NASA/TM–2019–220336

Use of UAS Reports (UREPs) during TCL3 Field Testing

Joseph L. Rios
Ames Research Center, Moffett Field, California

Lynne Martin
Ames Research Center, Moffett Field, California

Joey Mercer
Ames Research Center, Moffett Field, California

July 2019

NASA STI Program ... in Profile

NASA/TM–2019–220336

Use of UAS Reports (UREPs) during TCL3 Field Testing

Joseph L. Rios
Ames Research Center, Moffett Field, California

Lynne Martin
Ames Research Center, Moffett Field, California

Joey Mercer
Ames Research Center, Moffett Field, California

National Aeronautics
and Space Administration

Ames Research Center
Moffett Field, California 94035-1000

July 2019

This report is available in electronic form at

https://www.sti.nasa.gov

1. Executive Summary

During the NASA Unmanned Aircraft System (UAS) Traffic Management (UTM) Project's Technical Capability Level 3 (TCL3) demonstration, a service for stakeholders to share weather and aircraft observations was tested. The overall goal was to increase awareness of airspace and weather activity to increase a pilot's ability to fly safely. To achieve this goal, a mechanism to share data was created, called "UAS Reports" or UREPs, which were generated by client systems and sent to a central data service. The data service provided subscriptions and allowed for data requests to share the reports that had been sent in by stakeholders.

To execute this functionality, four FAA-designated UAS test sites performed UREP testing as part of TCL3. NASA provided the centralized service and test site partners flew missions and simulated activity at the test sites to generate data to send to the service. The loop was closed by having other clients (usually other small UAS operators) request those data from the service or subscribe to feeds from the service.

Overall, the tests demonstrated the utility of such a service. In this report, the testing setup, data collection, and analysis of results are presented. The concept of UREPs has since been incorporated as a service within NASA's Conflict Mitigation Model for UTM. The concept will continue to be tested in NASA's TCL4 activities.

2. Background

For a comprehensive overview on the UTM concept and NASA's efforts to develop it in partnership with the Federal Aviation Administration (FAA), the NASA UTM Project currently has a document repository [NASA 2018b] that contains documentation of many UTM R&D capabilities. In terms of singular references, the two Concept of Operations papers, one from NASA in 2016 [Kopardekar 2016] and one from the FAA in 2018 [FAA 2018], are the best current options for gaining an initial understanding of UTM.

At a high level, UTM is focused on access to the low-altitude airspace for beyond visual line-of-sight (BVLOS), commercial, sUAS operations. Prior to UTM, such access had been governed by lengthy, one-off applications for waivers or was limited to restricted airspace (the exception being the UTM-based service known as "LAANC" described below). To make widespread sUAS operations safe, fair, efficient, and routine, a set of services to manage the airspace will be required. The functional decomposition of these services, in terms of which stakeholders provide which services, is an open research question. The major drivers of these questions come from the scale of operations (potentially orders of magnitude more than current manned operations [FAA 2018b]) and the automation envisioned to support that scale. As an illustrative example, flight planning services will likely be an operator function, authorization to access the airspace will likely belong to the air navigation service provider (ANSP), communication of the operation with other stakeholders would rely on the UAS Service Supplier (USS), and some conflict management services may reside with the vehicle itself. Injecting manual processes throughout this collection of services could degrade the overall effectiveness of the system, especially in regard to scalability.

The NASA UTM Project has provided initial insights into how such an architecture should look in the future [Kopardekar 2016]. The overall architecture (evolved from [Kopardekar 2016]) is shown in Figure 1 below. The Project has also provided inspiration and guidance for systems already providing services to sUAS that did not exist prior to NASA's efforts. The primary example is the FAA's Low Altitude Authorization and Notification Capability (LAANC), which "provides access to controlled airspace near airports through near real-time processing of airspace authorizations below approved altitudes in controlled airspace" [LAANC, 2018].

A key component of the UTM architecture are UAS Service Suppliers (USSs). A USS is a state-appointed or third party operated system that will provide service options that are similar to those which are traditionally offered to manned operations solely by a state-appointed ANSP. USSs are components that do not have an exact analogy in manned aviation, but are inspired by elements such as Airline Operations Centers and Flight Service Stations. One of the key differences between those examples and a USS is the set of responsibilities and capabilities envisioned for a USS. Services provided by a USS will include strategic deconfliction of operations, and conformance monitoring of live operations, amongst others. Many of these services are to be provided in a collaborative and mostly automated manner via communications between USSs, forming what is termed a USS Network. In UTM, there will not be a central authority providing guidance in every traffic management decision, as there typically exists in today's manned aviation system.

To ensure compatibility and interoperability for USSs, NASA has developed a set of Application Programming Interfaces (APIs) and protocols for exchanging data [NASA 2018]. These APIs describe many of the connections in Figure 1.

