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TCL3 UTM (UAS Traffic Management) Flight Tests, Airspace Operations Laboratory (AOL) Report

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Table of Contents

List of Figures

List of Tables

Acronyms and Definitions

2D..Two Dimensional
4D..Four Dimensional
ADS-B ....Automatic Dependent Surveillance-Broadcast
AGL ....Above Ground Level
AOL ....Airspace Operations Laboratory
BVLOS ....Beyond Visual Line-Of-Sight
C2...Command and Control
CNS......................................Communications, Navigation and Surveillance
CON ....Concept set of tests
COTS ....Commercial Off the Shelf Software
DAA......................................Detect and Avoid
DAT ....Data and Information Exchange set of tests
DMP.....................................Data Management Plan
DoT ....Department of Transport
DSRC ....Dedicated Short Range Communications
FAA ....Federal Aviation Administration
FIMS ....Flight Information Management System
ft ....Feet
GA..General Aviation
GCS......................................Ground Control Station
GCSO...................................Ground Control Station Operator
GDOP ....Geometric Dilution of Precision (of GPS signal)
GHz......................................Gigahertz
GNSS ....Global Navigation Satellite System
GPS ....Global Positioning System
GUFI ....Globally Unique Flight Identifier
GUI ....Graphical User Interface
HDOP ....Horizontal Dilution of Precision (of GPS signal)
ID ....Identification
iOS ....Apple company operating system
ISM ....Industry, Scientific and Medical
ISN ....Internet Services Network
iUTM....................................insight UTM Visualization tool
LOS......................................Line-of-Sight
LTE ....Long Term Evolution
LUN ....Local USS Network
LZ...Landing Zone
m/s..Meters per Second
MSL ....Mean Sea Level

NASA....................................National Aviation and Space Administration
nc...National Campaign
nmi ....Nautical Mile
NOAA....................................National Oceanic and Atmospheric Administration
NUSS ....NASA UAS Service Supplier
PIC ....Pilot-in-Command
PII..Personally Identifiable Information
PKI ....Public Key Infrastructure
RC ....Radio Controlled
RF..Radio Frequency
RTB.......................................Return to Base
RTT ....Research Transition Team
SA ....Situation Awareness
SAA ....Sense and Avoid
SD ....Situation Display
SDSP.....................................Supplemental Data Service Provider
sec ....Second(s)
SOW......................................Statement of Work
TCL ....Technology Capability Level
TCL2-nc.................................Technology Capability Level 2 National Campaign
TFR ....Temporary Flight Restriction
UA...Unmanned Aerial Vehicle
UAS ....Unmanned Aircraft System
UAV ....Unmanned Aerial Vehicle
UFO ....Unidentified Flying Object
UREP ....UAS Pilot Report
USS ....UAS Service Supplier
USS Op ....USS System Operator
UTM......................................UAS Traffic Management
UUID.....................................Universal Unique Identifier
UVIN.....................................UAV Vehicle Identification Number
VLOS ....Visual Line-of-Sight
VO...Visual Observer
Wi-Fi.....................................IEEE 802.11x
Wx...Weather

TCL3 UTM Flight Tests, Airspace Operations Laboratory (AOL) Report

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Executive Summary

The Technology Capability Level-3 (TCL3) flight tests were conducted at six different test sites located across the USA from March to May of 2018. The campaign resulted in over 830 data collection flights using 28 different aircraft and involving 20 flight crews. Flights not only varied in duration, but also in the environments and terrains over which they flew. The TCL3 tests highlighted four different types of tests: three tests focused on Communication, Navigation and Surveillance (CNS); six tests focused on Sense and Avoid (SAA) technologies; six tests focused on USS Data and Information Exchange (DAT); and five tests focused on exploring fundamental Concepts of the project (CON). This document presents data collected during the TCL3 tests that informed the operator's experiences—the quality of the unmanned aerial system (UAS) Service Supplier (USS) information that the operator was provided with, the usefulness of this information, and the usability of the automation, both while airborne and on the ground. It is intended to complement the reports written by the test sites and the quantitative reports and presentations of the UAS Traffic Management (UTM) project.

With the goal of instructing what the minimum information requirements and/or best practices might be in TCL3 operations, the driving enquiry was: How do you get the information you need, when you need it, to successfully fly a UAS in UTM airspace? This enquiry touches on two requirements for displays, which are to provide adequate situation awareness (SA) and to share information through a USS.

The six test sites participating in the TCL3 tests flew a subset of the 20 tests (outlined above), with most sites working on a subset of each of the four types: Communications, Navigation and Surveillance (CNS); DAT; CON; and Sense and Avoid (SAA). The, mainly qualitative, data addressed in this report was collected by the AOL (Airspace Operations Laboratory) both on-site and remotely for each test. The data consists of the contents of end-of-day debriefs, end-of-day surveys, observer notes, and flight test information, all submitted as part of the Data Management Plan (DMP).

The topics of inquiry were selected via a process of analyzing the human-automation interaction

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elements of each TCL3 test, which were gleaned from the statement of work and test site proposals. Elements of interest were grouped under six major categories to facilitate later data analysis. These six categories were: the *information* that UTM users to complete their tasks; the characteristics of the UTM/ground station displays that facilitated the use of information, as this is where *information meets the user*; the state or experience of the *operator* while working in the UTM environment—their level of load and awareness, in particular; the functionality and usefulness of the UTM-related *automation* in the flight tests; the *methods* the operators used to make use of that automation and UTM information; and, the exploration of the UTM *concept* during each flight test.

There were up to three teams of researchers collecting data from the participants during field test days. For at least one of each sites' test weeks, an AOL researcher was physically present at each test site to collect data. To the extent possible, researchers observed all flight crews at some point across the test days. In the AOL, a team of UTM developers verified data flowing through the system and teams of three or four AOL researchers remotely collected data from the participants at each test site about their experiences.

During the 831 test flights of the TCL3 effort, participants provided a number of positive points of feedback within 280 individual survey responses and 40 debriefs conducted with crews at test sites. Data from CNS and DAT tests were very helpful, and the tests were completed as expected. The tools investigated as part of the SAA tests were well-received by operators and helped with their overall situation awareness. CON tests were interesting and varied, and generated a good deal of data while flying different vignettes and afterwards at broad concept-level discussions. From this wealth of data, 11 points are highlighted about the information required, information usage, operator approach, automation, concept, and UTM methods or procedures that operators had worked with during the flight tests.

- Test sites appreciated the additional sensor tools that provided increased situation awareness about the airspace they were flying in. Telemetry that provides such situation awareness to operators came from a range of sensors, and one type of data was not distinctly better than another when comparing across tests. However, it was emphasized that the data provided needs to be reliable and consistent.
- Crews stressed that command and control (C2) link displays should be both simplified and, if possible, situated on the USS client. Moving forward, indication of the strength of the C2 connection might be added to USS displays.
- The interfaces for generating outgoing and reading incoming messages including those for alerting need to be improved. Clutter needs to be reduced in all displays.
- Users were concerned about being flooded with messages if every non-normal UAS reading were to be broadcast to the community. This led to a wider discussion of how much is "too much" for all types of alerting. Crews differed in their opinions of UTM alerting depending on the situation. They wanted to be alerted as soon as possible to events that could affect their flight or airspace, but did not want to be distracted by repeated alerts or warnings that were "obvious" and suggested that the community specify some lower limits on this.
- Although users admitted to not wanting to share their data/ information with other companies/operator groups, they agreed that some level of sharing has to happen to make UTM useful. Implications are that the community should specify lower limits on what needs to be broadcast, outlining information that must be shared and when.
- Crews understood that maintaining an awareness of DAT messages and USS interactions was both useful and important.

- Although participants appreciated the ability of their SAA tools to alert them regarding the nearness of approaching vehicles, they reported a number of issues with this new-to-UTM technology, ranging from telemetry reliability to interface interaction issues. They concluded, in general, that these tools need more development to become truly useful.
- Procedures for reservations and negotiations could be more formalized. UTM users were able to "step on" each other to reserve airspace, and some did this accidentally, while others gamed the system in order to gain an advantage. These loopholes should be identified and solutions considered, where incentives could promote efficiency, and feedback about the status of applications needs to be improved.
- The proper method to respond to SAA events was an area of uncertainty for crews. Discussion highlighted the variety of approaches crews considered that might be used to respond to conflict situations.
- Although participants did not question the need for Temporary Flight Restrictions (TFRs), they indicated that the rules and procedures governing them were unclear. Rules for when TFRs will be generated need to be clarified, as do exit times and procedures for exiting, and who, if anyone, has clearance to remain within a TFR.
- Rules or procedures for sending messages and methods for interacting with messages need to be formalized.

These themes each relate directly to one of the six overarching categories described above that were the focus topics for this effort, and guided the data collection process, to inform the AOL's question: "What information is required to successfully fly in a UTM environment?" As outlined in the points above, under the first theme of information properties, alerting was a key topic of discussion and concern to many of the operators; where information meets the user, it was found that the transparency of the UTM and USS tools was extremely important. Generally, operators indicated that they liked the tools that presented data clearly and reliably in this study, but felt that further training would be needed to increase SA, acceptance of the UTM concept, and operator willingness to participate in such an environment. Operators' situation awareness was both influenced by the usability of the information presented by a crew's window into UTM—their USS client—but also by how aware they were of what information was accessible to them. Further development and research on possible procedures, standards, and/or recommendations are needed. All of these themes together help us understand to how UTM was used, what went well and should persist, and how the UTM experience can be improved. In sum, the TCL3 flight tests were successful, and more was learned about the operators, the information they need to fly within UTM, and the procedural requirements in a TCL3 environment.

1. Background

As part of NASA's Unmanned Aircraft Systems (UAS) Traffic Management (UTM) effort (Kopardekar, et al., 2016), the Technology Capability Level-3 (TCL3) flight demonstrations took place across three months from March through May 2018 and involved six partner groups, or test sites, located across the USA. Those three months encompassed 37 calendar days on which vehicles flew test flights, sometimes at more than one test-site concurrently (see Table 1 and Appendix 1). There were 10 official shakedown (i.e., 'practice') flying days and 51 flying days for data-collection[2]. Each test-site was utilized and configured to meet the needs of the vehicles and the criteria specified in the test scenarios written by test sites to fulfill the criteria set out in the NASA Statement of Work (SOW, Rios, 2017). Some test sites had as many as five ground control station (GCS) locations, from which flight crews conducted their operations, while others had one, depending on the test type (see Figure 1a and Figure 1b for examples). Some test sites moved the locations of their GCSs depending on the tests they were flying that day, while others were fixed bases. Flight crews varied in composition and size but generally were smaller than for the Technology Capability Level-2 national campaign (TCL2-nc) (Martin, et al., 2018). Flight crews from some test sites were composed of individuals from one organization, while other test sites sent multiple crews, each from different teams. Depending on the test, half to two-thirds of the test sites (sites 1, 4, 5 and sometimes 6) centrally managed their UTM service supplier (USS) onsite, with one USS system operator (USS Op), in some cases located separately from the flight crews, overseeing the USS operations for a number (or all) of that test-site's crews. The other test sites integrated a USS Op within each flight crew. Scenarios were developed by each test-site to demonstrate the UTM capabilities that they had proposed. Most test sites created multiple unique scenarios to meet the variety of test requirements.

Table 1. Flight Days and Shakedown Days for the TCL3 Flight Demonstration

	Site 1	*Site 2*	*Site 3*	*Site 4*	*Site 5*	*Site 6*
Week 1						
Week 2						
Week 3						
Week 4						
Week 5						
Week 6						
Week 7						
Week 8						
Week 9						
Week 10						
Week 11						simulation only
Week 12						
Week 13						
Shakedown days	1	1	4	0	3	1
Test days	11	4	6	9	13	7
Total days in field	12	5	10	9	16	7

Key: orange fill = a shakedown day; green fill = a data-collection day; blue fill = a simulation only day.

[2] One site retested some of their data collection in the lab—hence there were 51 days of testing for data collection with 50 of these flying vehicles in the field and one simulating all flights in the lab.

Figure 1a. Example of a test site with one GCS area for two vehicles (colored lines denote vehicle volume plan-areas).

Figure 1b. Example of a test site with multiple GCS area for its vehicles (colored lines denote vehicle volume plan-areas).

2. Method

2.1 Participant Roles and Responsibilities

Flight crews varied in number and affiliation: some consisted of just one individual, while others had up to six in their crews (Appendix 2). Primary flight crew positions are listed in Table 2, with many crew members fulfilling more than one role. Additional positions staffed by some, if not all, of the flight test sites are listed in Table 3.

Table 2. Crew Member Roles and Responsibilities

Crew Member Role	*Crew Member Responsibilities*
Pilot-in-command	Serve as the main pilot for the vehicle
GCS operator	Work the vehicle's flight planning and flight execution software
USS operator	Monitor and interact with USS displays (NASA)
Hardware and software flight engineers	Support specific technical aspects of the vehicle
Visual observers	Safety monitors who provide visual contact with the vehicles at all times

Table 3. Test Site Support Personnel Roles and Responsibilities

Test Site Personnel Role	*Responsibilities of this Role*
USS manager	Ensure the USS software was running and undertook troubleshooting when needed
Radio control safety pilots	Serve as alternate pilots if the PIC needed assistance
Flight Test Manager	Coordinate the crews and flights to conduct the test scenarios properly
NASA researchers/observers	Collect observational and survey data, observers were available to support media day and answer flight team questions

Although each test-site created their own configurations of personnel, two types of team organization persisted from the previous flight test, TCL2-nc, with respect to UTM (Figure 2).

One type of team organization included having the USS Op role as a dedicated member of the flight crew, either completing USS client management tasks alone, or by having one crew member splitting the USS Op role with another role (e.g., at Test-Site 3 the flight crew consisted of two people: a GCSO/PIC/USS Op and a safety pilot/launch engineer). The advantages of having the USS Op role within a flight crew team was that this person was able to focus completely on the crew's mission and communications were reduced. The cost was the number of additional personnel, or, if the role was timeshared by one team member, that periods of high workload were compounded if all roles were busy at the same time, (e.g., at launch). The second type of team organization was one in which a dedicated USS Op fulfilled that role for a number of crews (e.g., at Test-Site 1, one USS Op submitted and managed the 4D plan-areas for the flight, also called flight "volumes," for four flight crews, where each flight crew consisted of a PIC, a GCSO, and a launch engineer). Three test sites took this "hub-spoke" approach—Test sites 1, 4 and 5. One test site was a hybrid where some crews were co-located, and others were not (because multiple USS were being used). The advantage of separating out the USS Op role was that this person became a specialist and overall required manpower was reduced. The cost was the increase in communications load as the USS Op had to stay in contact with all the flight crews they were serving, and the workload related to managing multiple flights in the case that one flight crew/vehicle was having an off-nominal event.

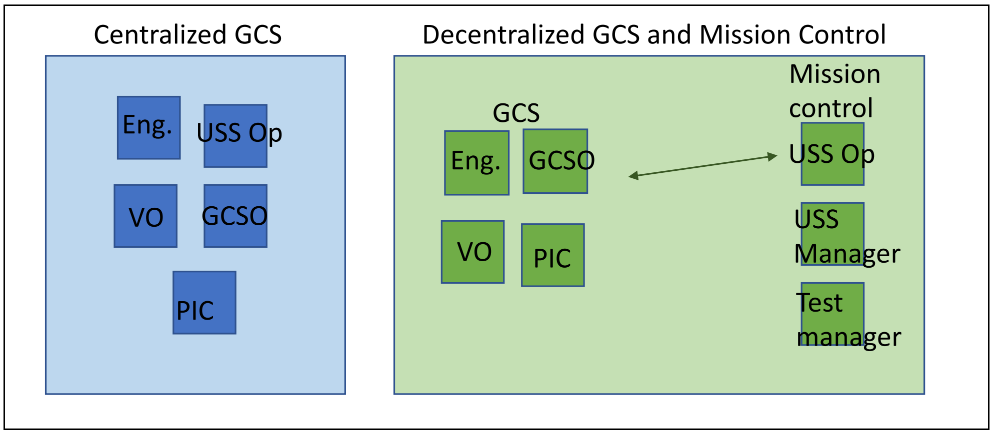

Figure 2. Illustration of two different types of team organization: Centralized and Decentralized.

2.2 Vehicle Characteristics

The vehicles flown during the demonstration were a mix of small fixed-wing, multi-rotor, and hybrid UAS vehicles, each with varying performance characteristics and endurance limits. There were 26 different models of aircraft flown (Appendix 3). The multi-rotor vehicles were able to take-off and land vertically in a small area and turn on a point in the air, while the fixed-wing vehicles flew similarly to manned light-aircraft, taking off on a climbing trajectory, making banked turns in the air, and either gliding down into a belly landing or descending to a lower altitude before deploying a parachute. All of these methods required larger areas on the ground than the multi-rotor vehicles. Hybrid vehicles performed similarly in-flight to fixed-wing vehicles, but with the vertical take-offs and landings of multi-rotor vehicles.

Most vehicles could be controlled either by providing point-to-point direction through a GCS or manually by a pilot-in-command (PIC), although some were fully-automated only (GCS control only). As an example of the latter, Test-Site 3 managed their operations with automated control only (a safety pilot was on hand to take over manual control in an emergency). During all flights, whether they were line-of-sight (LOS) or beyond visual line-of-sight (BVLOS), the behavior of the vehicle was monitored by at least one visual observer (VO) at all times[3]. In cases of unexpected vehicle behavior, the visual observer could contact the flight crew and/or the Flight Test Manager so that the appropriate compensatory action could be taken.

[3] Multiple VO were positioned along BVLOS routes to ensure "eyes on" the vehicles at all times.

