS and other USSs as well if present. The contingency situations and test responses varied across the test sites, which provided an opportunity for broader concept exploration. Fig. 4, for example, presents a scripted situation in which an unexpected low battery state was detected for a vehicle while conducting animal survey and population count type operations. In response to the battery state, the contingency response was to perform an immediate landing aided by the deployment of a parachute on the vehicle. Fig. 4 shows one of the actual parachute deployments that occurred as part of CON 2 on the left panel, and the associated data from that event on the right. The flight profile of the operation is presented on the right panel of Fig. 4 where the point at which the parachute was deployed can be seen along with the subsequent landing trajectory. Note that the operation volume for that operation is rendered in the background to show that this contingency event was handled within its defined volume and remained within conformance.

Fig. 5 presents CON 2 as performed at another participating test site where a different focus was placed on the types of situations that could play a role in contingency management within UTM. These sets of tests involved two vehicles in which one was performing nominal operations as part of UTM through the support of its USS. The other involved vehicle played the role of intruder whereby there was no connection to a USS and the airspace was accessed without going through the steps of strategic deconfliction and communication with the UTM network. However, the telemetry data of the intruder vehicle was captured in real time and treated as sensor data for the detection of the vehicle locally and visualization of the operation remotely mediated by ingestion of that data through UTM endpoints. Fig. 5 presents a variety of information that capture the breadth of what was covered in the CON 2 approach just described. The participating UTM vehicle is shown within the bounds of its operation volume (the orange box) reporting positions that are displayed as white dots. A yellow dot is visible to the right of the vehicle, which represented the current reported position of the intruder vehicle. The blue message box in the upper portion of Fig. 5 shows that the "contingency_plan_initiated" message was sent and received by the USS and available for other UTM participants to see.

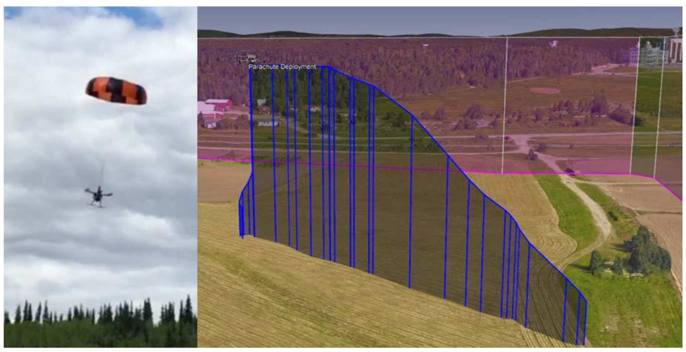

Fig. 4. Parachute deployment as part of contingency response (left) and associated flight profile and operation volume data (right)

Fig. 5. Cooperative UTM operation in the presence of an intruder aircraft that resulted in the initiation of contingency plan

Feedback from test participants during debrief discussions and through survey responses provided insight into the issues and considerations as experienced through participation in CON 2. At a high level, it was agreed that alerting is an important function during a contingency event. However, the required reliability, accuracy, and latency of alerting to conflicts and contingencies needs continued evaluation. For manually controlled operations, the approach to contingency management reflected in CON 2 might be difficult to implement and use due to ensuring safety of flight before interacting with the UTM system and pre-planning contingencies. Also, each contingency situation is unique, which may not lend itself to taking advantage of the approach taken for pre-planned responses. However, for the purposes of autonomous flights, contingency management as performed in CON 2 might be an appropriate approach for publishing intent to the UTM environment. With regard to what information is needed for actionable situation awareness by other airspace participants, it was reported that desired information consisted of the position of vehicle in distress, its altitude, heading, velocity, flight trend, position history, aircraft type, and distance from ownship. The nature of the emergency that necessitated the contingency response was considered unnecessary. It was also reported that as with any type of alerting, the frequency, saliency, and validity of alerts all impact the effectiveness.

C. CON 3: UTM Public Portal

CON 3 involved the design and development of an application intended to provide public users access to UTM information. One of the main objectives of the test was to understand the needs and concerns of the general public as well as public safety and other stakeholders with regard to UAS operations and how a platform such as the Public Portal could be designed to address those concerns.

Four of the test sites participated in CON 3. A total of five Public Portal prototypes were developed by industry partners across the test sites, each with their own unique designs and approaches. An additional portal was developed internally at NASA Ames that leveraged existing interfaces and tailored for CON 3. Fig. 6 presents a collection of screenshots from the interfaces that were developed where it can be seen that there was variability in the design approaches.