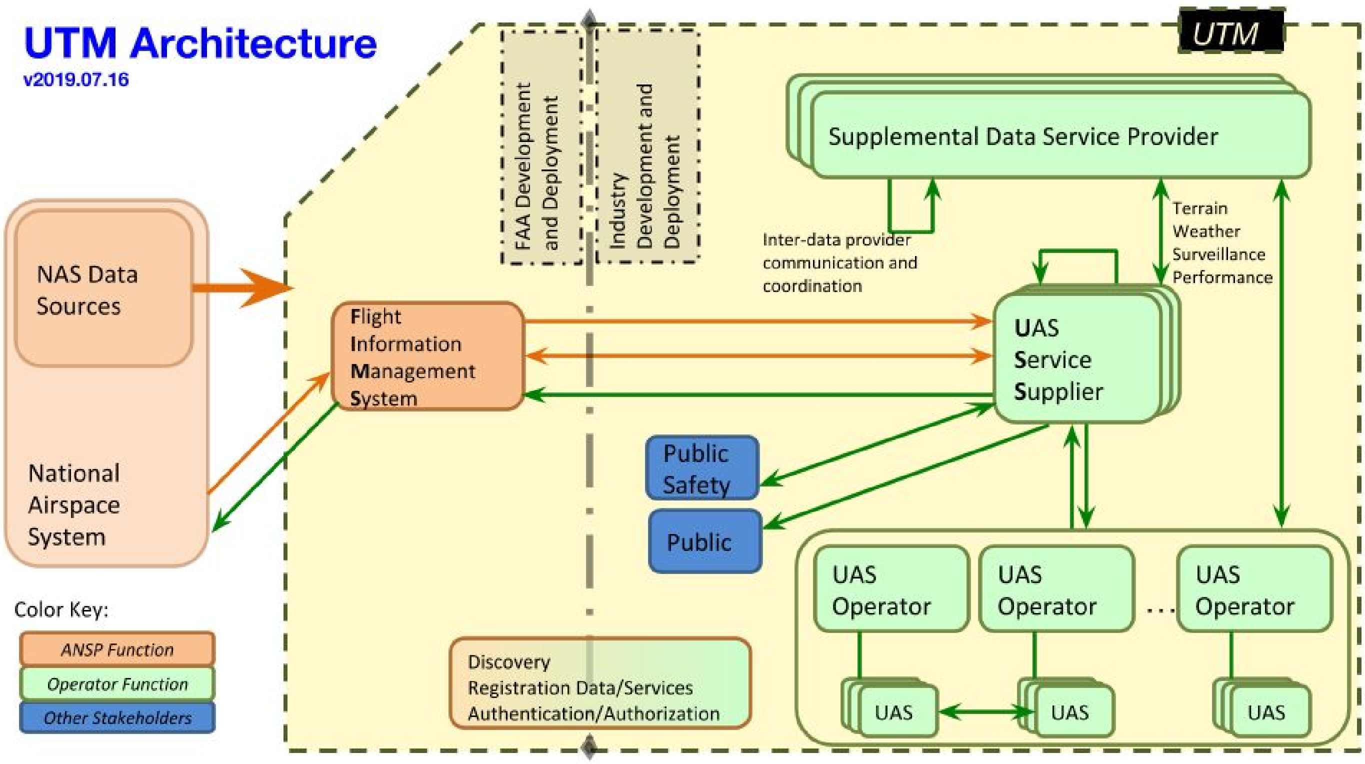

Figure 1. UTM architecture.

3. UREP Service Implementation

For TCL3, NASA implemented the UREP service. This implementation followed well-established REST (Representational State Transfer) principles [Fielding 2000][Fowler 2010] with a server implemented in Java, running on a cloud-based server (Amazon Web

Services), backed by a relational database system (RDBMS), using Postgres with PostGIS extensions. PostGIS provides geospatial data and query capabilities to Postgres. This enables clean implementation of queries such as “select all data within 1000 meters of this point.”

The REST Application Programming Interface was defined using OpenAPI Specification 2.0 [OpenAPI 2017] and was provided to all USSs that needed to interface with the service. The endpoints were simple HTTP GET and PUT calls with UREP data being exchanged. The data model, also defined in the OpenAPI Specification, is tightly modeled on Pilot Report (PIREP) data exchanges [FAA 2017]. UREPs add a feature to report aircraft sightings, which PIREPs do not allow. These are called “point outs” within UREPs. Information about aviation activity at low altitude is not often readily available by any other means. For more detail on the development and definition of the data model, the initial paper on UREPs is the sole resource as of this writing [Rios 2017]. The architecture as deployed for TCL3 also offered a data subscription service so that any new data sent to the UREP service would be provided back out to all subscribing USSs. This subscription feature was implemented using The Simple Text Oriented Messaging Protocol [STOMP 2018].

As an example of a weather-related UREP, Figure 2 illustrates a sample UREP collected during TCL3 testing. This sample is from the North Dakota test site with data collection via a ground weather station. The ground weather station collected temperature and wind data and submitted it to the UREP service at regular intervals. Note that depending on the report, elements are optionally submitted, hence the various ‘null’ values in the example. This weather station, for example, did not collect visibility information.


```
{
 "time_submitted":"2018-05-25T16:25:04.018",
 "user_id":"uss_name",
 "source":"GROUND_SENSOR",
 "time_measured":"2018-05-25T16:24:18",
 "location":
    {"type":"Point",
     "coordinates":[-98.9251631,48.0606731]
    },
 "altitude":1470.09999999999991,
 "turbulence_intensity":"NEG",
 "air_temperature":5.59999999999999964,
 "icing_intensity":null,
 "icing_type":null,
 "visibility":null,
 "weather":null,
 "weather_intensity":null,
 "wind_speed":3,
 "wind_direction":84,
 "proximity":null,
 "aircraft_sighting":null,
 "remarks":null
}
```


Figure 2. Example Weather UREP.

The UREP service is protected from unauthorized access via the same authorization mechanism used within UTM. Data are provided voluntarily by operators in the UTM concept and are not verified for quality[1]. This is analogous to today's PIREP system. Only USSs are allowed to write data to the UREP service. To do so, the USS obtains an access token from the FIMS authorization server, and then provides that token to the UREP service when writing data. The UREP service is able to verify that the token is valid and then accepts the supplied data. The high-level architecture is illustrated in Figure 3.

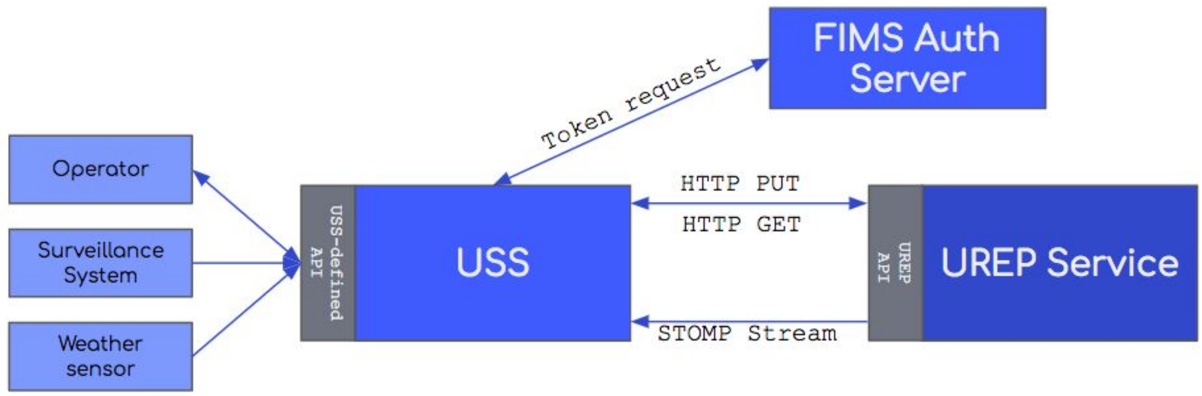

Figure 3. High-level UREP architecture.

4. TCL3 Testing

Four of the six FAA Test Sites tested UREP functionality and were instructed to test the concept of UREPs from end-to-end. This meant UREPs passed from the collection of the observation data (weather or aircraft sightings), through a USS interface, to the UREP service, and back out through a USS to a stakeholder, which was typically a sUAS operator (see Figure 3). Each Test Site's specific implementation strategy is described below.

4.1 Nevada Implementation

Nevada emphasized manual entry of UREPs by operators during an operation. The submission of the data was through a form provided by one of three USSs: Amazon Prime Air, AiRXOS, and ANRA. In general, this demonstrated the interoperability of the specification through three implementations at the same test site. In addition, it provided good insight into the workload placed on operators to enter data while operating a mission. The full loop for UREP data was not closed since operators did not fetch UREPs from the service.

4.2 North Dakota Implementation

North Dakota emphasized automated collection and submission of data. Data for both weather and airspace activity were established and connected to a USS.