2.3 Interfaces and Information Displays

Equipment available at each GCS location varied widely across and within test sites. At most GCSs, several displays were available to the flight crews to give them information about their vehicle's flight, and some also included displays to show surrounding operations, and/or aspects of the UTM system. For example, Test-Site 3 provided four screens for its GCSO/PIC/USS Op. This individual did not have LOS contact with (could not see) their vehicle. Standard tools shown on their displays were their flight planning/execution software, a USS client, and a fusion of radar, multi-lateration systems and GCS telemetry. The fourth screen was available for use to show other information of the GCSO/PIC/USS Op's choice, including weather, vehicle and USS data, radio frequency usage, etc. Other test sites, which had more mobile/portable GCSs, used fewer displays. At Test Site 5, for example, flight crews only had a hand-held controller, and one display showing the autopilot software for their vehicle. These flight crews did not have access to a display of UTM information. Instead, UTM information was verbally relayed to them from a nearby centralized location, where the USS Op had such a display.

All test sites used at least one surveillance system to provide information about the airspace not provided by vehicles' on-board sensors (GPS: global positioning system; ADS-B: Automatic Dependent Surveillance-Broadcast), helping to identify other manned and unmanned aircraft flying near the test-site and most added radar capabilities or other tools that they used to complete test requirements. During the testing, a NASA-built iOS application (insight UTM, or iUTM), provided visualizations of UTM system information and current operations, and was made available to the test sites. Test Site 3 elected to use iUTM as an additional situation awareness display. Another in-house situation display (SD) tool facilitated data collection within the AOL at NASA Ames Research Center, allowing the research team to check flight details and monitor UTM messages in real time (see Figure 3).

Figure 3. Suite of tools in use by the AOL research team for TCL3.

In the same way that there was a mix of team members and vehicle types, the partner-built interfaces to UTM also differed. Across the test sites, five different partner-built UTM Service Suppliers (USSs) and the NASA USS were employed during the flight demonstration. Four test sites used more than one USS (Test sites 2, 4, 5, and 6), and two test sites used the same USS (Test sites 1 and 4). The tools and displays available within these USSs varied, primarily because each partner developed their USS independently, with no standard regarding how to display various pieces of information. The USSs were still under development and had a wide variety of available functions and features. To participate in TCL3, all USSs needed to have certain basic capabilities (i.e., capabilities to allow proper FIMS/USS and USS/USS communications, plan submissions, position reporting, messaging, and alerting), but the manner and extent by which the partners met those requirements differed, and are not examined in this paper.

2.4 Method

During test days, there were up to three teams of researchers collecting data from the participants in the field. In the NASA labs, a team of UTM developers verified data flowing through the system and teams of three or four AOL researchers remotely collected data from the participants at each test-site about their experiences and during shakedowns. To the extent possible, researchers observed all flight crews at some point across the test days. In addition, for at least one of their test weeks, an AOL researcher went to the field to collect data. Data were collected in a number of ways:

- observations of the participants during flights
- end-of-day surveys
- end-of-day group debriefs

All of these methods solicited feedback on the six areas of interest for these tests (Table 4). In total, 34 end-of-day group debriefs were collected across the six test sites, some in person and some over the phone. Test-specific debrief questions were pre-defined and asked along with alternate questions that probed into unique events of that particular day. During these end-of-day debriefs, flight crews discussed the UTM-specific topics as they related to the UTM operations at their test-site. Survey items were generated with the four topics (Table 4) in mind, but were presented to the participants in the context of the flight tests that the Test Site had just flown. Approximately 30–54 questions were generated across four surveys, but conditions were set so that participants only answered around 25 at any one time. Most questions used a seven-point rating format, with 7 representing a very positive rating and 1 representing a very negative rating, but some questions were multiple choice or open-ended. Researchers in the field also took notes while they were watching flight tests. Two sources of operational data were also obtained:

- test sites telemetric flight data, and sometimes other logged data, were shared with NASA
- NASA's internal records of USS data, were captured through a separate, data-aggregation server

Table 4. Information Topics used for Organizing Qualitative Data Collected

High level category	Sub category
Information properties	Quality of alerting information
	Saliency of information
	Usability of information
	Intuitiveness/ interpret-ability of the information
	Usefulness of information
	Reliability/accuracy of information
Information meets user	Trust in the information presented
	Reliance on information presented
	Information required/ desired by operator
	Appropriateness of decision made/ maneuver
	Confidence in maneuver
	Effectiveness of data (message)
	Transparency of tool
	Usability tradeoffs

High level category	Sub-category
Operator status	Situation awareness
	Timeliness (includes Time to detect, time to respond and perceived timeliness)
	Workload
Methods	Planning process & considerations
	Procedures for flight / event
	Description of operator role
UTM concept	Operator buy in
	Public & hobbyists
	Confounds
Automation	Design of system or hardware
	Definition of terms
	Functions

2.5 Research Objectives

With the goal of instructing what the minimum information requirements and/or best practices might be in TCL3 operations, the driving enquiry was: How do you get the information you need, when you need it, to successfully fly a UAS in UTM airspace? This enquiry touches on the requirement for displays to:

- provide adequate situation awareness (SA)
- share information through a USS

And, the additional requirement for operators to:

- have enough knowledge in order to understand what they are seeing
- respond quickly enough when an action is needed

There are six overarching categories in the consideration of information required to fly under UTM: information properties, information as it interacts with the user, the operators' responses, methods, automation, and concept issues (Table 4). Each of these higher-level categories were split into between three and seven subcategories.

- *Information Properties:* concerned with features of the information items themselves, such as saliency, usability and intuitiveness of information items
- *Information meets User:* concerned with tool features that made the information more or less usable and the operator's interaction with the tools
- *Operator Status:* concerned with the impact of the information on the state or activity of the crews, such as workload and situation awareness
- *Methods:* concerned with the procedures and processes that crews put in place to interact with UTM and achieve their flights

- *Automation:* concerned with the way the automation worked and functions that were present or desired
- *UTM Concepts:* concerned with the wider world of UTM, encompassing how different users might interact with the system and issues that require a higher-level policy or concept consideration not just an automation solution (see FAA, 2018 or Kopardekar, et al., 2016 for a description of the UTM concept)

The first four categories of the matrix (information properties, information meets user, operator status and methods) were included in Revision F of the Data Management Plan (DMP January 2018) that was constructed to inform and assist Test Sites with their data collection process. These categories were used to guide organizing the comments from debrief discussions and field notes.

2.6 Test Scenarios

The test aims were presented to the sites as twenty test objectives: three CNS; six Sense and Avoid (SAA) technologies tests; six USS Data and Information Exchange (DAT) tests; and five Concepts (CON) issues tests. The six test sites opted to look at different sets of objectives, and different numbers of tests were awarded to each. The tests completed by each test site are shown in Table 5.

Table 5. Test Objectives that Each Test Site was Awarded with the Date(s) on which they Flew Missions to Meet those Objectives

	Site 1	*Site 2*	*Site 3*	*Site 4*	*Site 5*	*Site 6*
General Shakedown						
CNS 1	25, 27 Apr	6, 7, 9 Mar	10, 11 Apr	11, 12 Apr	5, 6 Apr	
CNS 2	30 May	6, 8 Mar			5, 6 Apr	
CNS 3		7, 9 Mar	24 Apr	9, 10 Apr	5, 6, 16 Apr	
SAA 1						3, 5 Apr
SAA 2	23 Apr				23 Apr	
SAA 3					10 May	10, 11 Apr
SAA 4	10 May				7, 9 May	
SAA 5					11 May	10, 11 Apr
SAA 6						3, 5 Apr
DAT 1		6–9 Mar		16 Apr	19 Apr	24 Apr
DAT 2		6–9 Mar		16 Apr		
DAT 3		6–9 Mar		16 Apr	19 Apr	24 Apr
DAT 4			11 Apr	16 Apr		24 Apr
DAT 5		6–9 Mar		16 Apr	19 Apr	24 Apr
DAT 6		6–9 Mar		16 Apr		24 Apr
CON 1	4, 17 May		17–19 Apr			24 Apr
CON 2	25 May				15 Apr	25 Apr, 15 May
CON 4	23, 25 May			19 Apr	26 Apr	25 Apr, 15 May
CON 5	16, 18 May			22 Mar	27 Apr	

The 20 tests were designed to give insight into specific aspects of the UTM concept, each focusing on a different problem or interest. CNS tests focused on data interference and blocking (see Appendix 4 for a listing), SAA tests focused on different methods to sense and avoid other vehicles, DAT tests focused on the functioning of the UTM system, looking at the impact of adding information to the system and the impact of system degradation. CON tests looked at aspects of the way UAS may potentially be used, from long flight times to unintentionally breaching restricted airspace. Combined, these tests touched on most of the themes from the National Campaign flight tests of 2017 (BVLOS operations, dynamic re-planning, responses to alerts from the UTM System, and the implementation of off-nominal contingency plans).

With the direction given in the SOW (Rios, 2017), test sites created their own test scenarios to investigate one or more of the specified tests. Procedures were not firmly defined in the SOW, and test sites were allowed to interpret the document in their own way. Site differences were expected and encouraged, and test sites built scenarios that were as large or small in scope as required to investigate the questions put forward by the SOW. For those addressing CNS issues, test sites were able to address their objectives with several, small variations of a single, simple scenario (see example in Figure 4). For CON tests, in general, the scenarios had to be more complex, involving multiple vehicles interacting within close proximity (see example in Figure 5). The test sites' local geography and environment also influenced their test scenarios. For example, some GCSs were at airfields while other locations were in farmers' fields, and some GCSs had tree cover, while others were on marshy ground close to water, which influenced the scenarios that were created and the "stories" that sites tried to tell.

Figure 4. Example of a simple scenario (square survey pattern).

Figure 5. Example of a more complex scenario with 5 vehicles and more than one USS.

Note: Magenta polygons are active volumes, cyan polygons are accepted volumes and the brown area is the USS client coverage area. The position of an airborne UAS is visible in the lower left corner/volume.

3. Results

3.1 Metadata

In the TCL3 tests, sites were required to define specific information about each operation along with each submitted operation into UTM. Some of the required fields included the test site, the exact test(s) being conducted, if the operation was intended for data collection (as opposed to debugging or shakedown), and whether the operation was a live flight or if it was simulated. As these data were input manually before flight, and some partners had more capability to alter the content than others, there is a margin of error in the accuracy of what was originally reported. NASA employed two efforts to increase the accuracy of the data. During each flight, a NASA researcher would crosscheck the data in the lab and query the test site if there was a concern, then publish an amendment to the submitted data. Then, once all tests by all test sites were completed, researchers crosschecked 3,020 rows of data and 2,201 submitted operations to define the set of 831 operations that are currently being considered as valid data collection flights. However, it should be noted that error still remains within these data. One of the concerns is that, although operations might have only one test listed, that test may have been run simultaneously with another (i.e., DAT 5 during CON 4); therefore, the counts of flights per test may be askew. Secondly, 35 operations do not have a test specified in the data. A third concern is operations that were intended for data collection when submitted, but were later scrubbed and re-flown without notice and without changing the previous marker from "data collection".

With the above error sources in mind, the current data set for TCL3 operations includes a total of 831 operations submitted to UTM for data collection (Table 6). Of these, NASA submitted 43 simulated operations to virtually interact with the test sites during four specific tests (DAT 3, DAT 5, CON 2, CON 4, CON 5). The six test sites submitted 788 flight activities, 627 of which were live flights and 161 were simulated flights. Data for days that were identified as shakedowns for hardware and software testing have been excluded from the final analysis.

Table 6. Number of Live and Simulated Flights Providing Data for TCL3 by Test Site

Test Site	*NASA*	*Site 1*	*Site 2*	*Site 3*	*Site 4*	*Site 5*	*Site 6*	*Totals*
Live flights	0	94	49	58	111	48	267	627
Simulated flights	43	0	59	0	0	0	102	204
Total submitted operations	43	94	108	58	111	48	369	831

4. Data and Information Exchange Tests

The DAT tests were created to explore the exchanges between key system components in both nominal and off-nominal situations. These were designed to capture system-level robustness and usability through detailed evaluation of individual components and their interactions. Specifically, the DAT effort looked at the following three interactions: USS-Operator; USS-USS; and Flight Information Management System (FIMS)-USS, through six unique tests (DAT 1 through DAT 6). In the End-to-End UAS pilot report (UREP) test (DAT 1) operators submitted UREPs while completing other tests. Some elements that were evaluated were the usability of the data to the human operator and the appropriateness of the data elements. The FIMS Failover test (DAT 2) simulated FIMS, or a key FIMS component, failing while there were active flights. Recovery time and the effects on operations were measured. The USS Failover test (DAT 3) simulated USS, or a key USS component, failing while there were active flights under its management. Recovery time and the effects on operations were measured. For the UAS Identification test (DAT 4) UAVs were registered with UTM public key infrastructure (PKI) and broadcasted identity information. This identification (ID) was received on the ground and others aimed to identify the flight. The general effectiveness of this procedure was the focus of this test. In the USS-to-USS Negotiation test (DAT 5), two operations with overlapping geographical/temporal areas were submitted to UTM, each using a different USS to plan and execute a mission. The USS of the second operation had to initiate a negotiation with the USS of the first operation to coordinate a strategic resolution of the conflict, either by space, by time, or both. Test sites used both automatic and manual methods to detect and resolve the conflicts. The Weather Service test (DAT 6) was designed for crews to use a UTM-focused weather service to aid in the planning of an operation. While the test could be completed in conjunction with other tests, the weather data needed to be provided via a defined and published interface.

Five of the six test sites were awarded one or more DAT tests, with two sites being awarded all six DAT tests. In total, 22 DAT tests were awarded, and these awards were distributed so that each DAT test was performed by either three or four test sites (see Table 7). Test sites conducted these 22 tests over 10 calendar days, often performing them in parallel with other tests.

Table 7. Number of Live and Simulated Flights Providing Data for TCL3 by DAT Test								
	NASA	*Site 1*	*Site 2*	*Site 3*	*Site 4*	*Site 5*	*Site 6*	*Total*
DAT 1			12		8	6		26
DAT 2			9		4		1	14
DAT 3	3		21		6	5	3	38
DAT 4				14	5			19
DAT 5	13		38		17	7	53	128
DAT 6			10					10
All DAT	16		90	14	40	18	57	235

Note: Colored cells with no flight number identify where the number of operations to fulfill this test are unknown

4.1 Method

4.1.1 Surveys

There were 54 questions in the DAT survey, with the questions preselected to show only between 15 and 21 of these questions depending on the test, e.g., those completing DAT 1 saw 19 questions—10 general and 9 specific to the DAT1 test—as well as a couple of information questions. Many questions asked the participant to rate their answers on a 1 to7 scale, where 7 was high, or positive, and 1 was low, or negative. Other question types were multiple choice and free-response. One hundred and eleven surveys were started in total across the five sites. All 111 surveys had some data entered but not all were complete. The greatest number of surveys started at one site was 47 and the fewest was six, but note that, although three sites undertook five or more DAT tests, one site only undertook one.

4.1.2 Debriefs

There were eleven debriefs that focused on DAT tests hosted across the five test sites. Six were specific debriefs focused on one DAT test while the other five touched on more than one DAT test (see Appendix 8). Numbers of discussion prompts varied as researchers wanted crews to discuss and explore the topics within the time available. Prompts were on the topics of operator situation awareness, the procedures for UREPs and negotiation, what crews had gained from the tests and technical issues of concern.

4.2 DAT Metadata

There were 235 operations submitted to UTM for DAT testing, 16 of which originated from the NASA AOL for collaboration with the test sites, and 219 originated from the test sites themselves. DAT 1 had 26 operations submitted by the test sites, DAT 2 had 14, DAT 3 had 35, DAT 4 had 19, DAT 5 had 115, and DAT 6 had 10. As shown in Table 7, there are gaps in the data where it is likely that the DAT tests were run during the same flight as another test, but this was not noted in the logs.

4.3 General DAT Feedback

A standard set of 10 questions were asked at the end of every DAT survey. Participants were asked to rate their workload, their reliance on UTM, their opinions of the information they received through the USS clients, and their safety concerns.

4.3.1 Operator Experience

After a DAT test, on average, participants rated their workload at their busiest time as "moderate" ($\overline{x}$ = 4) and there was very little difference between ratings across DAT tests (Figure 6). There was also little difference between tests in participants' average ratings of the timeliness of messages, which was "okay" ($\overline{x}$ = 4.4) overall. Average ratings for reliance on UTM information were "moderate" ($\overline{x}$ = 3.8), although the mean ratings for DAT 2 were slightly higher ($\overline{x}$ = 4.8) than for other tests. Participants reported that their awareness of their UTM state was "good" ($\overline{x}$ = 5), although this is the most variable set of means across the six tests.