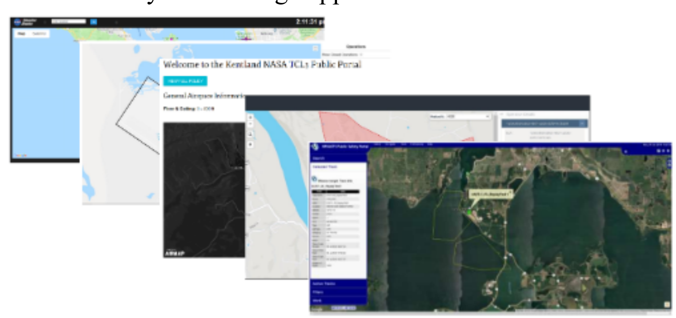

Fig. 6. UTM Public Portals developed by Industry partners and NASA to support CON 3

The design requirements were not prescribed to the participating partners. The intent, rather, was to allow the partners freedom to approach the development independently. While all of the portals included a base version intended for general use, three of the interfaces included a public safety version for testing with relevant personnel. As the CON 3 window opened, a reference guide was sent to all of the participants that detailed the expectations and required deliverables in terms of reporting and testing with users. As each of the Public Portals were complete, participants were brought in to take part in usability tests and discussions. For the usability tests, a number of simple tasks were administered that were designed to exercise different functionalities of the portal and present opportunities for the user to think about what types of information are important for them given their background and perspectives.

With respect to usability, a total of 16 participants completed the tests and associated survey. General satisfaction of the portals was rated fairly high across portals with average ratings on a 7-point scale (with 7 representing ‘Very Satisfied’) ranging from 4.67 to 5.75. Some common feedback that likely impacted satisfaction and usability ratings were related to difficulties in information access and issues with responsiveness and lag experienced with the interface.

In addition to usability aspects of the Public Portal, participants were also asked questions that were more fundamental to the UTM concept related to transparency and accessibility of information. Through the responses of the participants, an overarching theme emerged: desire for knowing more about the flight’s purpose and the operator. For example, in response to the question, “What types of information do you think would be most valuable?,” one response was:

- Ownership, make, model

- Who, what, where, why

- Payload type (is a camera on board)

- Type of operations (individual/hobby or commercial)

- IFR/flight plan (if applicable)

The provided response was frequently echoed in various forms across the participating test sites. It should be noted, however, that there were concerns by some participants regarding the sharing of certain data related to identity and contact information. However, there was general agreement that there should be different levels of information access depending on the user’s role or position. For example, an indicative response to the question, “What data should be available for Public vs Public Safety?,” was: “GCS location, Contact Information on Public Safety Portal and not on general public portal (analogy to license plates).” There was also a pattern of opinion that information should not be publicly available that could impact general safety or missions in support of public safety.

In parallel with the CON 3 tests, an effort was also initiated at NASA Ames Research Center to engage with the general public, government, industry, and public safety entities regarding UTM and the areas addressed in CON 3. A number of focus group sessions were held for demonstrations as well as discussions on topics relevant for the group demographics. A total of 31 individuals participated in these discussions and the outcomes of those focus group sessions can be found in [9]. Usability tests more directly in line with CON 3 were also conducted using a Public Portal that was developed within the Airspace Operations Laboratory. Eleven individuals participated in these local CON 3 studies and the results will be included in a forthcoming publication. Fig. 7 provides examples of participants in the laboratory studies. The findings of that study were in general alignment with what was observed more broadly in CON 3.

Fig. 7. Participants of the CON 3 Public Portal studies at NASA Ames Research Center

D. *CON 4: Multiple Operations for Long Durations*

In the TCL3 demonstration, tests were designed to more specifically address a particular research area within UTM. CON 4 was unique among the tests as it more broadly sought to assess the abilities of operators to perform a variety of interactive operations that, at a higher level, provided an opportunity to observe the performance and capabilities involved in achieving and sustaining an operational tempo over longer durations of time. While most tests in TCL3 did not last much longer than the battery life of individual vehicles, CON 4 had a minimum duration of two hours with longer times encouraged.

Due to the longer duration of these tests and the intended interactions between operations, there was an opportunity to perform other tests in conjunction with CON 4. Many of the other CON tests were performed within the CON 4 umbrella as well as others from the data exchange tests such as USS Failover and USS-to-USS Negotiations. Conflict situations and contingency events were also incorporated in CON 4 tests across the test sites. The types of missions flown varied and included package deliveries, surveys, search and rescue, photogrammetry missions, surveillance and mapping, precision agriculture, and animal counts. CON 4 was conducted at four test sites over a combined seven days of testing.