A commercial off-the-shelf weather sensor was used to collect temperature and wind data. These data were submitted to a USS implemented by Simulyze for further submission to the

[1] In future enhancements, a completely digital system for UREPs would be more amenable to automated quality controls and confidence in the data. This is not explored in the current concept.

UREP service. From there, Simulyze queried the UREP service and provided the UREP data to operators to assess the utility to those operators. The weather station was positioned at Camp Grafton in North Dakota (see Figure 4).

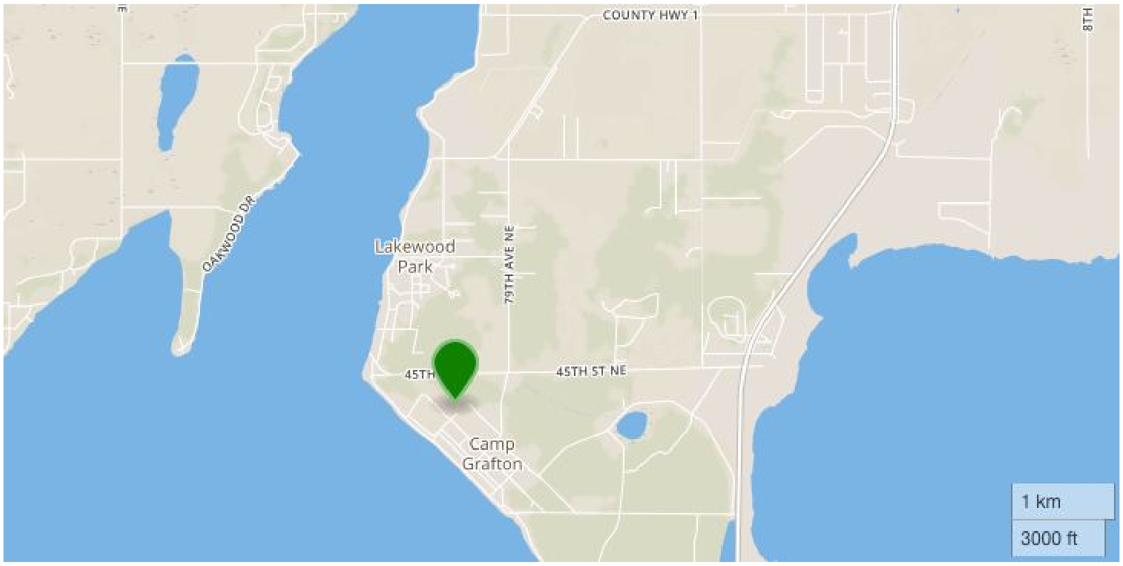

Figure 4. Weather station placement for North Dakota flight tests.

For airspace data, the Test Site utilized multiple ADS-B receivers located on the range as well as data feeds from Harris Corporation for additional ADS-B and radar data. The various sources were aggregated and correlated into an integrated surveillance data set. Aircraft that were near TCL3 operations were automatically reported to the UREP service at 30 second intervals [ND 2018]. In addition, vehicles that were identified through the UTM Remote ID implementation were pushed into the UREP system as a “point out” (see [Rios 2017] for more details on point outs within UREPs). For more information on Remote ID testing in TCL3, refer to Ishihara [2019]. Manual submission of UREP data was enabled through the operator client of the Simulyze USS.

For illustration, all of the UREPs for a 67-minute period on 17 April 2018 are displayed in Figure 5. The positions are color-coded for illustrative purposes only, with the cyan markers indicating traffic near Devils Lake Regional Airport (almost certainly manned traffic) and the pink markers indicating traffic near Camp Grafton (almost certainly UAS traffic associated with TCL3). The live system deployed by Simulyze indicating aircraft via UREPs, as well as current UTM operations and their operation volumes, are shown in Figure 7.

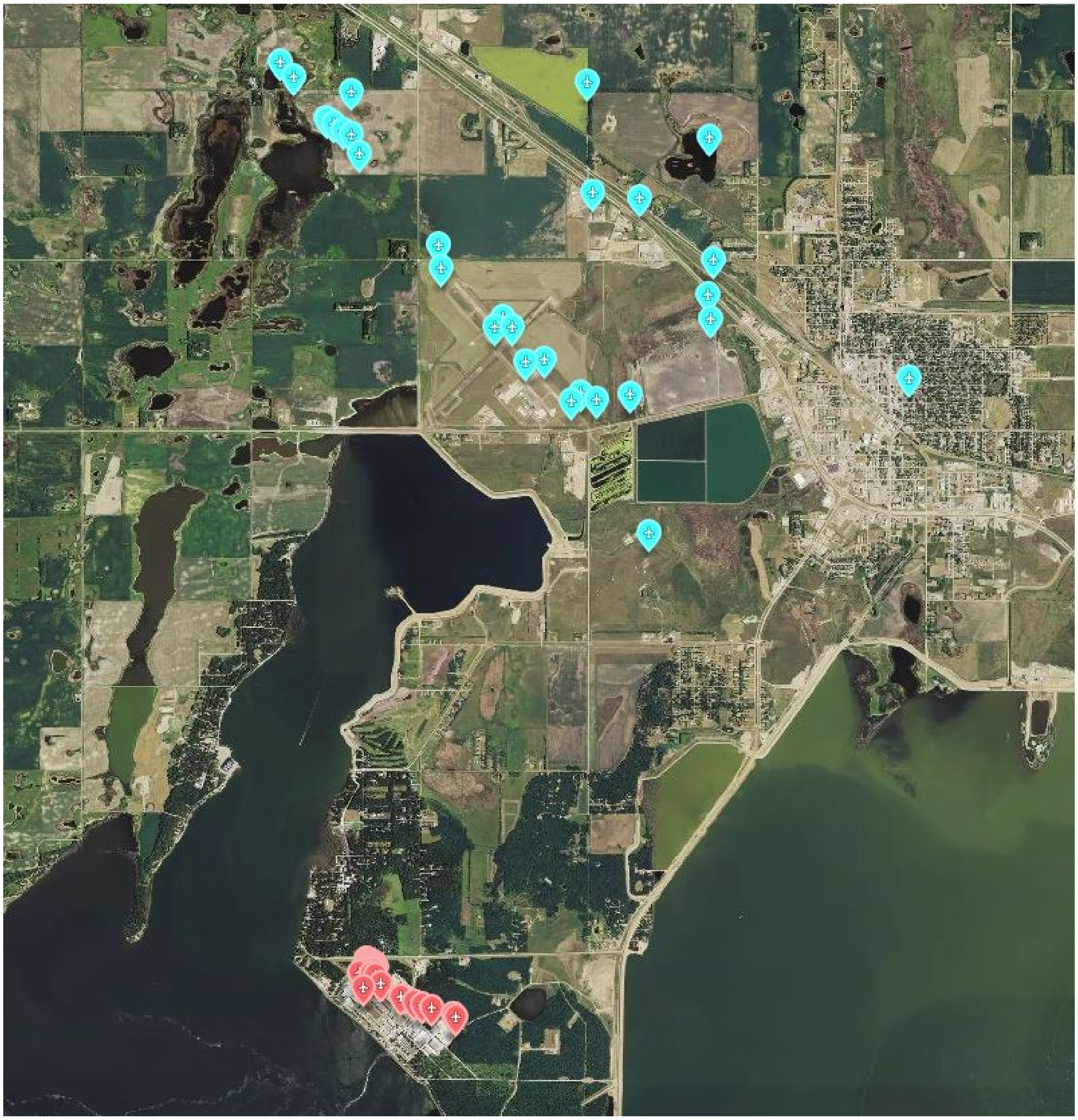

Figure 5. Auto-submitted Point-Out UREPs during 1+ hours of testing in North Dakota.