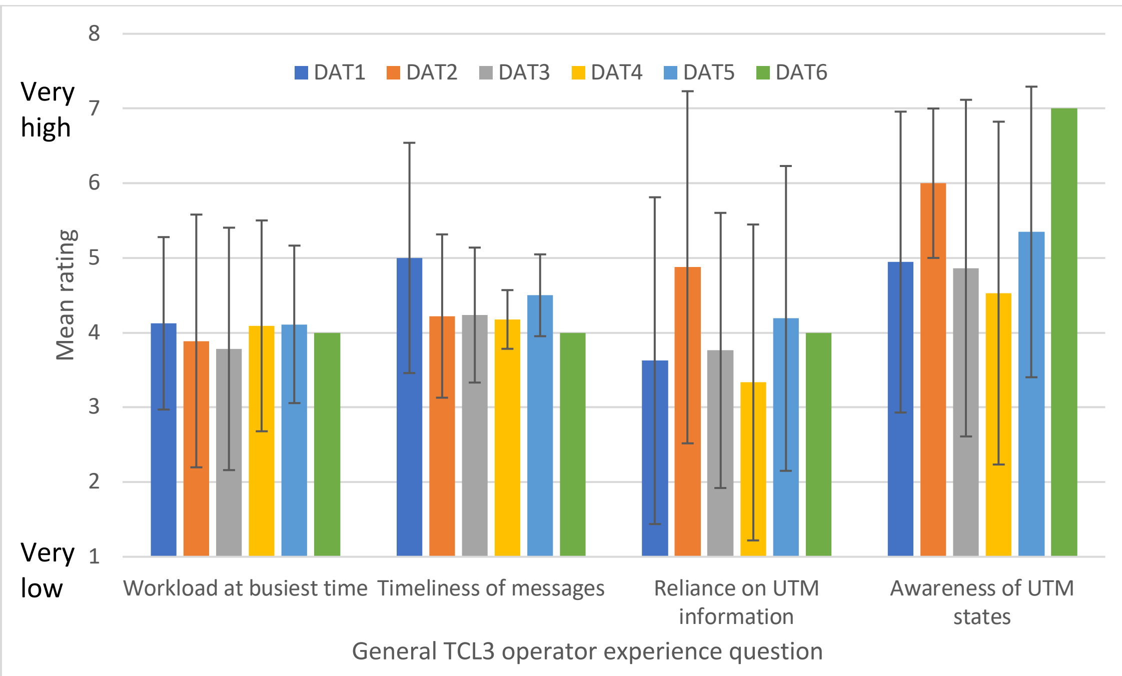

Figure 6. Operator experiences during DAT testing in TCL3 shown by type of DAT test (n = 67–90). Note: Rating scale was 1–7; y-axis is longer to show SD.

Of note is how large the standard deviation of the mean is for responses about SA, reliance (and workload) given the relatively large number of respondents. This emphasizes that opinions varied widely within tests, which could be due to the specific test site environment, the specific instantiation of the USS client or the way the scenarios were organized and run. In general, participants did not have any safety concerns during the DAT testing, although 25% of respondents said they were concerned once or more. Half of these responses were related to flight test execution—changes in test cards—but a second account for their concern was that participants felt the USS client they were using was "distracting" and caused confusion.

4.3.2 Information Properties

On average, participants rated all the properties of the UTM information they received as "good" with means varying from 4.7 for clarity of information to 5.3 for accuracy of information. Participants gave the highest ratings (on average) after DAT 5 (USS-USS negotiation) and the lowest after DAT 4 (UVIN/UAS ID exchange) (Figure 7).

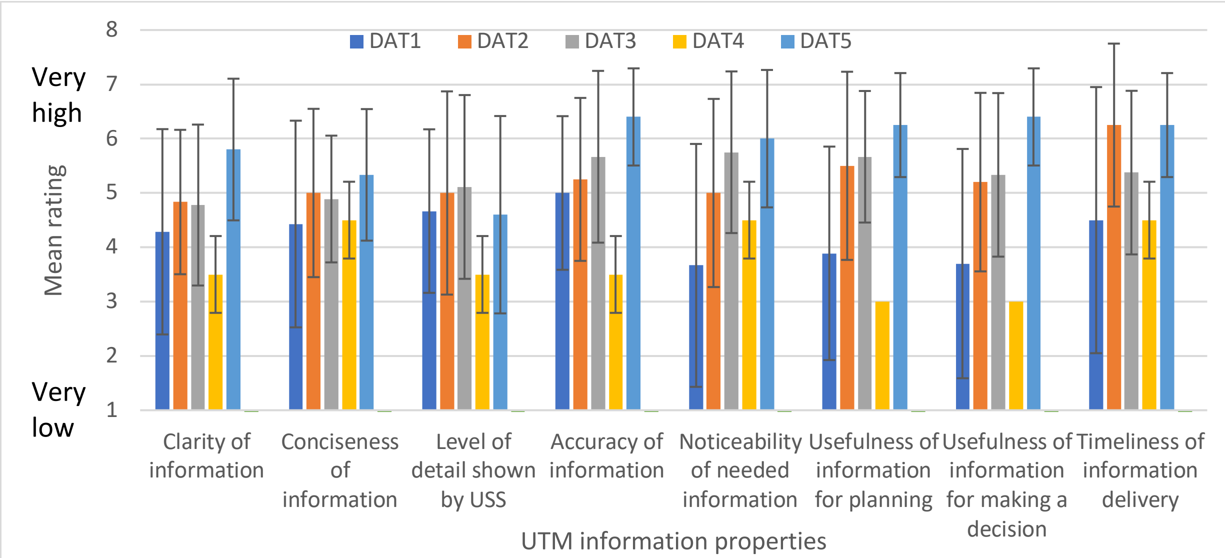

Figure 7. UTM information properties during DAT testing in TCL3 shown by type of DAT test (n = 24–30). Note: Rating scale was 1–7, y-axis is longer to show SD.

4.4 DAT 1: End-to-End UREP

The DAT 1 test was to send UREPs (UAS operator reports) through the UTM system to be received by others in the vicinity (see Rios, et al, 2018, for more details). Test sites were to gather data on the update rate, the data quality, the appropriateness of the data elements, and the effectiveness of the Supplemental Data Service Provider (SDSP) architecture. Survey questions asked about messages sent and users' thoughts about the information that UREPs provide (information exchange), while debrief prompts focused on the uses for, and automaticity of, the UREPs sent (Table 8).

Table 8. DAT 1: Discussion Topics and their Notional Categorization into Information Themes

Information Category	*Site 2*	*Site 4*	*Site 5*	*Site 6*
Information property	3		4	
Information meets user	2	3	3	1
Operator status				
Methods	3	1		
Automation	1	3		
Concept				

Test sites reported they sent five types of UREPs and received three types of UREPs, with point-outs of other traffic being the most frequently sent and received. Two sites (1 and 4) sent thousands of automated UREPs through the system (see Rios, et al, 2018, for details) whereas the other sites compiled and sent UREPs one at a time. Few crews relied solely on UREP information, with most saying they supplemented it by looking at data from other sources, and one or two participants reported they could not rely on the UREP information they received.

Participants were asked about the usefulness and timeliness of the UREPs they received in the DAT 1 survey (Figure 8). In general, crews gave a positive assessment of the usefulness of UREPs. Participants at one site said being informed of manned aircraft in the vicinity and having weather information was useful. There were some comments about feature usability, with one crew saying they did not like pop-up messages[4]. For specific survey questions, where only two sites responded, it should be noted that those participants were answering based on their experience with different USS client displays. Taken overall, participants at Site 5 rated their experience sending and receiving UREPs more favorably than those at Site 2. Site 5 participants reported having "enough" time to act, on average ($\overline{x}$ = 5) and that the UREPs were "somewhat useful" ($\overline{x}$ = 4.33).

For DAT 1, UREPs were generated and sent in a number of ways across four test sites. While one site (and a second unofficially) had the option to send automatic or manual UREPs, other USSs offered manual UREP generation only. Those who had to construct and send UREPs manually were keen to try an automated option. Crews commented that, although sending UREPs with information about what they were observing around their GCS was providing good information, it seemed strange to send 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.

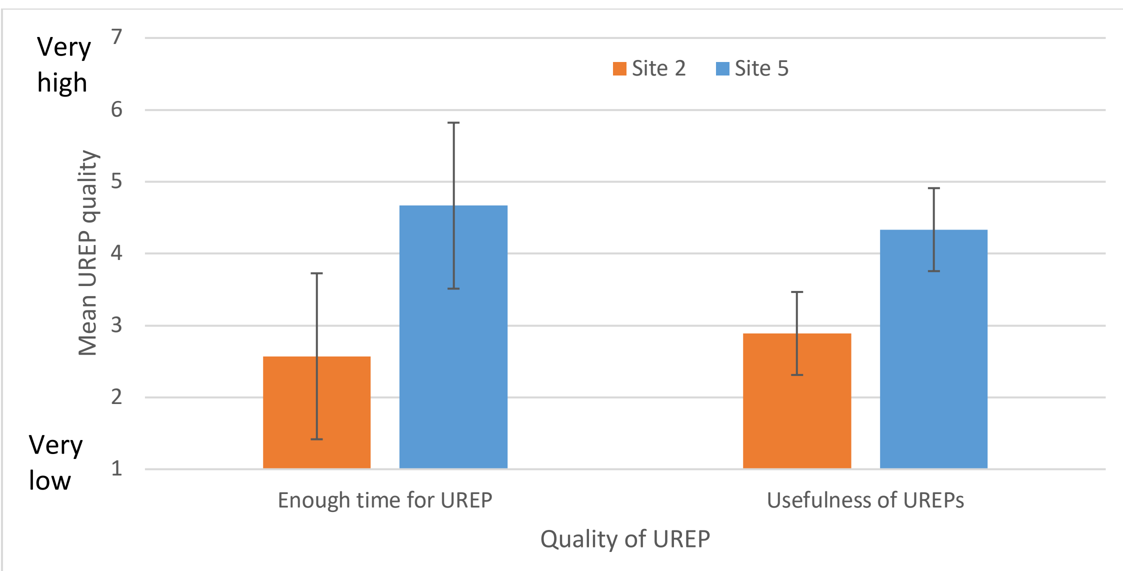

Figure 8. Quality of aspects of UREPs sent as part of DAT 1(n = 10–2).

One or two crews found bugs in their UREP software, e.g., one instance where the message self-deleted. Another crew stated that although it was easy for them to send a UREP through their USS, it was not easy to search for a new incoming UREP. Crews felt that UREPs could be useful to send

[4] On their instantiation of a USS client.

information about the local flying environment, such as noting flocks of birds or manned traffic in their flight area, and other UAS. Whereas one respondent said they would use UREPs to broadcast safety issues, another said that other means should be used for sending safety critical information as UREPs are only meant to share non-critical information. Users cited a number of additional features they would like to be offered by their USS UREP software: an ability to categorize the type of UREP sent, a tighter integration of UREPs in the USS software, and an alert to draw attention when a UREP arrives. (Note that some USS clients already have some of these features and every USS implemented the UREP functions differently.) When asked if they would like a way to send a return message, as this is not a function currently available, some crews declined, stating that UREPs are for information only, they are not intended to be a conversation channel.

4.5 DAT 2: FIMS Failover

The DAT 2 testing was to note the effects on operations and the UTM system in the event of a FIMS failure. Survey questions asked about operator awareness of the failure and concerns while FIMS was down (operator experience). However, most participants did not know FIMS had failed; only one in four confirmed that they knew when the system went down. Answers to subsequent questions were predictably, and perhaps artificially, benign due to the lack of awareness, with participants (very low n) reporting low levels of additional effort to maintain operations during FIMS failures, low levels of concern for safety, and good operational consistency while FIMS was down.

4.6 DAT 3: USS Failover

The DAT 3 testing was set up to fail all or part of the USS, note the effects through the UTM system, and to develop procedures for such an event. Survey questions asked about the impact of the failure on both the operator and the flight operations (operator experience), while debrief questions focused on the operator's experience, procedures and alerting (Table 9).

Table 9. DAT 3: Discussion Topics and their Notional Categorization into Information Themes

Information Category	*Site 2*	*Site 4*	*Site 5*	*Site 6*
Information property			4	
Information meets user		2	1	
Operator status		4	3	
Methods	2	8		
Automation		1	4	
Concept		4		

4.6.1 Operator Experiences

Crews reported that when their USS client was down for only a short amount of time, they did not have any issues when the system came back up. And if it was a limited fail, there were still some USS features available to them. But, when the USS client was down for longer, there were "surprises" as it came back on line, such as finding your UAS status to be rogue. Crews noted that the system does not know it has failed and is "catching up" as it comes back on line, that means they have to wait for information to repopulate also.

Crews realized they have to keep some awareness of what the USS client is displaying, so that when/if it goes down, they are able to assimilate what they know (and what information they have "lost"). They noted, if you are visual line-of-sight (VLOS), there is no issue but if you are BVLOS you have to be aware that aborting your mission, and that a return to base (RTB) could cause problems if you cut across in-use airspace to return home. Other crews noted that there should be a certain level of preparation for this prior to flying. You should know where your volume boundary is and you should never penetrate that boundary, especially when the system fails. This means that you can still operate safely under UTM and under a USS failure, as long as your boundaries are not conflicting because, as long as everyone plays by the rules, they will not be in your airspace, whether or not you can see their position through the UTM system.

Participants were asked about the additional effort required of them to maintain operations during the USS failure, whether they were concerned about safety during this time, whether their recovery time was reasonable and the efficiency of flight operations during USS failure in the DAT 3 survey (Figure 9). In Figure 9 the first two items are negatively scored (a higher rating is more negative), with participants noting that they were not concerned about safety and only had to put in a small amount of additional effort to manage the USS failure, on average. Those at Test Sites 5 and 6 reported the lowest concern about safety ($\overline{x}$ = 1), although only Site 5 also reported a low level of additional effort ($\overline{x}$ = 1). Participants at Test Site 6 reported their operations were "very efficient" ($\overline{x}$ = 7) and their recovery time was "very reasonable" ($\overline{x}$ = 7).

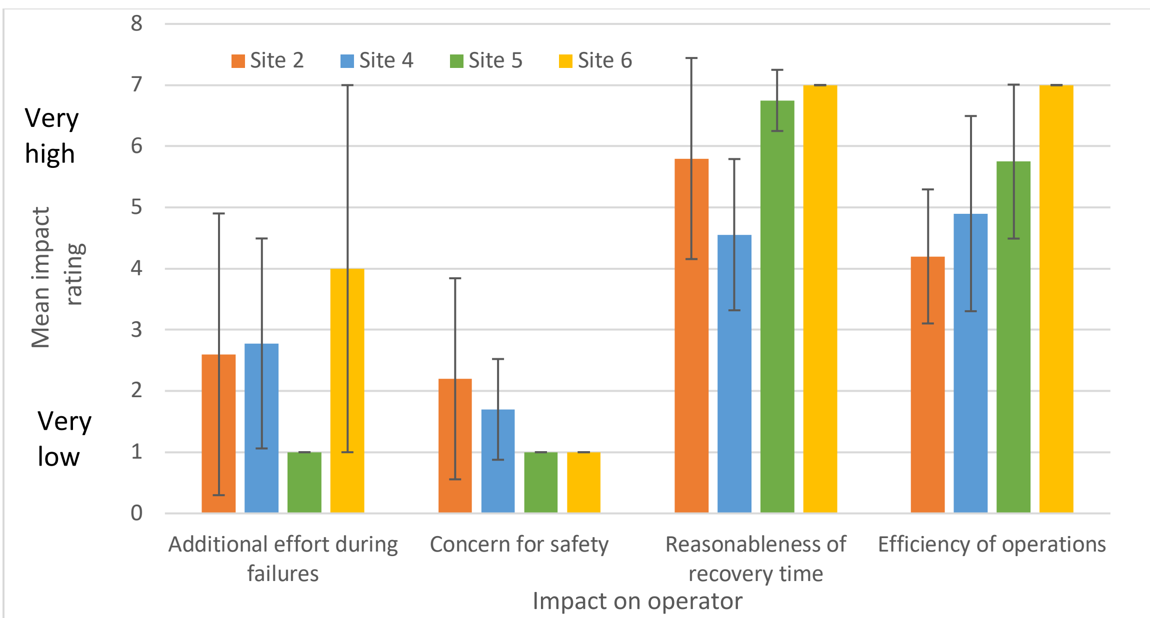

Figure 9. Operator effort, concerns and recovery during USS failure (n = 19–21). Note: Rating scale was 1–7; y-axis is longer to show SD.

4.6.2 Operator Experience: Situation Awareness

Only 21% of respondents reported they had problems executing flight operations while managing a USS failure, noting that it was difficult to maintain SA for those who could not see the vehicle when their USS was down, and that operational USS clients could not plan operations while a USS client covering the same area was down. One or two participants noted there was no issue with their USS client being down by invoking Part 107, a set of Federal Aviation Administration (FAA) rules for

UAS operations under 55 pounds. For these crews, Part 107 was a way to keep flying outside the confines of UTM, with one participant noting that "operators don't want to be restricted" when they feel there is no "reason" for it.

4.6.3 Methods: Procedures

Crews noted that, having executed DAT 3, they would like more definition about how to handle USS failures. They realized they needed to assess what was happening, what the impact of the failure was, what other tools they had available, and what they knew at that point in time about other operations in the air. Based on this assessment, they needed to decide about how to act. They felt that if this evaluation and option choice process was more formalized, it would have helped them react to the DAT 3 situation. Also, for those using a different client, what should they do on finding that another USS client operating in the same area is down? One test site discussed that procedures could be defined for different levels of USS failure—a short outage, versus a medium length outage, versus a long outage. For example, with a short outage, you may have an option to hover in place until the USS client comes back up, but for a long-term outage you may need to RTB or land in place.

4.6.4 Information Exchange: Alerting

Crews suggested that when a USS client fails, there should be some kind of alarm or alert to warn them that it is offline. Crews noted there were too few indications that their client had failed, as some parts of the display continued to update. There were also some concerns about the strain that would be placed on the human-communication system during a USS client failure, as users call client suppliers when they lose their display.

Crews talked about the wider ramifications of a failure like a USS failure. If you have other tools that allow you to see the locations of other vehicles, i.e., some redundancy between systems, then the loss of your USS is not critical, however, if your USS client is your only source of detecting other aircraft, losing it is a critical failure and your choice of action would need to reflect that. For example, if the USS was providing a surveillance service, then when it goes down you lose your awareness of what is close to your airspace, and if you happened to have a vehicle transiting your area then you would lose awareness of what it is doing. At this point the threat is very different from a situation where your USS is not providing surveillance. Hence, threat assessments when a USS goes down can vary widely by situation.