Each of the test sites took a different approach and focus in their performance of CON 4. One representative example can be seen in Figs. 8 and 9, which represents a day in which there were more than 3 hours of operations with 80 flights that performed different missions in a complex operational environment. One of the key elements in this example was the management of airspace and the ability to provide strategic deconfliction for multiple operations across multiple USS through data exchanges. Fig. 8 presents the full complement of operations and their volumes that were successfully deconflicted between two USSs. The colors of the volumes shown in Fig. 8 map to the USS that supported the operations such that blue volumes represent operations supported by one of the USS and the purple volumes map to the other. From this figure, it can be seen that there were many interacting operations involving different flight profiles and mission types that required well-defined procedures for ensuring strategic deconfliction between USSs. Fig. 9 presents a zoomed in view of what is presented in Fig. 8 that focuses on the operations supported by one USS where the complexity of volumes and demand focused in localized airspace was quite high.

Fig. 8. Full set of Operation Volumes supported by two USSs as part of one CON 4 iteration

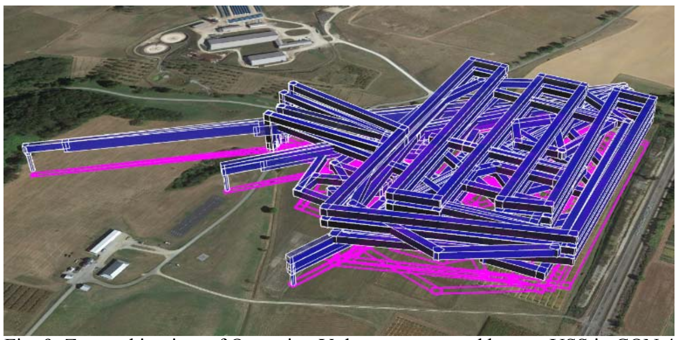

Fig. 9. Zoomed in view of Operation Volumes supported by one USS in CON 4

Across the test sites and throughout the CON 4 testing window, multiple hours of operations were successfully performed under a variety of conditions and with the integration of a number of targeted tests. The ability for multiple USS to provide strategic deconfliction as observed in CON 4 and exemplified in Fig. 8 demonstrated the viability of USS to USS communications and laid the foundations for achieving high density operations envisioned in environments such as those described as part of TCL4. In addition to USS to USS communications, the application of segmented Operation Volumes and ability for altitude stratification was noted to be of strong value in reducing congestion and more effectively managing the airspace to safely enable higher levels of complexity and density. Relatedly, CON 4 also incorporated the concept of shared airspace in which multiple vehicles were able to enter the same volume of airspace to perform cooperative missions.

E. CON 5: Unauthorized Airspace Entry/Exit

The CON 5 test assessed the ability for USSs to provide alerting to operators regarding their proximity to or position within airspace that the operation is not authorized access. This test also exercised the functionality for a USS to establish airspace structures referred to as UAS Volume Reservations (UVR). In CON 5, UVRs were either established prior to commencement of a given run to serve as a static structure within the airspace, or activated within the testing area while operations were already underway. Traditional airspace boundaries were also utilized as part of the tests (e.g., Class E airspace). Fig. 10 presents a collection of these airspace structures that were used as part of CON 5 testing at one of the three participating test sites.

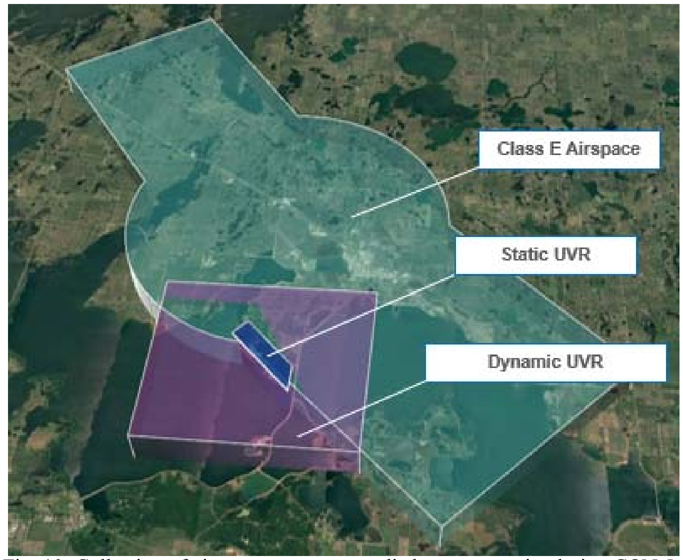

Fig. 10. Collection of airspace structures applied at one test site during CON 5 testing