While Alaska did not officially run UREP testing for TCL3, Simulyze deployed their UREP infrastructure for Alaska's TCL3 testing. Thus similar data from AK are used in the overall analysis presented in Section 5.

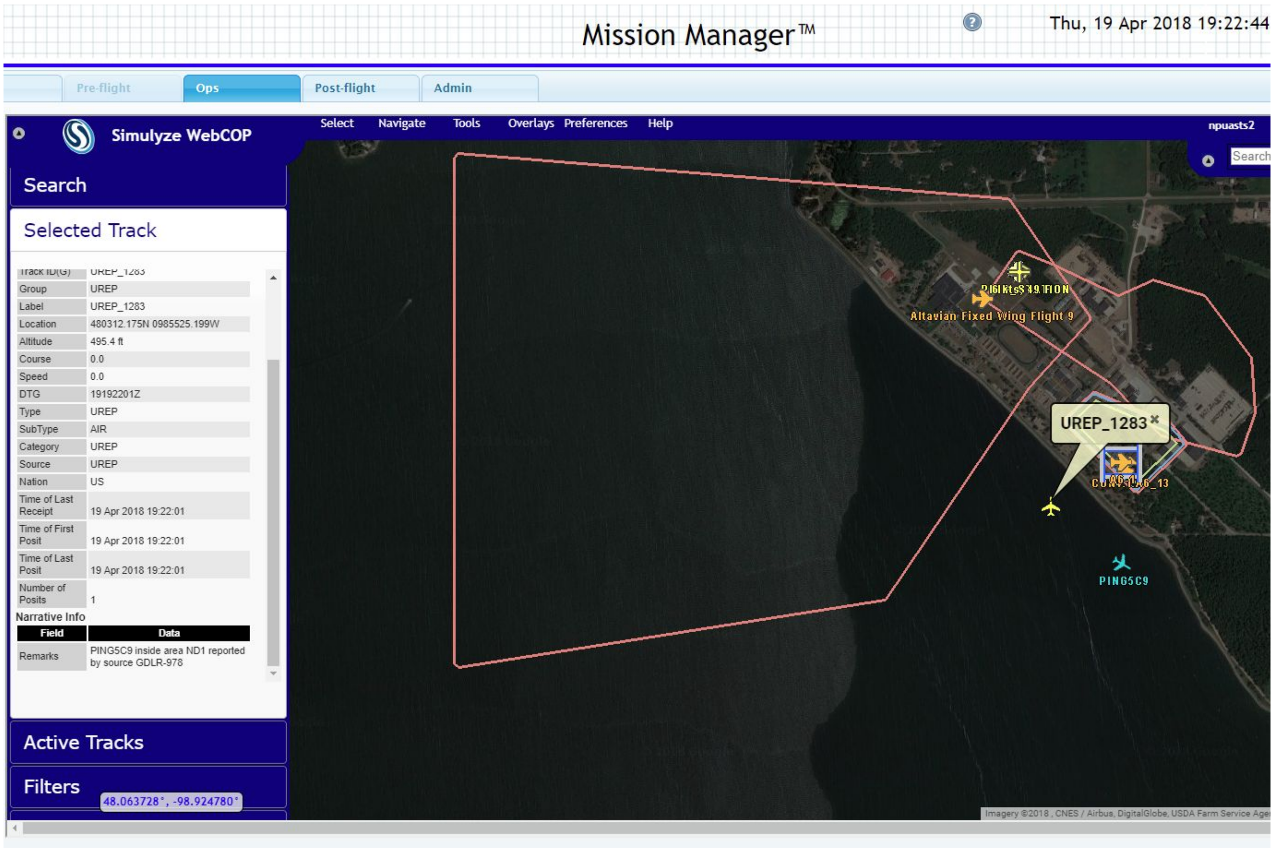

Figure 6. UREP interface deployed by Simulyze for use by UAS operators in TCL3

4.3 Texas Implementation

The Texas Test Site focused on the use of UREPs to allow USSs to share airspace data between operators. An operator with a USS in the air would simulate the sighting of a manned operation at low altitude. In this situation, the operator would immediately land (within visual line-of-sight (VLOS) of the pilot-in-command) and then file an aircraft sighting UREP by manually entering data via an interface to the AiRXOS USS implementation. Another sUAS operator in a nearby location, but out of physical contact with the first operator, would receive that aircraft sighting UREP and return to launch. This second operator was using the services of the Lonestar USS implementation.

Figure 7 provides a concrete example of the testing at Texas. The two operations are indicated by their submitted operation volumes. The manned aircraft is indicated by the red marker. Note that there was no actual manned flight, so the position is notional. The tracks for the small UAS flights are indicated within their respective volumes. The two ground control stations are indicated by the color-coded markers (yellow and blue) matching their respectively colored operation volumes (for more information on how UAS operations are defined in UTM see [NASA 2018]).