4.6.5 Automation

Test sites did learn about the functionality of, and the graphical user interface (GUI) of, their USS clients through this exercise. While some found that their USS sent automatic RTB notices some number of minutes after failing, others found their vehicles were assigned a rogue status. One commenter was concerned that having one USS down may bring others down as the system keeps trying to report data to a USS that is not accepting data. Crews said that the only message that needs to be continually shared when a client is down are "rogue" messages, and all others could be suspended to reduce load on the system. Observations made as a result of using the USS GUI during a failure included that the USS status indicator (health) needs to be very clear, as does vehicle volume status.

4.7 DAT 4: UAS Identification

DAT 4 evaluated the general effectiveness for retrieving vehicle/operator information from a registered vehicle that is broadcasting a UAS Identification (UAS ID) signal. Test sites were encouraged to develop multiple configurations or implementations of the concept for this test. In one case, a test site identified two vehicles flying simultaneously using three different communication methods; ADS-B, secure C2, and an infrared beacon. Other crews noted that this scenario could be made complex but that they had designed a simple scenario that looked at when the UAS ID dropped out. Survey questions asked about this data exchange (information exchange), while debrief discussions focused on the crews' experiences during the test and technical issues (Table 10).

Table 10. DAT 4: Discussion Topics and their Notional Categorization into Information Themes

Information Category	*Site 4*
Information property	
Information meets user	
Operator status	15
Methods	8
Automation	12
Concept	11

Overall, crews reported that their DAT 4 testing went well. They enjoyed the scenarios the site had put together and thought the test showed some interesting aspects of the concept. Crews reported that the UREPs added awareness and they liked the interrogation feature. Some crews took part in a scenario in which the UAS ID dropped intentionally as the vehicle flew away to test the effect of having no identification. Other crews reported that it took them a long while to find the "bad actor" vehicle when it was not reporting. However, other UAS' IDs dropped unintentionally as they flew further from their GCS, causing the same effect of lack of SA, but in this case, they could not switch the UAS ID back on, and had to wait until the vehicle came back within range to receive UAS ID reports.

Participants agreed that some aspects of DAT 4 could be more streamlined and reported that they had added some features to their USS clients (above the basic test requirements) that they found useful. The group reported that NASA had issues participating in their DAT 4 test, because on that day there were too many connections into the NASA server, i.e., the server had more traffic than it could manage. Once the issues on NASA's side had been resolved, the problems for the test site cleared up as well.

4.7.1 Information Exchange

Participants were asked about the usefulness and timeliness of the UVIN/UAS IDs that they received in the DAT 4 survey (Figure 10). With only two sites responding to these questions, it should be noted that participants were looking at different USS client displays. Taken overall, participants at both sites rated the data exchange process favorably. On average, they thought the UAS ID data exchanges were "useful" ($\bar{x}$ = 5.6) and "quite timely" ($\bar{x}$ = 5.3).

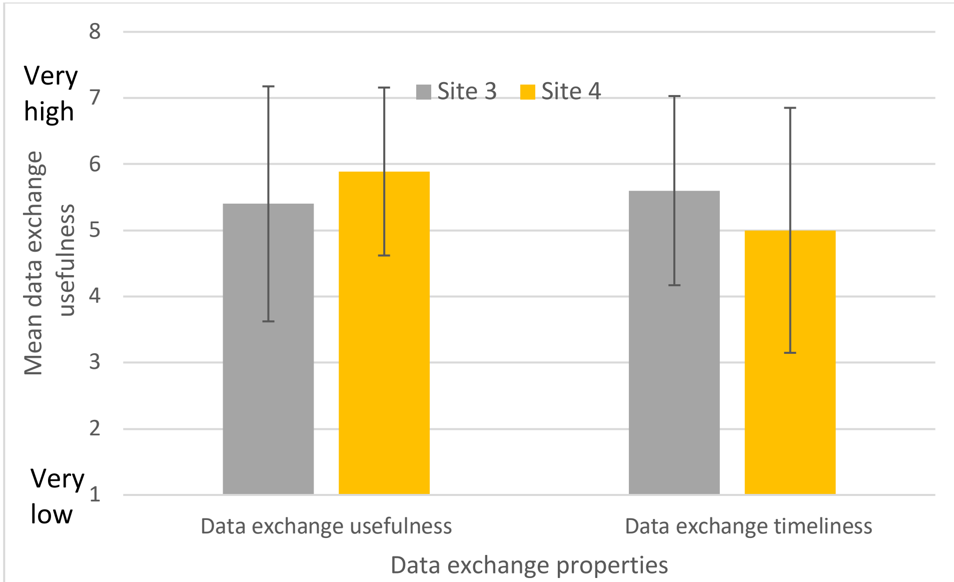

Figure 10. UVIN/ UAS ID data exchange usefulness and timelines (n = 18–19). Note: Rating scale was 1–7; y-axis is longer to show SD.

4.7.2 Operator: Communications

Participants suggested that voice communications (over the radio) worked well in certain circumstances. They noted that if you were a UAS operator working where there are manned aircraft, a good way to ensure broad situation awareness among all parties would be to announce your intentions on the radio in the same way that pilots of small general (GA) aircraft do. To do this, all UAS operators would need to know how to follow aviation radio conventions and carry a handheld radio. The participants acknowledged that this may not be a scalable solution if there are hundreds of UAS in the air but in a local area with just a few operations this could be a workable solution.

4.7.3 Concept

One crew stated that they thought the concept was useful to enhance situation awareness for their operation to be able to identify a UFO in real-time. Crews noted that the UAS ID procedure will identify operators who are “clueless” but not those who are malicious. In general, crews reported that pilots will comply with the UAS ID procedures as they do not want to get into trouble, but again, those who have ill-intent will not care about this. One crew noted that the registered user for their vehicle, who was revealed during the UAS ID test, was someone who no longer worked in the group. They commented that managing and checking valid information attached to UAS ID could be a large task.

4.7.4 Automation: Technical

A number of technical issues were raised during debrief discussions:

- Crews thought that when they were flying their vehicle away from their GCS, that the vehicle itself shielded the UVIN/UAS ID transmission. More testing is required to explore this.
- Crews had some concerns that the ISN spectrum may not be broad enough for the usage that it will get for UAS ID transmission but thought that it worked well.

- Crews noted that they did not have a good idea of what the transmission station searches for as it looks for the UAS ID but that it seemed to work well in this small-scale test.
- They also wondered whether pilots will push-back if they have to purchase more equipment/ tools for their UAS (like the UAS ID transmitter).
- There were still some bugs in the software, one crew noted that there was no indication when there was an imminent intrusion into their volume, while another crew said there was no *alert* when there was an imminent intrusion.
- Another crew could not see the "unidentified" vehicles on their displays.

4.8 DAT 5: USS-to-USS Negotiation

Test sites reported they sent four types of messages and received five types of messages as part of their negotiations, with non-emergency re-planning messages being the most frequent topic of negotiation (5 sent and 15 received). The message negotiation process varied by site, two sites had a choice of methods for sending negotiation messages while the other two sites had a fixed method to send negotiation messages. Having a pre-determined message was by far the most prevalent method but sometimes this message was sent manually and sometimes it was sent automatically.

As DAT 5 testing was concerned with USS to USS negotiation, survey questions asked about types of messages sent and users' thoughts about negotiation (information exchange and operator), while debrief discussions covered all topics of interest but focused on automation, how information is used in UTM and the impact of negotiation on the operator (Table 11).

Table 11. DAT 5: Discussion Topics and their Notional Categorization into Information Themes

Information Category	*Site 2*	*Site 4*	*Site 5*	*Site 6*
Information property	8			
Information meets user	1	3	4	2
Operator status	7	7	6	
Methods		2	1	
Automation	1	14	4	2
Concept	1		1	1

4.8.1 Information Exchange

Participants were asked three survey questions about the value of USS to USS negotiations to their operations and whether they had any concerns. As shown in Figure 11, participants reported that the information they received during USS negotiations "moderately helped their understanding" of the situation ($\bar{x}$ = 3.6), they rated the negotiation as "somewhat efficient" ($\bar{x}$ = 4.1) and were "not concerned" about safety ($\bar{x}$ = 2). Participants from Test Site 2 were the most positive about negotiations increasing both the efficiency and their understanding of their operations, although they were also the most concerned about safety.

Figure 11. Opinions of aspects of the USS-to-USS negotiation process (n = 2–24). Note: Rating scale was 1–7; y-axis is longer to show SD.

4.8.2 Information meets UTM

Trust: Debrief teams raised a key issue that USS-to-USS negotiation requires crews to trust each other because each team has to share enough information to allow other teams to see the issue that requires the negotiation. Crews noted that if all teams are reasonable, negotiation works well, but that currently one crew can easily cut others out. Crews suggested that another variable to share with others could be the flexibility of your operation—e.g., if you can fly later or at a different altitude—knowing that may help negotiations go more smoothly.

4.8.3 Operator Experiences

Participants were asked four survey questions about their workload and SA during USS-to-USS negotiations. As shown in Figure 12, participants rated their workload, on average, as "quite low" ($\overline{x}$ = 2.8) and their awareness of both their operation and the surrounding airspace as "reasonably good" ($\overline{x}$ = 5.1 5.4). They also felt they had a "good amount of time" ($\overline{x}$ = 4.9) to take action after they had received negotiation information. Participants from Test Site 5 rated their average SA higher and their workload lower than other sites and were positive about receiving negotiation information with enough time to act. Crews also reported they had enough time to make decisions after the USS indicated there was a need to negotiate.

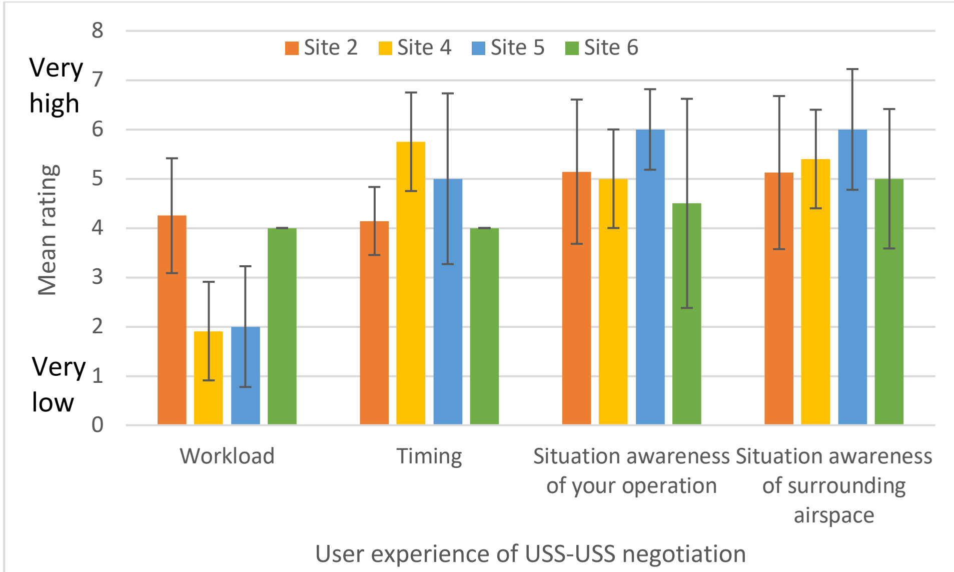

Figure 12. User experiences during the USS-to-USS negotiation process (n = 19–26). Note: Rating scale was 1–7; y-axis is longer to show SD.

4.8.4 Method

The methods for USS-to-USS negotiation need polishing. Crews suggested one area in particular is to set a limit so that negotiation is not occurring at the time of launch. Participants said firstly, that it is awkward and distracting to be negotiating during the take-off sequence and procedures should be set to avoid this. Secondly, if you have planned and set up a flight for weeks or months, it will be disruptive, frustrating and disappointing to have your plan negotiated away. They suggest there should be a clear window before you launch where someone else cannot request your planned volume.

4.8.5 Automation

The amount of automation employed for the DAT 5 tests differed among the test sites. One on-site NASA representative noted that human intervention was not required for the operations at one test site because of the high level of automation. At another test-site, the NASA representative observed that verbal communication was necessary for coordinating DAT 5 tests, and asked, "What if pilots or GCSs weren't close enough to each other to verbally chat. Would that change a response to a request for clearance to fly in the same airspace?" (Appendix 8).

4.8.6 Concept

In their survey comments, many agreed that USS-to-USS negotiation was an interesting and useful exercise, although more complex than they had anticipated. The issue of other USS "policing" or "blocking" space was raised a number of times. Participants noted instances where they were unable to complete their testing as they wanted because they had been blocked by others, e.g., an interesting case with one USS policing other operations in the local USS network (LUN). The crew with this USS viewed that as a capability but others who were shut out did not: "We were conducting coordinated flights. With the not-involved USS sending a rejection, we had to cancel." All commenters recommended that this should not be possible within UTM.

4.9 DAT 6: Weather Service

The DAT 6 testing aimed to send weather (Wx) UAS operator reports through the UTM system to be received by others in the vicinity (see Rios, et al, 2018 for more details). Survey questions asked about the weather messages sent and what weather information users' make most use of (information exchange), while debrief questions focused on the usefulness of weather information at a GCS. USS clients pulled in weather data from a variety of sources including national weather data and local university weather reporting.

In preparing their flights, crews use all sources of weather data available to them. Crews noted that UAS operators who have manned flight qualifications, already have a routine for collecting weather data during flight planning, the sources they prefer, and checklists that they like to use. Even though crews usually used weather reporting systems, for DAT 6 they did look at the weather data on their USS client and reported that much of the weather data they would want to look at was available. Most often used was 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, because you could see clouds and precipitation by looking out from the GCS.

The range of weather information crews used reduced as they moved on to flying their vehicles. Pilots said that once they were flying their UAS, weather checking is all local and observational, they do not refer to weather sites any more. Although this might suggest that crews did not like the USS weather reports, this was not the case. Those who did not have their own weather station liked receiving the USS weather reports, and none said they did not like the additional source of weather information. They reported continuing to check winds on the ground and aloft, visibility, density altitude and temperature, as well as just looking at the sky, but stopped checking precipitation and humidity once they were in flight. Their confidence in the weather data they used was high, as they reported it was accurate ($\bar{x}$ = 6), reliable ($\bar{x}$ = 6) and trustworthy ($\bar{x}$ = 5.75).

Crews listed a number of improvements that could be made to the USS weather reports (note that each USS client is unique and these comments only apply to the tool a participant used). There were some issues with weather UREPs populating over other data–crews felt a minute-by-minute update rate was too frequent–and updates every 15 minutes would be regular enough. Someone suggested using National Oceanic Atmospheric Administration (NOAA) symbology on the USS clients to indicate weather more efficiently, while another suggested weather reports should not be used to share critical information. One USS developer reported they are trying to organize the input to weather reports and UREPs to reduce the typing load as much as possible.

4.10 DAT Tests Summary

DAT tests exercised functions of the USS and different types of UTM messages; they were successful, with test site crews reporting they learned more than expected from the exercises and gained an appreciation of how complex message exchange could become. Opinions and experiences varied greatly across these tests depending on the USS development.

Despite this, there were three points that crews made consistently:

- Rules or procedures for message sending and methods for interacting with messages need to be formalized

   - Procedures: When a USS failed, it was unclear how crews needed to react. Moving forward, test sites should be encouraged to have a set of procedures that specify what to do in the event of a USS failure.
   - Procedures: Crews found negotiation as they were trying to launch their vehicles distracting and workload intensive. Moving forward, it is suggested that the negotiation end time be specified before a flight begins and/or before the volume becomes active.
   - Gaming: When they found their airspace already in use, some crews switched to become a Part 107 flight to avoid delays, others set up large volumes to clear the airspace for themselves. Moving forward, rules need to be developed to prevent users gaming the system.
   - Trust: To negotiate successfully, users need to share an amount of information, which may vary depending on the conditions. Moving forward, an effort to specify the information that needs to be shared for productive negotiation under a variety of circumstances would be useful.
- Interfaces for reading and generating messages need to be improved, including alerting and reducing clutter
   - Usability: USS client usability in general, and their available features, varied. Moving forward, useful steps could be to implement some of the suggestions crews had for improving their USS client displays (e.g., a UREP search function, that messages persist somewhere but do not clutter the main screen).
   - Alerting: Crews thought the system failure alerts were poor. Moving forward, there is a need to improve the alerting for system crash events.
- Crews realized that maintaining an awareness of DAT messages and USS interactions is useful and could be important
   - SA: While general SA was reported to be good, crews recognized the need for good SA at all times, as they will need to draw on their own knowledge in the event of a system crash.
   - Function: As some USS came back after a (planned) system failure, crews discovered a number of unexpected features in their USS clients. Implication: It would seem useful to explore these corner cases, with an aim to make the functionality of USS recovery more user friendly.

5. Concepts Tests

The Concepts and Use Cases Research Transition Team (RTT) Working Group is responsible for the collaborative development and definition of the UTM concept in terms of overall principles and assumptions. Elements of the concept are conveyed through use cases that span the range of UTM operations and serve to identify information flows, highlight roles and responsibilities of stakeholders, and provide an understanding of envisioned operating environments. For the TCL3 flight tests, there were a total of five concept tests that were conducted at multiple test sites and were referred to as CON tests. These tests were designed to exercise key areas of the TCL3 concept and provide input to other UTM RTT Working Groups and programs as required.