Regardless of the type of airspace structure used, the USS functionality developed in support of CON 5 involved a phased alerting scheme in which an operator, via the supporting USS, first received an airspace proximity warning message when the vehicle was within a prescribed distance to the defined airspace. As an initial approach, the decision was made to set the distance at which the airspace proximity warning message was sent to the operator when the vehicle was within 3038 ft (~0.5 nautical miles) of the airspace boundary. If a vehicle breached the bounds of the unauthorized airspace, an unauthorized airspace entry message was sent to the operator, alerting them to the status of the operation. Standard conformance monitoring protocols were also in place that first alerted the operator to Non-conforming and Rogue UTM states when vehicles approached and exceeded the outer bounds of its Operation Volume. In certain iterations of CON 5, vehicles were intentionally diverted to exit the Operation Volume and subsequently approach and enter the identified airspace as part of the testing protocol. Fig. 11 provides an example of the alert messages sent to two operations where the yellow dots represent the positions where airspace proximity warning messages were sent by the USS to the operators, and the red dots represent where the operators were sent unauthorized airspace entry messages.

Fig. 11. Airspace proximity (yellow) and entry messages (red) sent in CON 5

Although the distance to airspace boundary was prescribed with regard to triggering the appropriate alert message to send, the frequency at which the messages were sent was not prescribed. This was by design and viewed as an open research question that CON 5 could provide a window into possible answers. Of the USSs involved, two differing approaches were taken with respect to the alert messages. One approach was to send the proximity or entry message every 30 seconds while the triggering conditions still applied. The other approach was to only send the relevant message upon a change in status (e.g., once when within the proximity distance and once when the airspace was breached). Debrief discussions held with participants at each of the sites resulted in a general debate as to what the most appropriate approach should be to alerting for airspace interactions. While there was consensus on the value of the alerts, a clear consensus was not reached with regard to the timing and parameters set for where and when the alerts are sent. There was, however, concern for the danger of over alerting if the messages are sent too often. Refer to the CON 5 section of [8] for a more in-depth discussion of the issue.

In addition to the implementation of UVRs and the proximity/entry messages discussed thus far, there were additional advances that were brought forward to test as part of CON 5 by the industry partners. One example can be seen in Fig. 12 where the concept of dynamic operation updates were performed as a means of remaining in conformance. In this case, the vehicle was initially nearing the outer bounds of its Operation Volume and on trajectory to continue outside, which would result in a state transition to Rogue status. To avoid that situation, the operation updates were dynamically made to contain the vehicle along its trajectory in order to remain in conformance and provide some level of intent information to the UTM system. The capability to allow selective access for priority operations was also successfully demonstrated as part of CON 5.

Fig. 12. Dynamic Operation Volume updates to remain in conformance

A final example to present for the CON 5 tests can be seen in Fig. 13 where a dynamic UVR was established via USS to which all affected operations responded to clear the airspace. In this example, live flights were initially taking place and performing their assigned missions. Simulated operations were also injected into the environment from the Airspace Operations Laboratory at NASA Ames Research Center. Once all operations were fully in progress, a dynamic UVR was established in the airspace (denoted by the blue box in Fig. 13). Once the UVR was established, the appropriate alert messages were sent to all affected operators, which was followed by return to launch procedures to clear the UVR of active operations. All live and simulated flights were able to successfully return to their launch locations and close their UTM operation. This particular test iteration demonstrated the integration of live and simulated UTM operations, dynamic UVRs and messaging, as well as the procedures necessary to respond to such airspace structures.

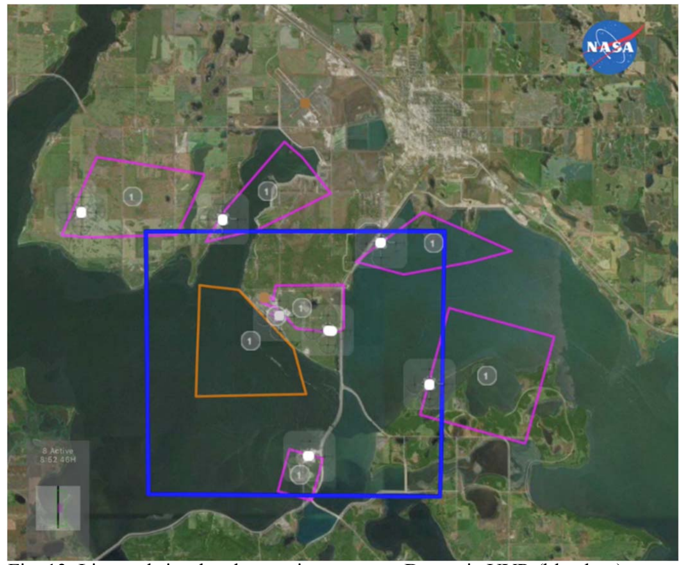

Fig. 13. Live and simulated operations react to Dynamic UVR (blue box)