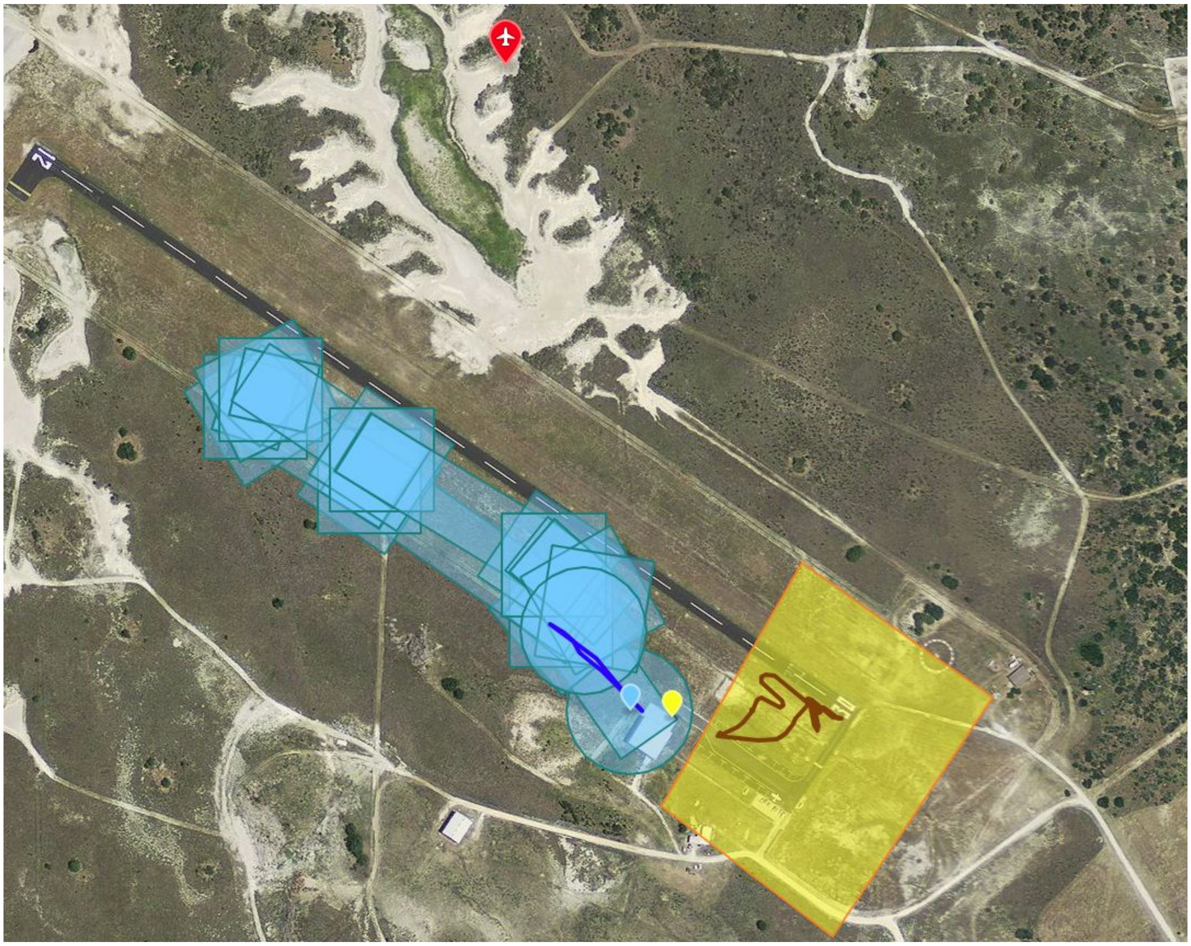

Figure 7. UREP Test data collected from the Texas Test Site.

The timeline of this test is provided in Table 1. The times describe the key operation messaging together with the UREP timings. Missing times are those that were not clocked during the test, but are known to have occurred in the specified order. Operations are identified by their call signs during the test, in Table 1 the operations are “X” and “LONESTAR”.

Table 1. Details of Single UREP Test at Texas

Time	Activity
–	Test Begins
2018-04-19 17:20:18.836	Operation "X" accepted
2018-04-19 17:22:17.994	Operation "LONESTAR" accepted
2018-04-19 17:25:02.920	Operation "LONESTAR" first position report
2018-04-19 17:25:21.149	Operation "X" first position report
–	Operation "LONESTAR" sights manned aircraft in vicinity
–	Operation "LONESTAR" lands

2018-04-19 17:27:07.325	Operation "LONESTAR" submits Point Out UREP
2018-04-19 17:27:08.038	Point Out UREP received by UREP server
2018-04-19 17:28:35.763	Operation "LONESTAR" closed message
–	Operation "X" receives UREP from UREP server
–	Operation "X" lands
2018-04-19 17:30:22.124	Operation "X" closed

4.4 Virginia Implementation

The Virginia Test Site focused on the manual entry of UREPs (both weather and aircraft sightings). Observers on the ground would make a reading from a weather station or observe an operation and make a manual entry via an interface to the ANRA USS implementation. The data from that submission was then accessed by another USS to demonstrate the end-to-end functionality. A sample of the interface developed by ANRA is provided in Figure 8.

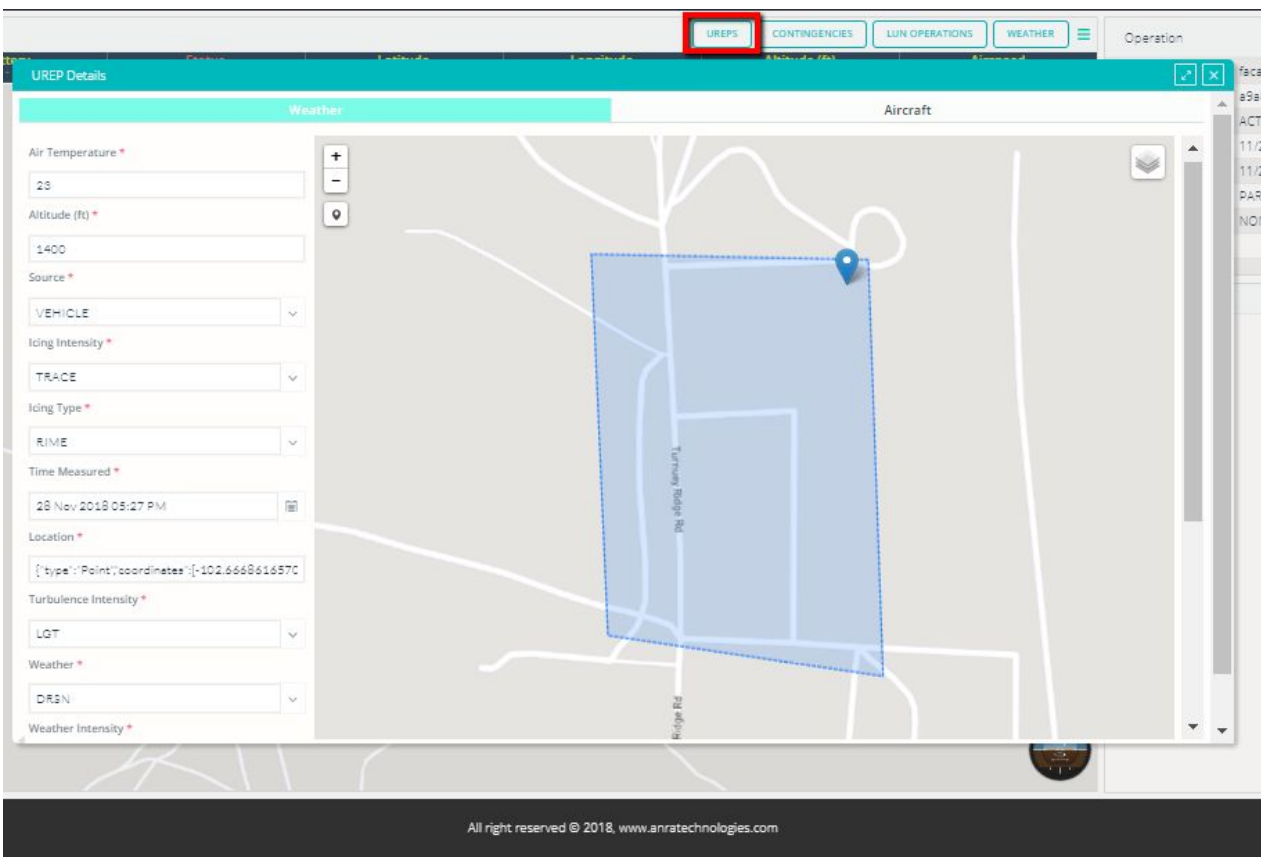

Figure 8. UREP interface as implemented on ANRA's operator platform.