The CON 1 test investigated the planning considerations and technologies associated with a BVLOS landing, takeoff, and return to base. Test sites were encouraged to vary the locations of their BVLOS operations to provide insight into a wider range of applicable scenarios. The Contingency Initiation test (CON 2) had test sites coordinate a planned emergency that necessitated activating a prepared contingency plan. Examples of possible contingencies were given as a "ditch" at a known location, a return to base, or an automated loiter, and test sites were again encouraged to develop several configurations of this test. CON 3 looked into the usability of a UTM public portal. Test sites demonstrated the safety of flying Multiple TCL2/3 Operations for a sustained period in CON 4, in the same airspace, demonstrating a more realistic dynamic environment. These were interacting operations with distinct scenarios (e.g., multiple deliveries, traffic monitoring, infrastructure inspection, real estate photography) to be flown for a few hours. Lastly, the CON 5 tests explored the FIMS/USS interaction when a vehicle headed towards controlled or unauthorized airspace.

Five of the six test sites were awarded one or more CON tests, with one site being awarded all five CON tests. Note that the CON 3 public portal test results will be analyzed in a separate effort from the current document. From here onwards, CON3 will be excluded from the counts and tallies reported. In total, 14 CON tests were awarded and these awards were distributed so that each CON test was performed by either three or four test sites. Test sites conducted these 14 tests over 15 calendar days, across three months, often performing them in parallel with other tests.

5.1 Method

5.1.1 Surveys

There were 58 questions in the CON survey, with the questions preselected to show only between 15 and 29 of these questions depending on the test, e.g., those completing CON 4 saw 15 questions—nine general and six specific to the CON 4 test—as well as information questions to determine participants' role and test site. Those who answered questions about CON 2 received 29 items, the same nine general items and 20 CON 2-specific questions. Many items asked the participant to rate their answers 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. Sixty-one surveys were started in total across the five sites, all of which had some data entered but not all were complete. The greatest number of surveys started at one site was 19 and the fewest was eight, but note that although one site undertook all five CON tests, another only undertook one.

5.1.2 Debrief

There were 16 debriefs that focused on CON tests hosted across the five test sites. Twelve were specific debriefs focused on one CON test while the other four touched on more than one (see Appendix 10). Numbers of discussion prompts varied as researchers wanted crews to discuss and explore the topics within the time available. Prompts focused on operator situation awareness, the way the UTM system added value to the test flights, the perspective crews had gained from the tests and technical issues of concern.

5.2 CON Metadata

CON tests accounted for the most operations for TCL3 testing with 401 operations submitted to UTM. Of these, 27 originated from the NASA lab for collaboration with the test sites, while 374 originated from the test sites themselves. CON 1 had 13 operations submitted by the test sites, CON2 had 22, CON4 had 311, and CON5 had 28. As shown in Table 12, there are gaps in the data where it is likely that flights that were participating in certain CON tests were simultaneously serving a role in a parallel test but were not noted as such in the data.

Table 12. Number of Live and Simulated Flights Providing Data for TCL3 by CON Test								
	NASA	*Site 1*	*Site 2*	*Site 3*	*Site 4*	*Site 5*	*Site 6*	*Total*
CON 1		4		4			5	13
CON 2	10	8					14	32
CON 4	5	34			25	2	250	316
CON 5	12	18	1		6	3		40
All CON	27	64	1	4	31	5	269	401

Note: Colored cells with no flight number identify where the number of operations to fulfill this test are unknown.

5.3 General CON Feedback

A standard set of nine questions were asked at the end of every CON survey. Participants were asked to rate the information they used, timeliness of actions, their opinions of the information they received through the USS clients, and their safety concerns.

5.3.1 Methods: Operational Effectiveness

In the surveys, CON participants rated their flight operations in terms of their efficiency, timeliness, and the degree to which they relied on UTM information to achieve those. Crews were positive about their operations. On average, they rated the timing of UTM messages as "right on time" ($\overline{x}$ = 4.1, note the midpoint of the scale was the most positive option in this rating) and reported that their operations were "efficient" ($\overline{x}$ = 5.4). To do this, they relied on UTM information "about half the time" ($\overline{x}$ = 4.0), although this degree of reliance varied between crews (Figure 13).

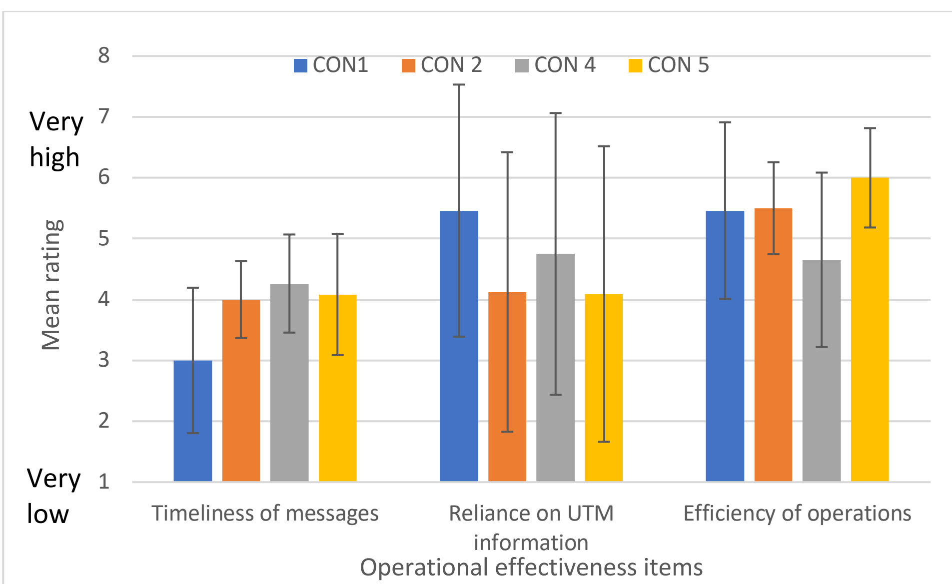

Figure 13. Operational efficiency for CON flights in TCL3 shown by type of CON test (n = 45–48). Note: Rating scale was 1–7; y-axis is longer to show SD.

5.3.2 Information Properties

Participants were invited to rate eight properties of the UTM information they received through their USS (Figure 14). On average, participants rated all the UTM information they received as "good" with means varying from 3.7 for noticeability of needed information to 4.8 for accuracy of information. Participants gave the highest ratings (on average) after CON 1 and the lowest after CON 5, where there was a FIMS/USS interaction.

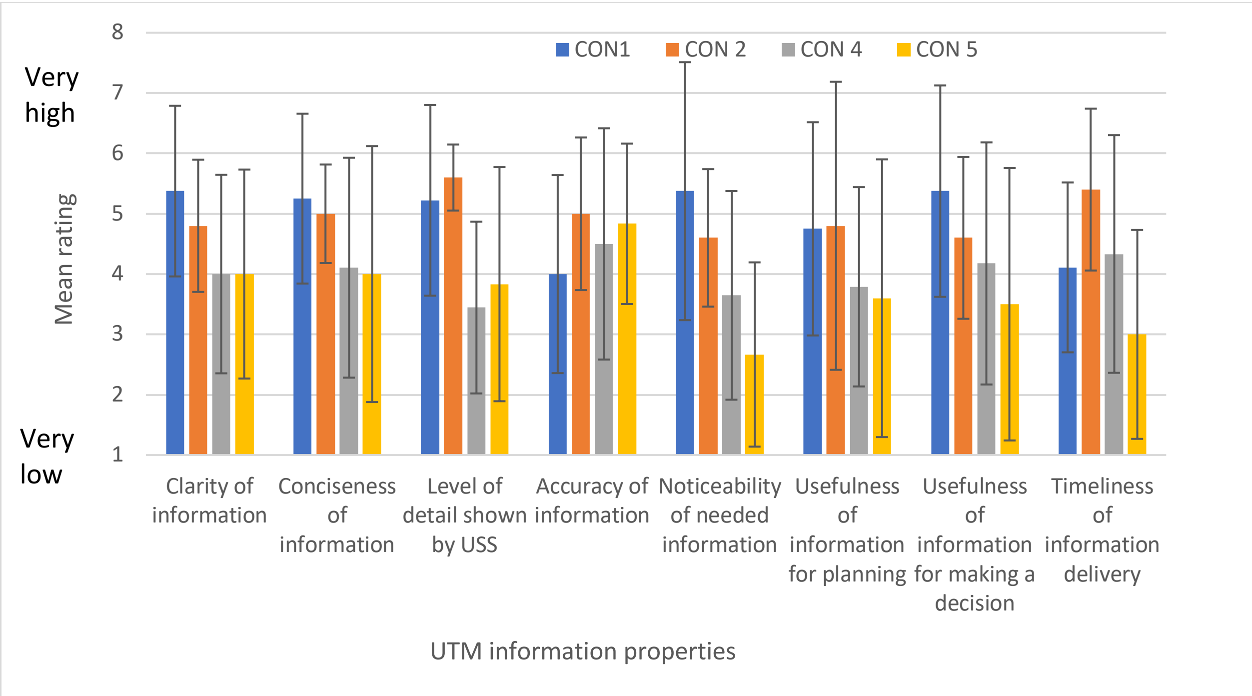

Figure 14. UTM information properties during CON testing in TCL3 shown by type of CON test (n = 33–39). Note: Rating scale was 1–7; y-axis is longer to show SD.

Participants were asked about workload after every CON test, but the question was tailored to a specific time, so each of the bars in Figure 15 represent slightly different questions. On average, participants rated their workload as "low" to "moderate" during the CON flight tests, with CON 4 having the highest ratings, when they were asked about workload during first and last flight sessions of the day. Crews' lowest workload ratings were during CON 1, when they were asked about when they were landing/taking off BVLOS.

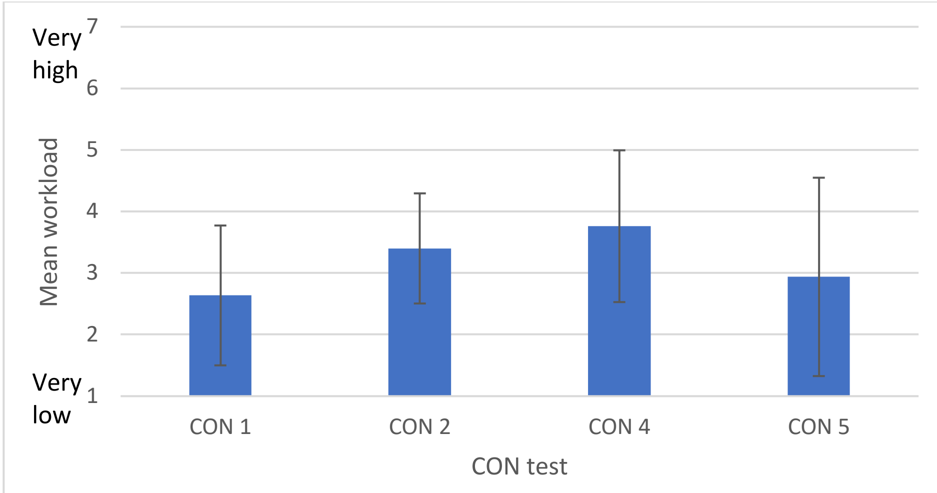

Figure 15. Operator workload during CON testing in TCL3 shown by type of CON test (n = 3–23).

5.4 CON 1: Take-off and Landing while BVLOS

The CON 1 testing asked crews to operate their vehicles beyond VLOS to land and take off remotely. Two of the three test sites arranged for their vehicle to launch within LOS, fly to a remote location, land, take off, and return to base. Test Site 3 operated their vehicle remotely for the duration of the flight and added an indoors/outdoors component to their CON 1 flight tests. Survey questions asked about users' situation awareness during these maneuvers and users' thoughts about the safety of their operations (operator experience and concept), while debrief prompts focused on situation awareness, risk assessment, and operation of UTM (Table 13). As intended, testing for the CON 1 TCL3 use case contributed to understanding of other non-CON tests and the general TCL3 UTM concept. For example, at one test site, an interior BVLOS takeoff and landing also touched upon strategically using multiple communications links to maintain command and control of the vehicle when there were physical obstructions blocking the primary signal, similar to CNS testing.

Table 13. CON 1: Discussion Topics and their Notional Categorization into Information Themes

Information Category	*Site 1*	*Site 3*	*Site 6*
Information property		3	
Information meets user		6	
Operator status		6	
Methods		1	
Automation		7	
Concept		4	

5.4.1 Automation: Technical

Crews from Test Site 3 discussed the difficulties of flying remote indoor/outdoor missions, as sending telemetry data from a vehicle inside one building to the operator inside another can be challenging. A change from one set of telemetry data to another was required as the vehicle exited the building, with the redundant secondary source having to be verified in flight. On re-entry, the crew brought the vehicle back into the building in a series of steps because they needed to make sure they had good video feed to provide the PIC with situation awareness. Crews stressed the importance of good telemetry data and multiple sources of data in this high-risk scenario.

5.4.2 Operator Experience: Situation Awareness

Participants were asked about their SA when they were operating BVLOS and how helpful the USS information was during remote flights (Figure 16). Crews estimated that their SA both for their operations and for the surrounding airspace was "high" ($\overline{x}$ = 6.25) but they reported that the USS was only "a little" assistance with their BVLOS maneuvers ($\overline{x}$ = 2.8), although the standard deviation for Test Site 3 is large, indicating that participants did not agree on the usefulness of the USS client. With such good SA, participants reported that they were only "sometimes" concerned about the safety of their BVLOS operations ($\overline{x}$ = 3.6), however there was, again, a large variation in participants' ratings, with some respondents saying they were "never" concerned and others saying they were "always" concerned.

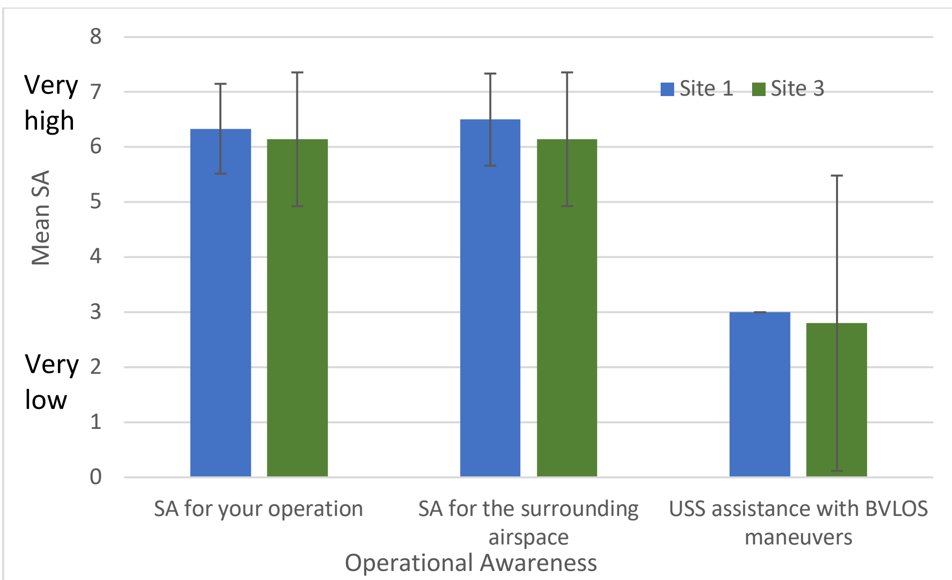

Figure 16. Operator awareness during CON testing in TCL3 for test sites 1 and 3 (n = 6–13). Note: Rating scale was 1–7; y-axis is longer to show SD.

Crews at Test Site 3 commented that on-vehicle cameras were important for remote landings to provide situation awareness to the PIC/GCSO, especially when that remote location was indoors, as other sources of information may become unreliable from within buildings. This meant that the PIC may have had to rely more heavily on their camera feed as they were trying to navigate indoors and other telemetry drops out. They noted that risk assessment is more challenging, and more stressful, when the PIC is remotely located than when s/he is in VLOS of the vehicle for takeoff and landing, as a remote PIC is relying completely on their sensors and the fidelity of the telemetry. If the sensors drop out, they have fewer resources to base their decisions on. The on-site NASA representative noted that as the vehicle approached the indoor landing area, the remote PIC and GCSO both gradually switched all of their attention from monitoring the mission planner software to tracking the vehicle's live video feed. For their test, there was an additional level of challenge because the various feeds the PIC needed to monitor were not all on one tool.

Crews were "moderately confident" ($\overline{x}$ = 4.2) that their vehicle was behaving as they expected. One person said this was because they had prepared well, while others commented on good telemetry, good person-to-person communication, good camera feedback and good visual observers as the reasons they felt confident. One person, who was less confident, reported this was because the winds were close to the upper operational limit for their vehicle.

Crews also discussed another situation where risk management and SA are crucial and good information can make large differences in quality of decisions made—incursion into one volume by another vehicle and, in general, emergency events. During an incursion, crews noted that they need information quickly and they need it to be accurate. However, respondents did not want as much information as possible, they wanted to be assured they would have key information. Everyone in the group cited different items of information that they would like to know about the vehicles intruding into their airspace: 1) its position, altitude, speed, and heading; 2) its mission; 3) whether the "other" PIC has control of their vehicle; and 4) whether they are getting position information. These elements would allow a crew to assess the best action to take with their vehicle. Others were hoping for new features in the UTM system, for example an alert and a direction arrow to point to the impending issue.

5.4.3 UTM Feedback

Having used the UTM system during their CON testing, participants provided feedback about their experiences which fell into three categories: comments on features or functions that are currently available to them through UTM, features or functions crews would like to have in UTM, and how much they used their USS client.

Use of client: Crews reported looking at their USS client for information to varying degrees. One PIC reported that s/he never looked at his/her client when s/he was flying as it was not something that was useful to him/her operationally. But this PIC noted that "there was a lot of weird stuff happening" on their USS on that particular day. The NASA representative for these flights noted several times that the PIC and GCSO rarely checked the USS client unless it was in their checklist to do so.