Through debrief discussions following tests that involved dynamic UVRs, one issue emerged regarding its implementation in CON 5. The approach taken in this testing was for a UVR to be active as soon as the message was sent. This meant that all operations within the UVR that was just activated were immediately sent unauthorized airspace entry messages without having time to plan and react. Feedback from participants was that there should be some lead time to allow operators to plan an appropriate response to clearing the UVR that accounts for the various factors that need to be considered such as battery remaining or optimal routing.

SUMMARY

The UTM TCL3 flight demonstration was conducted in the spring of 2018 and focused on targeted tests in the topic areas of Data Exchange, Communications and Navigation, Sense and Avoid, and Concepts and Use Cases. Under the umbrella of the Concepts and Use Cases research thrust, five tests -referred to as the CON tests- were developed to exercise the capabilities, procedures, and interactions needed for BVLOS landings and launches (CON 1), contingency management within the UTM construct (CON 2), access to UTM information via a Public Portal (CON 3), sustained UTM operations over a prolonged period of time (CON 4), and alerting based on proximity and breach of unauthorized airspace (CON 5). These tests were performed at five different test sites and in different combinations, which resulted in a variety of approaches to the tests and unique environments in which to conduct them.

Seventeen tests were conducted in total in which multiple vehicles and vehicle types were flown in an environment in which multiple UAS Service Suppliers were supporting operations and providing the basis for information exchanges between the UTM system and individual operators. Many different types of missions were flown as part of an integrated storyline for the tests, each with unique flight profiles and associated Operation Volumes.

Each of the CON tests was successfully completed, which provided valuable insight into the underlying concept elements. Through the execution of multiple operations that included landing and launch phases as well as package deliveries while BVLOS, the importance of consistent and dependable communications and navigation systems with redundant features was made clear in order to ensure operational conformance and situation awareness for other airspace users. The ability to pre-define and enact contingency management procedures with appropriate messaging in response to simulated emergency and distress situations through the UTM system was also demonstrated. This capability becomes more important as operations reach higher densities in more complex environments such as those envisioned as part of TCL4. Multiple Public Portal prototypes were developed to explore the usability and information access considerations from user groups such as the general public and public safety entities. Important topics emerged regarding the balance between privacy and transparency in UTM that will be a continued area of research and discussion. Across the participating test sites, multiple interacting UTM operations were conducted and sustained over long durations. The importance of airspace negotiation and efficiency of use were common themes that emerged as a result. Finally, the establishment of UVRs with associated operator alerting to proximity and entry of the defined airspace was successfully integrated and tested. This test provided an opportunity to assess the key considerations in the management of airspace as part of UTM.

BEYOND TCL3

The results and lessons learned from TCL3 provided valuable input and laid a strong foundation for the research planned beyond TCL3. Following the research path laid out at the outset of NASA's UTM project, TCL4 is the next and final TCL to be addressed. TCL4 addresses high density UTM operations in a complex urban environment. Elements initially addressed in TCL3 will be further examined to understand the key considerations related to topic areas such as contingency management, USS negotiations, UVRs and priority operations, Remote ID, and many more, to understand how the interactions and operational environment change as higher densities and more complexities are realized. Fig. 14 presents TCL4 operations as they are being conducted at the Reno, NV test range. Testing will also be conducted in Corpus Christi, TX. Results from the TCL4 demonstration will be contained in forthcoming publications.

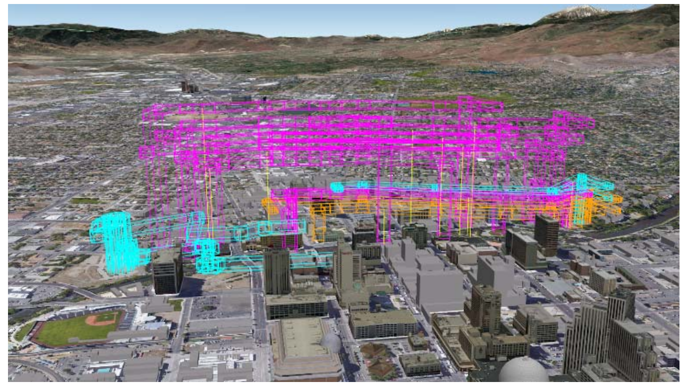

Fig. 14. TCL4 operations conducted in Reno, NV

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