4.5 Human Factors Data Collection

In addition to the UREP logs, test participants were asked for their perspective on using UREPs, during TCL3, in two ways: (1) through an end of day survey and (2) through a series of group debriefs. The survey asked respondents 19 questions about their general test experience and thoughts on using UREPs. Many of these questions asked for a rating on a 1-7 scale, where 7 was high, or positive, and 1 was low, or negative. Other question types were multiple choice and free-response. Twenty six surveys were started by participants in total across three sites. (As test sites often combined tests in their operations and were only required to complete one survey per day, survey data was not collected for all the TCL3 flight tests that test sites performed.) There were also five debriefs, attended by a group of flight crew and field personnel, during which the processes of generating and receiving UREPs through UTM were discussed. The prompts themselves varied, as researchers wanted crews to discuss and explore the topics within the time available. Prompts asked about operator situation awareness, the procedures for using UREPs and negotiation, what crews had gained from the tests, and technical issues of concern.

5. Analysis

Data from five Test Sites was collected during TCL3: North Dakota, Virginia, Alaska, Nevada, and Texas. The results related to those data are presented in this section.

5.1 UREP Types

Overall, during the testing window of TCL3, there were 26,657 valid UREPs submitted to the UREP service. A small percentage (< 1%) of the total number of UREPs collected by the UREP service were excluded from analysis; these represented conditions such as, test submissions with non-operational data. For example, the location may have been in a random location, the times were out of the range for TCL3 testing, or the user names were those reserved for testing. The breakdown of weather versus point out UREPs are presented in Figure 10, providing some insight on how the system was used during this testing.

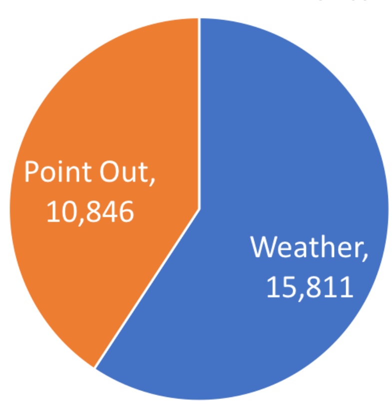

Figure 9. Breakdown of UREP types submitted during TCL3.

The vast majority of all UREPs were submitted by automated systems for weather and aircraft detection.

5.2 Test Site Submissions

The automated submission system implemented by Simulyze and deployed at Alaska and North Dakota dominate the volume of submissions. Other sites focused on manual entry of data and the effect of workload on operators to do so. Still, it is useful to compare the overall breakdown of successful submissions to the UREP server during the window of TCL3, as shown in Table 2.

Table 2. Submissions by Test Site in TCL3.

Test Site	Weather Submission	Point Out Submissions	Total Submissions
Alaska	173	0	173
Nevada	2	9	11
North Dakota	15,633	10,834	26,467
Texas	0	3	3
Virginia	3	0	3
Total	15,811	10,846	26,657

5.3 Latency

Overall, the latency of data exchanges was driven by design decisions of the client more so than actual network or server latency. In Figure 11, the latency from the USS to the UREP server was under 2 seconds, while the overall latency for a measured observation to be entered into the UREP server was just over 30 seconds. This was driven by the design decision of the automated systems to submit data roughly every minute for weather and every 30 seconds for point outs. Note that the two latencies for measurement to submission by the USS and the time of submission to reception on the UREP server sum to the overall latency from data measurement to reception at the UREP server.

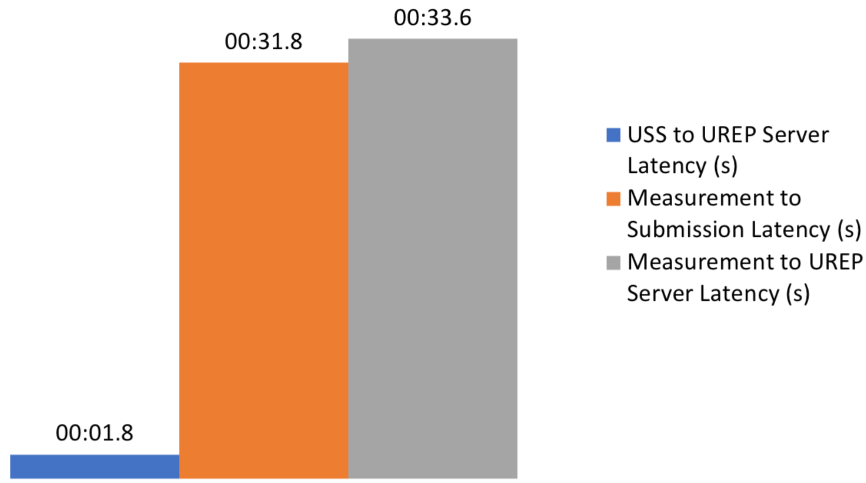

Figure 10. Latencies between UREP measurement, submission, and reception at UREP server.

An important caveat in these latency values is that three different clocks on three different systems were used and synchronization was sometimes lost. Efforts were made to synchronize often and to reject some submissions that exhibited excessive clock skew; however, the error introduced by clock skew is non-zero and unmeasured for this study. A skew of even 2-3 seconds would not be surprising and may account for the latency values between the USSs and the UREP server. Overall, the UTM team's goal was to determine if the latencies seemed reasonable to the users to support operations, so high precision was not highly valued in this testing. The USS supporting operators in this flight test determined that weather updates once per minute were a reasonable latency from an operational perspective. The effectiveness from the operator perspective is discussed in Section 6.

5.4 Data Quality

Overall, data quality management is an open topic for UREPs. The initial work summarized here describes the architecture and overall acceptance. There is not currently a concept in place to account for the quality of the input data. Data quality will vary from UREP to UREP due to sensor discrepancies and other potential errors (human and non-human). To fully realize the potential of UREPs, an approach to data quality reporting should be included.

During TCL3 testing, there were examples of poor data entering the system (separate from the test submissions). These problems included transposed latitude and longitude values and submission of Fahrenheit instead of Celsius (as specified in the API documentation). Some of these errors were not easy to detect for all cases. For example, 54°C may be a reasonable value in some locations, but not likely in the U.S. in early March, hence the clue that this was actually a Fahrenheit value.

In Section 6 below, the operator acceptance of the concept and approach is examined. There it is noted that despite open issues related to data quality, the concept is well-received and should be further developed.