Opinions on USS features: Crews liked some of the available UTM functions, but disliked others. Some participants disliked that a rogue status is unrecoverable. Participants noted that, in the future, operators would want their volumes as small as possible so that they can get as many vehicles flying close together, and something that impedes this is the volume buffers being standard sizes. Crews gave two additional reasons for disliking the way buffers are set up in UTM. Firstly, participants stated that they had to make their volumes much bigger than they wanted to account for the influences of wind and ensure that wind-drift did not put them into a rogue status. Others argued that this calculation is more complex than it seems and an algorithm would need to consider both vehicle performance and its interaction with environmental conditions, although these respondents thought it would be easier to create flight plans if there were custom buffers for different vehicle types. Secondly, the buffers impede a crew from getting multiple vehicles as close together as they would like if they wanted to run synchronized flights. Participants noted that if crews shared their flight plans and one was flying a longer-distance leg, the volume could either close behind it, leaving the space available to others, or the space could stay open and a second vehicle could follow exactly the same flight path, just a few minutes behind the first.

Suggestions for new UTM features: Crews suggested a number of improvements to the information they received through their USS client. Note that these features were currently unavailable to participants through the particular USS client that they were using, but many of these features are available through other USS clients.

- Crews wanted to be able to share a GCS launch area between multiple vehicles, that is launch one vehicle after another from the same pad.
- In the case of overlapping volumes, when you are the second volume in line, participants discussed having a feature that would compare the parameters of your volume with the other accepted volume and would give you feedback on how long you will have to wait before the area is cleared and your volume could be accepted.
- Crews felt that the UTM system should be able to take holds or delays into account and move all the schedules into the future by the right number of minutes. The example given was if one crew has a five-minute hold on the ground, UTM should estimate, based on the submitted flight speed or sensed speed of the first vehicle, how long the flight is likely to take and then tell other operators how long they might have to wait.
- Crews noted that they would like a “clearer” set of information from the UTM system—something close to a countdown—where they would receive a message telling them how long they needed to wait after a previous flight launched before they could launch, then receive a notification when the first flight exited the launch volume, and a notification that they are cleared to launch. These ideas describe a system that takes something more like an air traffic control role, where the system assesses and assures clear airspace, which is not how the current UTM system is designed to operate.

5.5 CON 2: Contingency Initiation

The CON 2 test had test sites coordinate a planned emergency that necessitated activating a prepared contingency plan. Options included an incursion of one vehicle into the volume of another, or an “event” that required a vehicle to make an emergency landing. Two of the three test sites chose to have one vehicle breach the volume of another. The third test site set up an “event” where their vehicle had to land in place. Survey questions asked about users’ situation awareness during these maneuvers, their decision making and their reactions to their contingency plans, while debrief prompts focused on situation awareness, information that is useful, and risk assessment (Table 14). The contingency scenarios demonstrated in CON 2 also relate to other tests from TCL3, such as the general goal of the Sense and Avoid RTT to investigate conflict mitigations, and specifically the off-nominal conditions tested in SAA 5. From the UTM concept perspective, NASA is able to specify use cases that illuminate whether the current infrastructure and capabilities meet the needs of the user.

5.5.1 Information Desired

Participants listed many items of information that they would like to have when there is a vehicle in their vicinity that is having a contingency event. These items included being told the location of the vehicle in trouble, also its position, altitude, heading, velocity, flight trend, position history trail, and aircraft type. Other desired information was whether the vehicle was hovering, how far it was from their ownship, and whether it was in compliance. Some crews said they wanted information about every vehicle within a set radius of their ownship. However, an item of information that crews were clear they did not need to know was the nature of the emergency that the other vehicle was having. Crews talked about the way this information could be represented on a display, noting that symbols, colors and icons are better than text for conveying information under time-critical circumstances.

Table 14. CON 2: Discussion Topics and their Notional Categorization into Information Themes

Information Category	*Site 1*	*Site 5*	*Site 6*
Information property	2		6
Information meets user	5		9
Operator status	2		2
Methods	5		
Automation			
Concept			

5.5.2 Operator Experience: Situation Awareness

Participants were asked about their situation awareness while the contingency event was occurring and how effectively the alerting drew their attention to the event (Figure 17). Half of the respondents obtained information about the event from another team member, and the other half obtained their information through tools, although only one used the USS client for this (n = 7). Crews estimated that their SA, both for their operations and for the surrounding airspace, was "very high" ($\bar{x}$ = 6.7) but they reported that the USS alerting was only "somewhat" effective at alerting the emergency ($\bar{x}$ = 4) and was "a little" useful ($\bar{x}$ = 3). For the alerting questions, the standard deviation for Test Site 5 is large, indicating that participants did not agree on the usefulness and effectiveness of the USS client's alerting. Participants discussed that alerting is an important function during a contingency event and that a key item of information to share with others is the status of a vehicle, especially if rogue or out of conformance. If the USS client provider knows this information, they can take steps to broadcast that, and a wide alert lets others know there is an event occurring. The on-site NASA representative noted that at one site, the test notifications for the contingency event would be so frequent, and persist for so long, that the primary function of the display was obscured during critical phases of the flight. Alerting is important for operator situation awareness, but consideration should also be given for the primary task of aviating safely.

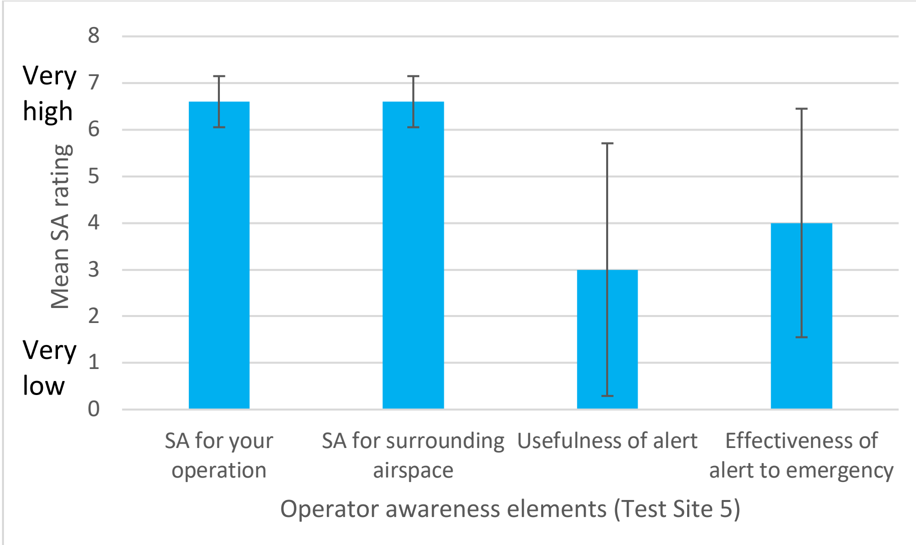

Figure 17. Operator awareness during CON 2 testing in TCL3 for Test Site 5 (n = 5). Note: Rating scale was 1–7; y-axis is longer to show SD.

Where participants found the USS client displays useful was in giving them a "birds eye" view of the activities going on in the airspace, so that they had an idea of how busy the airspace was even though they could not see it from their GCS. A second benefit was that, while the UTM tools are still in development, traffic displays give reassurance that the UTM tools are working properly. Crews at one test site liked the SA that the USS client gave them because it meant they were able to deconflict flights in real time.

5.5.3 Operator Experience: Decision Making

During the event, vehicles at Test Site 5 had the option to RTB, loiter or ascend/descend to resolve the situation. Crews reported they were "quite confident" ($\overline{x}$ = 5.2) that their contingency plans were the best response options to the event and thought they were "quite appropriate" ($\overline{x}$ = 5.2). They had no safety concerns during the flight tests. However, they estimated that they had "slightly less" time to react to the event than they had expected ($\overline{x}$ = 3.4). Despite crews reporting they were only "moderately confident" ($\overline{x}$ = 4.4) that their vehicle was behaving as they expected, crews reported in their surveys that they were not having any issues, e.g., "My aircraft was reacting as I controlled it. At no point did I feel that I had a loss or degradation of control." Crews reported that they were "moderately" confident that their USS client ($\overline{x}$ = 3.75) was behaving the way they had expected, although few people could see the display and so only these (few) people actually had the opportunity to see the messages that were sent through UTM.

Respondents varied in the amount of information they felt they needed to make decisions during contingency events. Some reported they just needed to make sure the airspace they wanted to operate in was clear of hazards and safe.

5.5.4 Operator Experience: Actions

Crews were divided over the best way to handle contingency procedures and alerting in UTM. The majority (4) thought that shared ability between manual and automated responses was the best solution, but others preferred fully manual or fully automated responses. Those arguing for fully manual responses did so because every contingency event is unique and needs a specific response. Those arguing for fully automated responses noted that the PIC will be too busy to send messages to other crews and local entities during an emergency situation.

Supporting the comments of those who said contingency events are unique, debriefs explored that crews were creative in the ways they reacted to events. One crew, who was operating the vehicle with the emergency, designed an RTB route and then built a TFR around it, essentially putting a volume around their vehicle for the RTB transit. They discussed the advantages of doing this; flying inside a TFR helps to flag the flight to other users.

The "innocent bystander" crews, who had another vehicle breach their airspace, said they would like the USS to tell them when that breaching vehicle (or vehicle that has an emergency and is transiting) has left their airspace, because they would like to know that it is safe to continue their mission at that point. One crew said that although their goal was to get their vehicle safely on the ground, they waited for the vehicle-in-trouble to land before they stopped their loiter, just to be sure that they would avoid a conflict.

5.5.5 Procedures: Emergency

In the case where there is an emergency, rather than have a TFR that requires operations to leave the airspace, crews discussed putting procedures in place where they make way for the emergency flight, "pull to the side of the road" to allow the flight to pass, but do not have to exit. From the other side of the problem, as an emergency vehicle, it would be good to know that the users of the airspace were being compliant and had vacated the space that you are now working in. The emergency responder would want to know that previous volumes were being closed and vehicles are down.

5.5.6 Procedures: Gaming the System

In general discussion, participants talked about some ways that bad actors could game the UTM system. They discussed that if you went rogue during the contingency event, this status then gives you priority over others, with the assumption that you are a disabled flight and you need direct routes to RTB. However, this creates a loophole that operators could take advantage of. If they submit a very small volume but then fly their mission in rogue status, under the contingency management rules this would give them a priority status over other vehicles to essentially bump accepted users out of their space, even though they were not in distress.

5.6 CON 4: Multiple Operations for a Sustained Period

The CON 4 test asked crews to fly their vehicles simultaneously for extended periods of time – two or three hours. Many test sites used these extended flight days to fly other tests concurrently. Survey questions asked about users' situation awareness and workload over time, while debrief discussions covered procedures, issues with reserving airspace, and alerting (Table 15).

Table 15. CON 4: Discussion Topics and their Notional Categorization into Information Themes				
Information Category	*Site 1*	*Site 4*	*Site 5*	*Site 6*
Information property	4	10	3	8
Information meets user		7	2	5
Operator status	2	7	1	1
Methods	3	11	3	6
Automation	7	11		7
Concept	3	10		2

5.6.1 Operator Experience: Situation Awareness

Participants were asked about different aspects of their situation awareness (SA) during the sustained flying period in CON 4 (Figure 18). At the beginning of the flight window, participants reported "reasonably good" SA on average ($\overline{x}$ = 5.4). By the end of the flight window, participants reported they felt their situation awareness was still "reasonably good" ($\overline{x}$ = 4.8) but it was a little lower than their rating at the start of the session, possibly indicating that participants felt some fatigue after flying for approximately three hours. However, this was very site-specific. Those at Test Site 4 reported the largest drop in SA during CON 4, while those at Test Site 6 reported that their SA increased (on average). To support this, participants from Test Site 4 reported that it was "moderately difficult" to maintain awareness at the end of the session (Figure 18), while teams at other sites reported they had less difficulty. The difference might be accounted for in part by differences in crew reports of how often they scanned their work area, with Test Site 4 scanning for nearby operations more frequently on average than other crews.

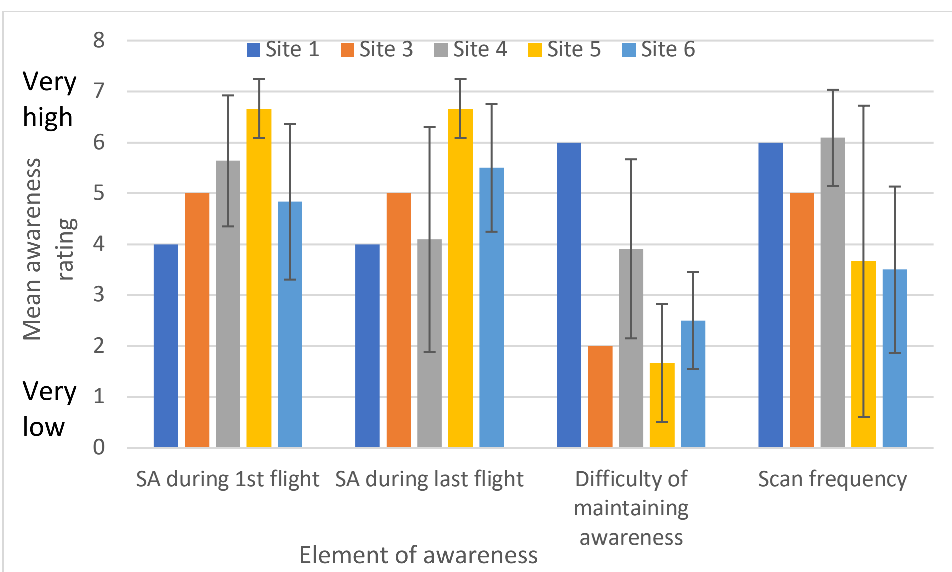

Figure 18. Operator awareness and awareness actions during CON 4 testing in TCL3 (n = 23). Note: Rating scale was 1–7; y-axis is longer to show SD.

Participants were asked which flights they paid most attention to. They gave a range of answers, from the flights during specific tests where a tool was intended to "fail," to flights that shared close launch/landing points (Appendix 9). In general, PICs were more concerned when they were flying BVLOS than when they could see their vehicles.

Crews discussed their awareness of other vehicles when they were flying. This was very dependent on the particular USS client implementation that they were using. Users were more comfortable with receiving information through the display if they could see flights visually (LOS). Knowing the location of adjacent flights was helpful, some users could see volumes, and one user could see volume start and end times, but others could not see any of these pieces of information. Those who could see volumes on their USS liked having this information. Information about other flights was limited for some USS Operators. One crew noted they were only sent the globally unique flight identifier (GUFI) of a flight that had gone rogue but no information about its location or the reason for the rogue state. Users said that if they were rogue, they would like to know the GUFI of the flight whose volume they were encroaching into—the universal unique identifier (UUID) of that volume. Crews were unsure whether they needed to know about vehicles that were having issues but that were not likely to intersect with their own operation in any way.

Other participants said they did not look at the USS client at all, even though it was available, because they were looking at other displays. To address this, some advocated that tools/displays should be combined to make it easier to track information from multiple sources.

5.6.2 Operator Experience: Workload

Crews were also asked to estimate their workload for the first and last flights of the CON 4 testing. On average, participants rated their workload as "moderate" at the beginning of flight testing ($\overline{x}$ = 3.9) but it reduced a little across the flight session ($\overline{x}$ = 3.5), although note that some test sites did not report a drop in workload. Those at Test Sites 4 and 6 reported higher workload initially but those at Test Sites 1, 3 and 5 did not, and this could have been due to the different site environments and the complexity of the scenarios. The usability of the USS client likely played into the level of workload experienced by the USS Operator.

5.6.3 Operator Experience: Roles

The crews at one site felt that using UTM was cumbersome. They had elected to have one USS Operator for all of their crews. The USS Op explained that having only one person to submit volumes for multiple crews was workload-intensive at times. And, if there were UTM messages that required a crew to change their plans, the USS Op had to relay these and then discuss the course of action with the crew before either party could take action. The USS Op explained that this was awkward and time consuming.

5.6.4 Concept: Procedures

Crews felt that the UTM system is vulnerable to operators being greedy and over-reserving space. There is currently no incentive to be economical with airspace, and it is easier to build a large geometric volume than it is to build a complex smaller polygon following your flight path. Also, having a larger space gives you a larger buffer. This is particularly true vertically. In the vertical airspace, crews said they prefer to reserve space from the ground to 400ft because they would only want crews they know and trust to fly in the altitude above them[5]. It is easier to book the whole vertical space to ensure that no-one flies over you. Examples of crews booking large volumes include: one USS Op, who said his crew's mission was to map the entire area, so he submitted a volume early that took over the whole test area, blocking everyone else from submitting. He said he felt bad because he knew he was stopping everyone else from flying, so the crew landed after their first flight and released the airspace but then they had to wait four hours to fly again. He said that in a real setting, the crew would not have done that and would have completed all their flights at one time, even if it was tying up the whole airspace. Another crew, who was on the field, described how they initially could not get a volume (because another crew had reserved the airspace they wanted to fly in). When the first crew had finished, the second crew reserved a huge airspace so now *they* could fly un-interrupted, but said they amended it to a series of smaller volumes, as they looked at the airspace usage for the rest of the day and realized that doing this would delay other groups in the same way they had been delayed. Instead, they organized who would use which space so everyone could fly simultaneously. A third crew felt that when their flights are for revenue, they would not be able to wait for another group who has booked the whole airspace where they need to fly. They concluded that, in this case, they would simply file to fly as Part 107 to make sure that they could complete their flight on time.