5.5 Stability and Scalability

The UREP service did not experience any adverse effects with the volume of submissions for TCL3 and the service stayed available and responsive throughout the test without any special tuning. While this volume of data would not qualify as "Big Data" by industry standards, the cloud-based implementation of the UREP server is scalable in multiple ways. Since most accesses to the DB are writes, the DB can likely be horizontally scaled with eventual consistency and still provide reasonable latency to readers, even at scale. Reading could be achieved through broadcast/multicast subscriptions to better scale to the number of readers of the data. In addition, more servers can be added to handle requests in a parallel manner, aided by implementing load balancers. Overall, the system is scalable using industry best practices and should be able to handle an operational volume of data if deployed as such. NASA will not prove this scalability.

6. Stakeholder Feedback

As well as submitting their UREP logs, participants at the test sites described their experience of using the system through surveys and debriefs. UREPs were generated and sent in a number of ways across five test sites. While two sites had the option to send automatic or manual UREPs, other USSs offered manual UREP generation only (see above). Surveys focused on the UREP tests were only completed from those sites that were generating UREPs manually. These participants, who had to construct and send UREPs manually, were keen to try an automated option. Test sites reported independently that the UREP messaging system worked well – there was no appreciable latency of messages. Experiences for those receiving the messages varied from acceptable to "exceeds expectations." After using them during the flight test, some crews expressed that they thought UREPs have the potential to increase situation awareness.

On average, participants rated their workload at their busiest time during flights focused on UREPs as "moderate" ($\bar{x}$=4.1, σ = 1.12, n=25) although participants at Site 5 reported lower workload than other participants (see Figure 12). There was little difference between participants' average ratings of their reliance on the UREP information, which they relied on "a moderate amount" ($\bar{x}$=3.6, σ = 2.1, n=17). Participants reported that their awareness of their UTM state was "good" ($\bar{x}$=5, σ =2, n=19), although this is the most variable set of means across the three sets of responses. In general, variance was large in response to all these questions, indicating that respondents held different views about their level of workload, etc. This could be due to the specific test site environment, the specific instantiation of the USS client, or the way the test scenarios were organized and run, or possibly whether the respondent created or received the messages. Three test sites independently reported that, because the manual UREP form included many required fields, completing and submitting a UREP was too workload-intensive for a crew to manage while their vehicle was airborne.

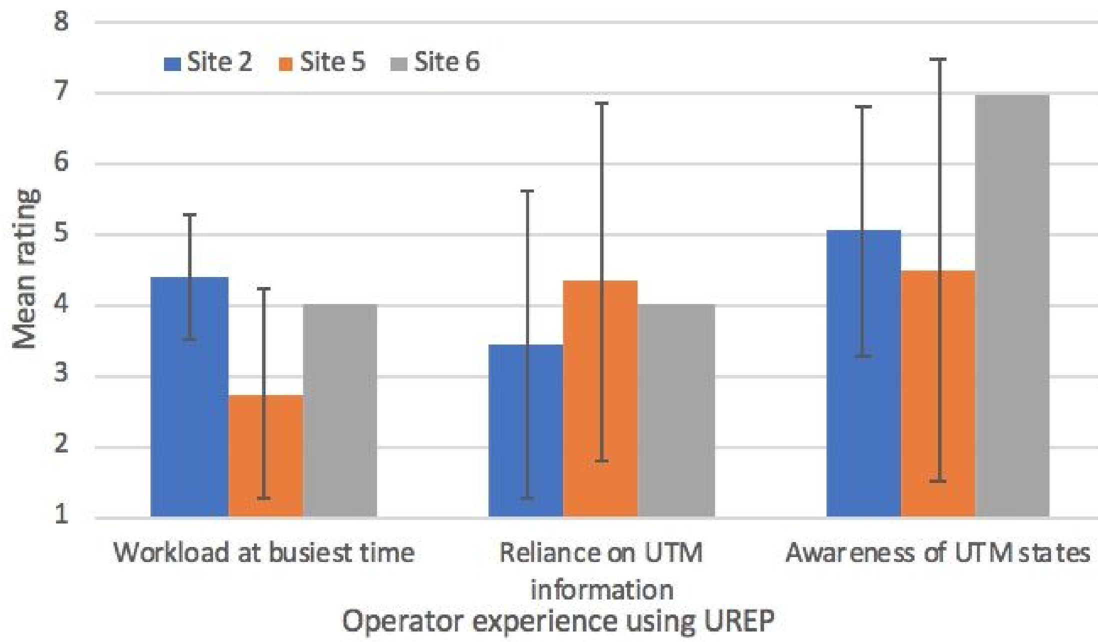

Figure 11: Operator experiences during UREP testing in TCL3 shown by test site, n=17-25

Having tried the UREP functionality, crews reported that UREPs could be useful to send information about the local flying environment, such as noting flocks of birds or manned traffic in their flight area, and other UAS, improving community situation awareness (see section 2.1 and Figure 11 above). One debate amongst the participants was whether UREPs could be used to broadcast safety issues. The argument for broadcasting safety notices arises from crews being present in the field and able to report information as it occurs, the argument against is that UREPs are designed to share non-critical information and other means should be used for sending safety-critical notices. Participants indicated that they supported sending UREPs containing local observations (close to their GCS), as these provided good situation awareness information. However, they expressed discomfort sending UREPs about the area around the location of their vehicle when they were flying BVLOS; they reported feeling "disconnected" when they were reporting for a remote location.

Despite having other weather reporting systems available, some crews did look at the weather data UREPs provided through their USS client, and reported much of the weather data they would want was available. Through a comparison with their other weather data, crews' confidence in the weather data was high, and they reported it was accurate ($\bar{x}$ =6, σ = 1, n=7), reliable ($\bar{x}$=6, σ = 1, n=7) and trustworthy ($\bar{x}$ =5.75, σ = 1.48, n=8). Most often used were winds on the ground and aloft, but precipitation, visibility, ceiling, density altitude and humidity were all considered as well. Crews reported that the most important information they wanted was wind speeds.

When asked about the usability of the UREP messages and methods for sending them, that is, to comment on the way UREP information was presented through the USS Client interface, crews cited both functionality and display issues. Note that some USS clients already have some of these features and every USS implemented the UREP functions differently, thus these comments are not universally applicable. Also, these comments apply to the Client interface to display UREPs and not to the UREP system (server and procedures). However, both parts – system and interface – contribute to a productive or frustrating user experience. Improvements requested to USS client functionality included:

- An easier method to search for incoming new UREPs as, although it was easy to send UREPs, it was difficult to receive them.
- A tighter integration of UREPs in the USS software to reduce the number of software tools required to complete a mission.
- An alert to draw attention when a UREP arrived.
- Customizable fields, especially for weather reports, so that the user can select to show only the information s/he needs to know for the flight.
- A slower update rate. Crews felt a minute-by-minute update rate was too frequent for UREPs, suggesting refreshing every 15 minutes.

When asked if they would like a way to send a return message, as this is not a function currently available, crews declined, stating that UREPs are for information only, they are not intended to be a conversation channel.

USS Client display/screen layout suggestions were also made in the context of working with UREPs. One was to change the screen layout to give UREPs their own window or space on the screen, as some crews had issues with weather UREPs populating over other data. A related activity by one USS developer is an effort to organize the input process for manual UREPs to reduce the typing load. Thirdly, NOAA symbology was suggested as a means to indicate weather more efficiently on the USS clients. Fourthly, crews expressed wanting an ability to categorize and display UREPs by their type.

6.6 Automated Submission

A major finding of this test is that the automation of UREP submission is likely the major mode of operation in a future system. Eliminating stakeholder workload concerns, minimizing data entry errors, and generating a scale of data input applicable to detailed model building are key benefits to moving toward regular, automated submission of data to the UREP system.

While UREPs are not considered a safety-critical element within the UTM architecture, they do increase situational awareness for stakeholders. In addition, the potential for massive generation, collection and centralization of weather data offers the potential for improved weather modeling. A large number of airborne sensors (the UAS themselves) collecting data in previously unmeasured areas provides truth data for model generation and validation.

From the point out data, this study has shown the potential for UREPs to be used as a simple form of surveillance. Again, while not being safety critical, the additional knowledge of aircraft in the vicinity is valuable for a sUAS operator in planning/executing a mission. UREPs offer a way for these operators to seamlessly share such data. Since the system is agnostic to the sensor collecting data in the field, it is not difficult to incorporate a variety of sensor types. Of course this opens up issues of duplicated and potentially conflicting data (many sensors providing a point out for the same aircraft), so protocol issues for the use of automated systems would need to be developed in regard to UREPs.

7. Summary

In NASA's TCL3 demonstration, one of the tests investigated the exchange of data from operator to operator via UREPs. NASA's implementation of a simple UREP server provided additional airspace and weather data that might not be available otherwise. Data were provided to the UREP server by both automated and manual means.

USS implementers explored several options for interfacing with the UREP server. Through these various implementations, end users were able to provide concrete feedback on the concept and the implementation. In general, the concept was well-received by end users and USS implementers. Most of the suggested improvements are targeted at the UREP client implementations and not on the UREP service itself, which is promising for the use of this concept in a future operational system. Work on the UREP concept including further field testing will continue through and potentially beyond NASA's TCL4 demonstration. Further efforts related to data validation, data quality, user confidence, etc., will add further value and acceptance to a future, operational version of UREPs.

Acknowledgements

TCL3 was executed as a Task under contracts with six of the FAA Test Sites. We appreciate the partnership with the test sites in the progression of UTM and their continued demonstration to perform complex, first-of-their kind flight tests. Industry partners are vital for the development, testing, and future implementation of UTM. For TCL3 and this report in particular, we acknowledge the USS implementers involved with UREP testing for their work to build software systems to our shared requirements: AiRXOS, ANRA Technologies, Lonestar, and Simulyze. Finally we thank the extended, dedicated UTM team at NASA, working across Ames, Langley, Glenn, and Armstrong to keep UTM on track and pushing boundaries.

References

[FAA 2017] Federal Aviation Administration, "Order JO 7110.10Z," Washington, DC, Nov 2018.

[FAA 2018] Federal Aviation Administration, "Unmanned Aircraft System (UAS) Traffic Management (UTM), Concept of Operations v1.0," Washington, DC, May 2018.

[FAA 2018b] Federal Aviation Administration, "FAA Aerospace Forecasts: Fiscal Years 2018-2038," https://www.faa.gov/data_research/aviation/aerospace_forecasts/media/FAA_Aerospace_Forecasts_FY_2018-2038.pdf. Washington, DC, retrieved Oct 2018.

[Fielding 2000] Fielding, Roy Thomas (2000), "Chapter 5: Representational State Transfer (REST)", Architectural Styles and the Design of Network-based Software Architectures (Ph.D.), University of California, Irvine. 2000.

[Fowler 2010] Fowler, Martin, "Richardson Maturity Model: steps toward the glory of REST." Blog article. https://martinfowler.com/articles/richardsonMaturityModel.html, Mar 2010.

[Ishihara 2019] Ishihara, Abraham, Joseph Rios, Priya Venkatesan. "Remote UAS ID for Rapid Assessment of Flight and Vehicle Information," NASA Ames Research Center, AIAA SciTech 2019, San Diego, CA, Jan 2019.

[Kopardekar 2016] Kopardekar, Parimal, Joseph Rios, Thomas Prevot, Marcus Johnson, Jaewoo Jung, John E. Robinson III, “Unmanned Aircraft System Traffic Management (UTM) Concept of Operations,” NASA Ames Research Center. 16th AIAA Aviation Technology, Integration, and Operations Conference, Washington, DC, Jun 2016.

[LAANC 2018] Federal Aviation Administration, “UAS Data Exchange,” https://www.faa.gov/uas/programs_partnerships/uas_data_exchange/, Washington, DC, retrieved Oct 2018.

[NASA 2018] National Aeronautics and Space Administration, “NASA UTM APIs,” https://github.com/nasa/utm-apis, retrieved Oct 2018.

[NASA 2018b] National Aeronautics and Space Administration, “NASA UTM Documents,” https://utm.arc.nasa.gov/documents.shtml, retrieved Oct 2018.

[ND 2018] Northern Plains UAS Test Site, “UTM TCL3 Testing -- Final Report,” Grand Forks, ND, Jul 2018. <NASA internal access only>

[OpenAPI 2017] OpenAPI Specification version 2.0, https://github.com/OAI/OpenAPI-Specification/blob/master/versions/2.0.md, retrieved Jul 2019.

[Rios 2017] Rios, Joseph, David Smith, Irene Smith, “UAS Reports (UREPs): Enabling Exchange of Observation Data Between UAS Operations,” NASA Technical Memorandum, Moffett Field, CA, Feb 2017.

[STOMP 2018] Simple Text Oriented Messaging Protocol, https://stomp.github.io/, retrieved Nov 2018.

Abbreviations

AK	Alaska
ANSP	air navigation service provider
API	application program interface
BVLOS	beyond visual line of sight
DB	data base
FIMS	Flight Information Management System
GCS	ground control station
ID	identification
LAANC	Low Altitude Authorization and Notification Capability
NASA	National Aeronautics and Space Administration
ND	North Dakota
NOAA	National Oceanic and Atmospheric Administration
PIREP	pilot report
R&D	research and development
RDBMS	relational database system
REST	Representational State Transfer
STOMP	Simple Text Oriented Messaging Protocol
sUAS	small unmanned aerial systems
TCL	Technical Capability Level

UAS	unmanned aerial system
UREP	UAS report
U.S.	United States of America
USS	UAS service supplies
UTM	UAS traffic management (system)
VLOS	visual line of sight