Participants stated that if the UTM system wants users to be as efficient as possible, it will need to provide incentives to users to construct efficient volumes (and possibly penalties for taking considerably more space than needed). Alternatively, the UTM system could help you to be efficient. Crews discussed that if you could put your flight path into UTM and have the system build a buffer around it, then that would enable efficient use of space, but the current system makes that impossible because it only accepts a limited number of points (10)[6].

In addition to issues of other crews booking large volumes and shutting them out of the airspace, crews told researchers that they had put dummy data into all the PII fields in their USS client. This meant when everyone at the test site began reserving airspace and their own reservations were rejected, they could not contact other teams to negotiate when the airspace would be free or how to share it. Crews complained they had to submit volumes using trial and error until they happened on an area that was accepted. One crew said they reduced the size of their volume until it was accepted, other groups used the site radio channel or personal phone contacts, i.e., pre-existing personal knowledge of other teams in the test, to negotiate verbally with others to carve out some airspace to work in.

5.6.5 Automation: Messaging and Alerting

Crews differed on their opinions of UTM alerting. One crew said they did not want too many alerts, while others said they would like warnings about nearing the edge of their volume to go directly to the vehicle. They suggested there could be automation that would allow the vehicle to interpret the message and speed up or slow down to address the issue.

Crews debated how flying their vehicle manually might interact with a fully-autonomous vehicle. They were not sure they could negotiate with an autonomous vehicle and suggested that there should

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[5] Also see section on faulty altitude readings. This is likely to add to crews' reluctance to let others fly above them.

[6] At the time of TCL3, the system only accepted 10 volumes, but this issue has since been solved; users can now have up to 250 volumes per flight geography.

be clearly defined "rules of the road" and either the manual or automated system should have priority. Others disagreed that priority should be based on level of automation, saying that every vehicle should have equal priority.

Participants suggested that USS clients should output the same messages as each other and these should be interpretable by whatever or whomever is receiving them (manual or automated). They stressed that every user should receive the same information and have equal chances to act on it. USS clients could display the information in different ways to suit the person/automation reading the messages but the base information going to all clients should be the same. That said, crews thought contingency messages should be automated rather than manually sent. Pilots noted that they did not have time to compose and send manual contingency messages in real time. PIC should not have to announce an emergency state to other crews in the area, that function should be automated.

5.6.6 Automation: Rogue

One USS operator said he would like to receive information from the USS about how close his vehicle is to the compliance boundaries. If he had this information, he would know whether he needed to adjust his vehicle to ensure that it stays well within its boundaries. He suggested it would also enable him to reduce his time allocated for different volumes. Others agreed for a different reason, saying that you do not get a lot of warning that you are going rogue and then you do not have time to react, and that more information about being in compliance might help you to avoid becoming rogue.

The USS designers informed researchers that they can assign whatever state that they wished to flights, that they did not have to assign rogue status because the definition of rogue used by NASA only applies to the NUSS. In some USS clients, when a vehicle went rogue, the system built a series of tiled volumes. This kept the rogue vehicle in a volume but crews wondered about the UTM state that they were in at this point, and about what happened to the other volumes in the airspace that they may have been overcutting. It seems that the new volume tiles were assigned higher priority than the original volume and so the vehicle went from rogue to priority status.

5.6.7 Automation: Safety

Eighty three percent of respondents reported that they had no safety concerns about the safety of their vehicle during the test. Of the four respondents who did have concerns, one said it was because their vehicle was only sending intermittent UTM updates, another had concerns about altitudes, a third had to take manual control of their UAS, and the fourth said that using UTM is a task in itself, which made it distracting and it took up time that should have been used to focus on flight control.

Crews debated whether UTM needs to be designed to accommodate airspace users who are not going to participate in UTM (Part 107 and others). They emphasized that there will always be vehicles in the airspace that are not following UTM, for example, crop dusters who may not want to install equipment so UAS can detect them. Others suggested that there should be incentives to encourage UAS crews and other airspace users to participate in UTM. This led to a discussion that UTM can be dangerous because it gives you a false sense of security that you are alone in your volume but, in reality, there could be other vehicles in that space that are not in UTM and that will not be shown on any of your displays. Discussions like this suggest USS developers might be encouraged to maximize transparency of the system and the use of detect and avoid (DAA) tools.

5.6.8 Automation: Using USS and UTM Information

Crews liked the USS client information that showed them volumes and said this helped them to stay in their volume. Some crews (depending on the USS client) were only able to see other flights that were using the same USS on their USS client display[7]. Not all crews were aware of this and that those using a different client would not be shown to them. They were confused at not being able to see the volumes for all operators in the area and commented that it made their task far more difficult. One USS operator said that his map was easy to use until he had to negotiate and then he could not see his plan to help him in that negotiation. Another USS operator said that managing only two flights was not an issue but he could imagine that trying to manage a dozen flights would be very difficult because the interface was not efficient. Another team commented that they would have liked to have their volume shrink dynamically as they covered the space they needed to survey, opening the area behind them up for others. Crews discussed that, with their USS client, that type of dynamic re-planning would have been very difficult to do.

Participants discussed the real-time reservation function of UTM. They complained about not being able to queue multiple volumes in advance and having to work in real time. They noted that the ability to reserve a space up to 24 hours in advance would have made their pre-flight roles much easier[8]. USS Operators complained that the process to manage multiple flights is cumbersome, they had to submit in one order, activate in another, and all while crews were waiting to fly.

One USS Operator reported that planning flights when there were many crews trying to submit volumes and plan was also challenging. He said his screen became cluttered with all the plans that were being submitted and, because he did not know the times of the other plans, it became difficult to make effective decisions. He had to submit plans and “see what happened” or waited until it looked like others were landing and tried to resubmit right at that point, hoping to get their space. He suggested a filter that would allow the USS Op to filter submissions by start time, but this would require all UTM users to share their volume start times.

Differences between clients were extensive: some users saw contingency messages, while others did not and had to integrate the information manually, because this functionality was not built in their client. Crews thought conflict alerting in the USS client would be useful, and automated messages from the USS would be helpful. They did not think the GUFI should be something that they should have to track.

Additionally, crews were still learning the way their USS clients operated. One crew, simulating a vehicle with an emergency, flew out of their volume to create an alert through the system. They were surprised when their USS created a new volume with a straight flight path to RTB. Users came across a couple of issues, or bugs, using their USS client. One group could not modify their start time to an earlier time and another group had an arrow that appeared as a target. A second group thought there was 30 seconds of lag in their system, which they said would make it of no use. Another USS operator could see his TFR, but was unable to select a new plan to stay in conformance, so their flight went non-conforming and then rogue while he was waiting for a volume, that would have kept him in conformance, to come live.

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[7] Again, this function/ capability is USS dependent.

[8] Reservations in the future were possible through the UTM system but the USS developer had to implement this functionality in their client also for it to be available to crews.

5.6.9 Equipment: Telemetry

As in previous flight tests, crews were still nervous that they were not receiving correct altitude readings from their equipment. They were also concerned about how crews measured their altitude differently—which point was considered zero [this is essentially the AGL (above ground level)/MSL (mean seal level)/height above landing zone issue that has been previously noted]. They commented that when you are flying in altitude bands of only 100ft there is not much room for error in crews' calculations and a different base altitude reading could cause this. They recommended that a common vertical data model needs to be put in place.

One crew was alarmed when a truck with a GPS jammer drove by and disrupted their GPS feed from their UAV. They noted that if their vehicle had its GPS blocked at the same time as it lost link from the GCS, the vehicle would automatically abort the mission and return home.

5.7 CON 5: FIMS/USS Interaction when Vehicle Heads Towards Unauthorized Airspace

The CON 5 scenario involved test sites flying their vehicle towards, and then sometimes into, TFR airspace that was controlled or restricted in some way. Examples of a TFR area that test sites simulated are a wildlife refuge and airport property. Survey questions asked about when USS information was used, and its quality and quantity, while debrief prompts focused on how TFRs should be managed, as well as USS alerts and warnings (Table 16). The use case for CON 5 sparked many interesting discussions with the flight crews, especially in respect to how the submission and associated notifications for TFRs should be handled. Comments from flight crews discussed here may lend information to the Data Information and Exchange RTT as they define what information should be shared, and when, for this particular situation.

Of the 13 respondents to the CON 5 survey, only one said that they had no access to a USS client. Everyone else (n=12) said they were able to see their ownship's protected geography, which they found "moderately useful" ($\bar{x}$ = 4). Four (30%) could see the protected geographies for other vehicles. Five respondents were able to see the boundary of the restricted airspace (38%), which they also found "moderately useful" ($\bar{x}$ = 3.5), and two could see pop-up TFR airspace. Despite having access to this information, participants reported they were only "reasonably aware" ($\bar{x}$ = 4.75) when their operation was approaching its volume boundary.

Table 16. CON 5: Discussion Topics and their Notional Categorization into Information Themes

Information Category	*Site 1*	*Site 4*	*Site 5*
Information property	9	20	
Information meets user	1	9	
Operator status	10	8	
Methods	2	3	
Automation	7	6	
Concept	9	8	

5.7.1 Operator: Situation Awareness

At two test sites, crews were distributed and had to put in additional effort to make sure that information was relayed to the field crew from the base. At Test Site 1, the base had access to the USS client and redundant data that was sent into the vehicle automation station.

5.7.2 Operator Experience: Workload

Crews were asked to estimate their workload at two different times and for two tasks while they were flying the CON 5 scenario (Figure 19). On average, their workload was "low" when their vehicle was approaching the restricted boundary ($\overline{x}$ = 1.6) but it increased as their vehicle went on to breach the TFR airspace ($\overline{x}$ = 3.4), although note that these ratings were provided by different test sites. Those at Test Site 4 reported a higher level of workload for coordination and navigation than those at Test Site 5 but this could have been due to the different site environments and the varying complexity of the scenarios. At Test Site 4, participants noted that the communications load to stay in touch by radio was unanticipated.

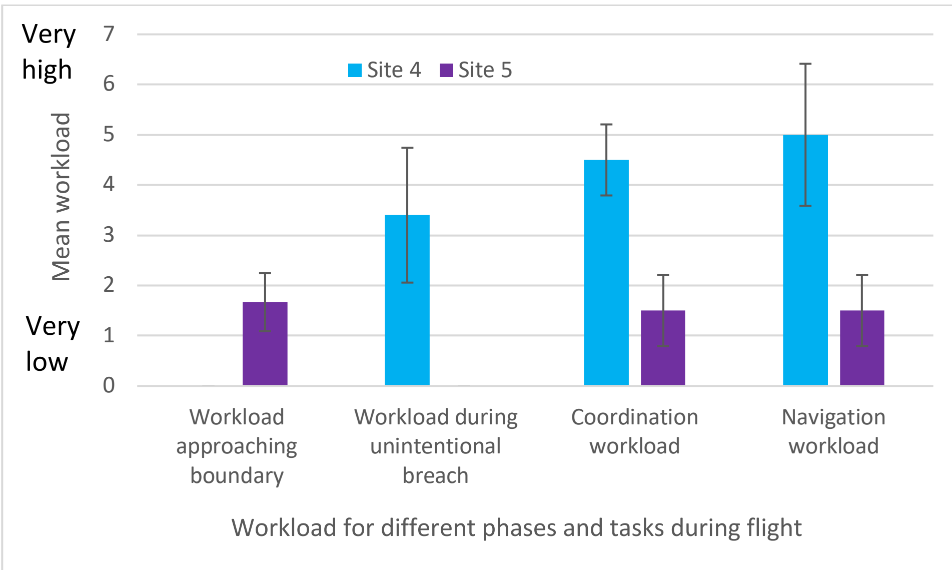

Figure 19. Operator workload during different phases and tasks for CON 5 (n = 3–5). Note: Rating scale was 1–7; y-axis is longer to show SD.

5.7.3 Information

Respondents reported they received "some of the information they needed" as their vehicle was breaching/nearing an unauthorized airspace ($\overline{x}$ = 4.18). Respondents were "reasonably confident" that they made the best resolution maneuver to exit the restricted airspace. As for other tests, participants noted that knowing airspeed, altitude, and heading for all the aircraft in their vicinity would be useful.

5.7.4 Information: Alerting

Eleven of 13 respondents reported that they received alerts about the proximity of their vehicle to different boundaries (Figure 20). Of these, the most common source of information was another crew member (42%), however 35% of the time, respondents reported receiving an alert from their USS client that they were breaching or nearing a boundary. Participants' opinions on receiving automated alerting of the restricted airspace varied. Some participants were "pretty impressed" that they received a proximity warning and an alert as they crossed the boundary. Another said this was "more than enough" information to receive.

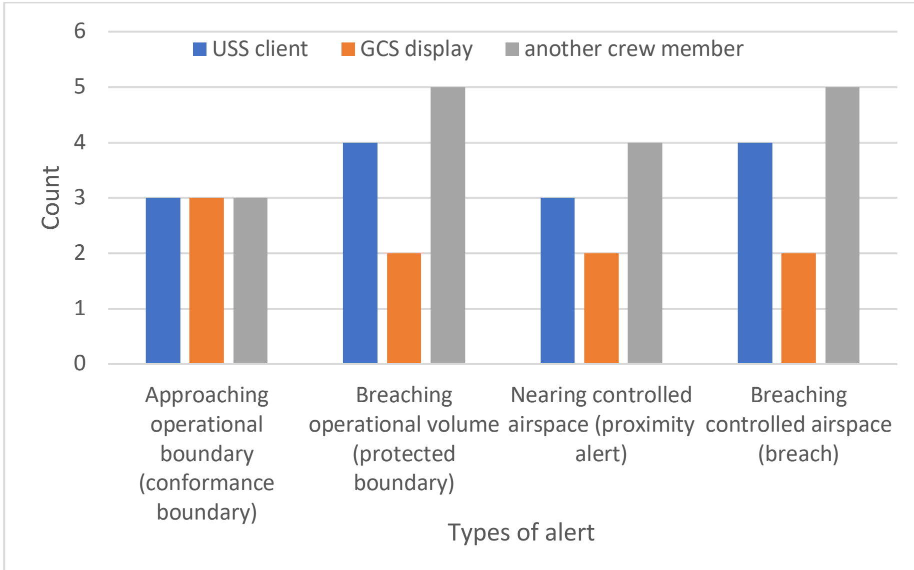

Figure 20. Types of alert and sources of this information (n = 11).

Alerting Format: Some participants appreciated that the audio-alert they received that gave them range and bearing of the intruding rogue vehicle. Others preferred a graphical representation and thought the PIC should consult a display.

Alerting Triggers: Participants were asked about the most appropriate way to scope and trigger alerting. Of the respondents (n = 12), 47% thought the most appropriate way to set alerts would be distance-based. Participants varied in how far they thought this distance should be, from 50m to 926m (0.026nmi to 0.5nmi). 29% thought a time-based alerting system would be the most appropriate, estimating a 10 second warning would be best. In debriefs, some said it should be sent when the vehicle is 50–75m from the boundary. Others said the warning should be based on vehicle velocity and the warning should be issued when the vehicle has 30 seconds before it will meet the boundary. Crews definitely wanted warnings if they were flying BLVOS but argued that when they would receive the warning depended on the type of boundary that was about to be crossed. They would like a warning for a TFR boundary but if it is another operator's volume then they did not think they would need a warning. Twenty-three percent of the group thought they should not receive alerts about breaching a restricted airspace because at that point the vehicle is already rogue (outside its volume), which would have already triggered an alert, and the crew should be doing everything they can to RTB or fly back into their volume.

Poor Alerting: There were two aspects of the alerting that participants felt could have better usability. The first was the short elapsed-time between being non-conforming and rogue. Participants commented that having only two seconds (some said 30 sec) to react and rectify the issue was not long enough, so they inevitably went rogue. In one case, the vehicle went non-conforming in its descent volume and, due to the descent taking longer than 30 seconds, the vehicle was rogue by the time it landed. Users also complained that once they had breached a volume or there was a pop-up TFR, their alerts repeated every few seconds. A number of crews said they did not need repeated messages that they were rogue, nor about the TFR, because they knew after the first alert. They would have liked a way to acknowledge, and then silence, that alert. Even without an acknowledgement, participants did not want it to repeat every few seconds and suggested a repeat cycle longer than 30 seconds would be better.

5.7.5 Warnings

Crews debated about who should be warned or sent a notification when one vehicle breaches the volume of another. Some participants advocated that only the two parties involved should know, and others went further to suggest that if UTM calculated that the vehicles were not on conflicting courses then the reserver of the volume (in conformance) did not need to be notified. Others argued back that the reserver of the airspace should always receive a message about activity in their airspace because if the intruder does not take action, the vehicles could quickly be on a collision course. Another group argued that everyone in the vicinity should receive the message as this kind of "party line" information can be useful[9].

Participants compared this situation to one in which a TFR is created near your volume while you are flying. Respondents argued that a notification about the TFR should go out to every operation that is now inside the TFR and along its borders. However, if someone breaches the TFR once it is in place, crews argued that only the intruder and the vehicles operating in the TFR should be notified. Associated with this operator awareness debate is a UTM concept debate. Currently, vehicles operating under one USS system cannot see the vehicles operating under another USS system, even though both systems may have a LUN that encompasses the same physical geographic area. Because of this, it was argued that more operators rather than fewer should be notified about volume breaches because there is not a way for them to notice this for themselves on their display if the intruder is using a different client (note that this situation is possible but is USS client-dependent). These same crews noted that, strangely, the general public would be able to see all vehicles through a public portal and so crews may have to run a public portal as well as a USS client if they would like to see all traffic in their LUN.

5.7.6 Usability of Warnings

Along with debating about who should receive messages regarding intruders into airspace, crews listed information and parameters that would improve the usability of the messages. One team thought that messages should contain a potential impact assessment. Another said that the severity of the intrusion should be color coded by comparing its flight path relative to the approved operator in the volume, e.g., red to indicate that the intruder is heading, within some band of degrees, towards the other vehicle, and yellow to indicate the intruder is not going to fly so close to the other operator.

5.7.7 Temporary Flight Restrictions

Crews discussed TFRs at length. The groups felt that notifications for popup TFRs should be through the UTM system, probably using a graphical feature to draw the area, as crews who only received text proximity warnings but could not see the boundary had trouble developing awareness of the situation. One participant stressed that they needed to know exactly where and when a TFR was going to be in order to assess how it would affect their operation.

Participants considered a number of the rules that govern UTM and how these impacted them in CON flight testing. One was the length of time that crews should be given to vacate their volume

[9] See the section below this section about how wide the broadcast of a TFR should be.

when a TFR is put up over it. One USS client gave crews two minutes to vacate while another gave crews five. Crews debated how even five minutes may not be enough to complete a mission, if you were flying a long way BVLOS and the TFR was large. Crews liked having a five-minute warning that a TFR was going to go active, but thought a graphical depiction of the TFR would be additionally useful to show which areas of your volumes are going to be affected.

With respect to long distance flights, i.e., if you are flying a distant BVLOS and the TFR pops up over your return route, meaning you may not be able to get back to and across that airspace during the five-minute limit, participants noted there needs to be a contingency for cases like this to allow them to RTB within conformance. One participant suggested that, since non-priority volumes have a time limit[10], if you are in the air the TFR should not apply to you. As many emergency responses are time critical, it is unlikely that First Responders would be prepared to wait for deliveries to complete.

Crews debated how far/close from their volumes that they would want to be notified about upcoming TFRs. One participant said they should be notified of any TFR within one or two miles of their volume when they were VLOS, but when you are BLVOS that the limits should be different. Another said that they would like to be notified of a TFR that is within a mile radius of any one of their flight path waypoints. All agreed that those which are “30-plus” miles away from your volume are not of interest (or do not necessitate notification) but could not decide on the maximum distance at which a TFR should be shown.

Crews thought it would be good to be notified how long a TFR is going to be in place. If you are flying a long mission, you may be able to work in one area of your volume until the TFR expires and then go back to working in the area that had been restricted.

Crews spoke about whether TFRs should be negotiable like volumes for non-priority flights. Although some crews thought that you should be able to negotiate, others said that only approved organizations (e.g., Homeland Security, the emergency services), should be allowed to put up TFRs and so you would have to trust that the TFR is necessary, at which point negotiation becomes moot. Others thought there should be a way for crews to request permission to enter a TFR, with the host entity having the ability to approve or deny the request.

5.7.8 Procedures: TFR

Crews voiced the need for more defined procedures for handling a TFR. From their GCS positions, some crews were unaware that there was a TFR. Others, who did see the alert, said it did not contain enough information for them to make decisions about it, for example, the message itself did not contain enough information about the nature of the TFR to allow them to determine if it was safety-related. They knew that they had to exit the TFR, unless they were coordinated with the organization setting it, but were uncertain whether they had to take the shortest route out or could exit along their flight path.

5.7.9 Emergency Situations: TFR

Participants discussed the use of TFRs in emergency situations, suggesting that the emergency event coordinator/manager (Airboss) would put up a TFR around an airspace that the emergency services need to work in. Participants considered who within that space would need to know about the activities and, in general, agreed that everyone within that space, manned and unmanned operators,

[10] For TCL3, this time limit was 10,800 seconds, which is three hours.

should receive messages from the Airboss about intruding/ breaching vehicles or vehicles that did not exit the space when asked. Crews also debated whether emergency UAS flights should have "more leeway" before they are declared rogue, as they are working in situations that are difficult to plan for.

5.7.10 Automation: USS Client Information

Participants were "confident" ($\overline{x}$ = 4.25 out of 5) that their USS client was correctly reporting positions as their vehicle breached its volume. This may account for why they were "not concerned", in general, when their vehicle was outside its volume ($\overline{x}$ = 6.5), with the majority of participants saying they had their vehicle in VLOS—implying they were only concerned about physical safety of the vehicle and not UTM constraints.

Some crews argued that the aim should be to create a completely automated UTM system but noted that that would entail automating many decision-making and risk assessment tasks that are currently completed by pilots. Crews noted that this would change the way they operate. In CON 5, for example, their vehicle went rogue and they opted to complete their mission before they initiated an RTB. They noted that under an automated system, their vehicle would likely RTB as soon as it became rogue. Due to this, they felt that having a semi-automated system, where there is an option for a manual override, would be better because it would allow for operators to negotiate under these circumstances.

5.7.11 UTM Rules

Participants discussed a number of rules that govern UTM and how these impacted them in CON flight testing. Crews tried to clarify how the rogue state works, noting that it is complex, and it is difficult for an operator to know what "rogue" really means and what actions to take to complete their flight in a way that complies with UTM. For example, some crews thought if you accidentally fly just a little over your protected boundary and are assigned a rogue status, then you are "kicked out" of your original volume. At this point they thought they were in a strange situation, where they could not use their volume any more but also did not have an approved volume in which to RTB. As a work-around, crews created new volumes around their vehicle as a series of small tiles to create a safe boundary to get them to their GCS. But then, crews argued, this indicates to other operators that the vehicle is not rogue but is in a volume. As these small, in-the-moment volumes are generated when a flight amends its status to "emergency," this also gave them a priority status (as a vehicle in trouble) which elevated them from being in the wrong to others having to make way for them. Some people argued that this conundrum will lead operators to book much larger volumes for longer times than they need, to gain additional protection against going rogue in this way. While others argued that they would try to exploit this loophole more often. For either case, crews argued there need to be some rogue conditions that are "forgiven" and operators are allowed to continue, if regulators do not want crews either booking much larger volumes or flying under an emergency banner.

5.7.12 Automation

Buffers: Crews did not think volume buffers should change dynamically to accommodate vehicles but that there should be a larger variety of buffer sizes for operators to choose from during planning, so that they can accommodate weather and vehicle characteristics. Although, none felt they could specify the range of buffer sizes by time. Another operator complained that, as the time between going non-conforming and rogue was too short, buffers should be larger.

Functions: One operator noted that a UTM function that assists with airspace design would be helpful—if you apply for a volume that is rejected because it is too big or overlapping another space, it would be useful to have the system tell you where or how to modify your volume (make it smaller or cut out a corner, etc.) in order to be accepted.

UTM issues: It should be noted that USS clients displayed TFRs and rogue messages in different ways. For some participants, their launch volume was not quite correct and they received non-conformance or rogue warnings as they took off. This was annoying but it also marred their opinions of the valid TFR alerting.

Participants found the repeated messages through their USS client irritating, arguing that they understood the message on its first announcement. They also found that some messages did not contain useful information. For example, the message through one USS client was "long" but did not contain information about where the breaching vehicle was.

One USS operator could not see volumes of other flights, he could only see where other volumes overlapped areas in his volume, so he had to flip between earlier and later versions of his volume plan and compare what areas were missing from his original submission to work out how he had to amend it to a point where it would be accepted.

5.8 CON Tests Summary

CON flight tests asked test sites to generate back-stories for missions, and fly BVLOS or for long periods. This exercised the UTM system in a different way from other tests, revealing a number of issues with procedures, rules-of-play and alerting, as well as the USS client/UTM usability issues that were common to all tests. Some of the main issues were:

- Procedures for reservations and negotiations could be more formalized. Incentives need to be given to promote efficiency, and feedback about the status of applications needs to be improved.
    - Function: Crews discussed issues they had with UTM volume buffers and with the UTM time element. Moving forward, they requested adding some flexibility to the UTM process (e.g., buffer options).
    - Design: Crews acknowledged that some USS will develop to be as automated as possible, while others will be much more manual. Implication: The same messages for an event may need to be displayed by all USS clients.
    - Procedures: Crews discussed both changing UTM status during an emergency and possible actions to maintain an 'active' status. Implications are that specifying procedures or rules for how operators should act under emergency conditions could assist.
    - Gaming: Operators gain if they over-reserve airspace but that puts others at a disadvantage. Other operators helped themselves by utilizing emergency status when they did not have an emergency and, again, that puts others at a disadvantage. Moving forward, rules should be set to prevent gaming the system.
    - SA: While general SA was reported as good, crews recognized the need for good SA at all times, especially during indoor-outdoor maneuvers and emergencies. Moving forward, crews listed information they would want provided about emergency operations.

    - Privacy: These tests raised the question of supplying personal information—in CON tests, crews found they needed to contact each other. Moving forward may require specifying the level of PII that needs to be provided with emergency handling in mind.

- Crews differed in their opinions of UTM alerting depending on the situation. They wanted to be alerted as soon as possible to events that could affect their flight or airspace but at the same time did not want to be distracted by repeated alerts or warnings that were “obvious”.
    - Alerting a): Crews were concerned both about being alerted in a timely manner but not being distracted by alerting. Moving forward, there is a need to establish a sweet spot, listing what should be alerted and how often that alert should repeat.
    - Message effectiveness: Users compared their USS displays and found they received different messages at different times. Moving forward, the same messages for the same events may need to be displayed by all USS clients.
    - Alerting b): Crews debated who should receive warnings when there is an intruder into another operator’s volume. Moving forward, this indicates that procedures or guidelines for which operators should receive intruder warnings should be scoped.
    - Distractions: Crews commented that they passed too quickly from the UTM active status through non-conforming to rogue, and having to respond to the rogue state created a distraction. Moving forward, a review of the UTM rogue parameters is suggested.
    - Usability: USS screens became cluttered by various items of information where there was either too much or repeated information. Implication: Encourage developers to review their USS client GUIs to keep information available but not overlay other information on the main screen.

- Participants did not question the need for TFRs but the rules and procedures governing them were unclear. Rules for when TFRs will be generated need to be clarified, as do exit times and procedures for exiting, and who, if anyone, has clearance to remain in a TFR.
    - Procedures: Crews were unsure of what they were meant to do when a TFR was set over the airspace they were using. Moving forward, procedures or rules may need to be specified for how operators should act under a TFR.
    - Public and hobby users: These tests led to more broad discussions including that of having users outside the UTM system and that this is problematic for SAA. Implication: Users suggested offering hobbyists incentives to encourage full participation in UTM.

6. Sense and Avoid Tests

The SAA tests focused on researching and defining technological solutions that will support successful sensing of conflicts in different situations. The sensor technologies employed in these tests included Dedicated Short Range Communications (DSRC) radios, ADS-B, and airborne and ground-based radars. Scripted situations included conflicts between two UAS, UAS and manned aircraft, and UAS and a ground vehicle. The interaction of these technologies as well as off-nominal procedures, including priority operations, were also studied.

For TCL3, six different tests were defined to explore these areas of interest. The first four SAA tests (SAA 1–SAA 4) evaluated the effectiveness of detecting and resolving airborne tactical conflicts. These four tests involved two airborne vehicles executing planned “conflict” events while gathering data on sensor and operator performance. Test sites were encouraged to fly a variety of conflicting live or virtual flight profiles and incorporate secondary conflicts and nearby airspace or ground constraints. Additionally, two of these four tests investigated cooperative technologies for conflict mitigation; SAA1 with a UAS-UAS interaction and DSRC, and SAA 2 with a UAS-manned aircraft interaction using ADS-B In for the UAS, and ADS-B Out for the manned aircraft. The other two tests investigated using airborne radar (SAA 3) and ground-based radar (SAA 4) as non-cooperative technologies for conflict mitigation in UAS-manned aircraft interactions.

SAA also looked at the interoperability between each mitigation technology in a system level assessment under nominal and off-nominal conditions (SAA 5). In addition to evaluating the technologies used, test sites were asked to develop procedures for off-nominal conditions and investigate how priority operations might change those procedures. The SAA 6 test aimed to demonstrate the interoperability and remote identification of a UAS with automobiles using DSRC cooperative technology. As DSRC technology was a primary target for two of these tests, the results of SAA 1 and SAA 6 are presented jointly in this report.

Three of the six test sites were awarded two or more SAA tests. In total, ten SAA tests were awarded, and these awards were distributed so that SAA tests 2–5 were performed by two test sites. Test sites conducted these ten tests over 27 calendar days, across three months.

6.1 Method

6.1.1 Surveys

There were 55 questions in the SAA survey, with the questions preselected to show only between 23 and 26 of these questions depending on the test, e.g., those completing SAA 6 saw 26 questions—nine general and 17 specific to the SAA 6 test—as well as a couple of information questions. Those who answered questions about SAA 5 received 24 items, the same nine general items and 15 SAA 5-specific questions. Eighteen surveys were started in total across the three sites. Many items asked the participant to rate their answers 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. All 18 surveys had some data entered but not all were complete. The greatest number of surveys started at one site was 13 and the fewest was two, but note that whereas two sites completed four SAA tests, one site only undertook two.

Although two test sites performed flight tests using ADS-B (SAA 2, with a total of 12 recorded data collection flights); two test sites performed flight tests using airborne sensors (SAA 3, with a total of seven recorded data collection flights); and two test sites performed flight tests using ground-based radar (SAA 4, with a total of nine recorded data collection flights), only the general section of the surveys were filled in for these tests.

6.1.2 Debriefs

Four debriefs were conducted which focused on SAA tests which were hosted across the three test sites. Three were specific debriefs focused on one SAA test while two focused on two SAA tests (see Appendix 12). Numbers of discussion prompts varied as researchers wanted crews to discuss and explore the topics within the time available (Table 17). Prompts focused on the topics of operator situation awareness, information required and obtained, the need for sense and avoid technology, and technical issues of concern. SAA directly related to SA tools and displays, so these topics were central to discussion in debriefs, also.

Table 17. SAA: Discussion Topics and their Notional Categorization into Information Themes

	Site 6	*Site 1*	*Site 6*	*Site 1*
SAA Test Discussed	*SAA 1 & 6*	*SAA 2*	*SAA 3*	*SAA 4*
Information Category				
Information property	9	17	21	15
Information meets user	17	10	15	6
Operator status	11	43	4	5
Methods	3	10	3	9
Automation	17	13	15	13
Concept	21	0	0	1

6.2 SAA Metadata

The SAA tests had the fewest submitted operations at 41, but the total number of flight activities is likely to be larger because not all flights were intended to be cooperative and connected to UTM as per the specific test requirements. Additionally, fewer sites were awarded these tests to conduct for TCL3. See Table 18 for a further breakdown of submitted operations.

Table 18. Number of Live and Simulated Flights providing Data for TCL3 by SAA Test

	NASA	*Site 1*	*Site 2*	*Site 3*	*Site 4*	*Site 5*	*Site 6*	*Total*
SAA1							8	8
SAA2		8				4		12
SAA3						2	5	7
SAA4		3				6		9
SAA5						2	2	4
SAA6							1	1
All SAA		11				14	16	41

6.3 General SAA Feedback

A standard set of nine questions was asked at the end of every SAA survey, requesting that participants rate the information they used, timeliness of actions, their opinions of the information they received through the USS clients, and their safety concerns. Sometimes discussion in debriefs took a more general focus and was not directed specifically at the test the site had just flown.

6.3.1 Information Properties

Participants were asked what information they used to stay within their flight geographies for the SAA flight tests. They were given eight items of information to choose from, and participants indicated that they used six of these (Figure 21) with two additional items of information that had not been listed (see “other” on Figure 21)—visual contact and the “well clear” radius. They reported having used vehicle position reports and volumes available on their USS client to stay within their flight geographies most often.

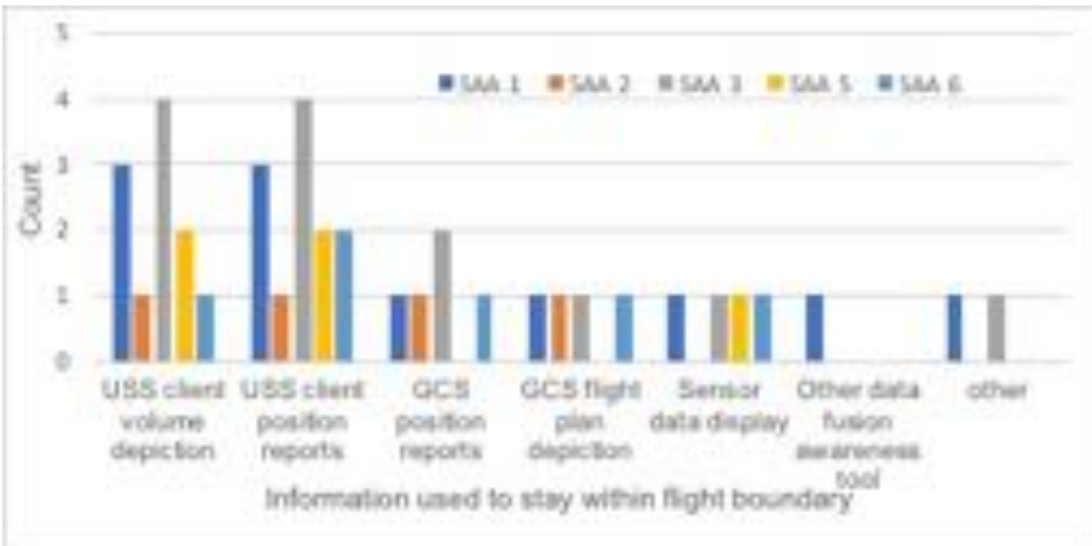

Figure 21. Information used to stay within flight boundary on SAA flights in TCL3 shown by type of SAA test (n = 14).

Participants were invited to rate eight properties of the UTM information they received through their USS (Figure 22). On average, participants rated all the UTM information they received as “okay” with means varying from 3.5 for usefulness of information for planning to 5.1 for accuracy of information, on average. Participants gave the highest ratings (on average) after SAA 2 and the lowest after SAA 1.

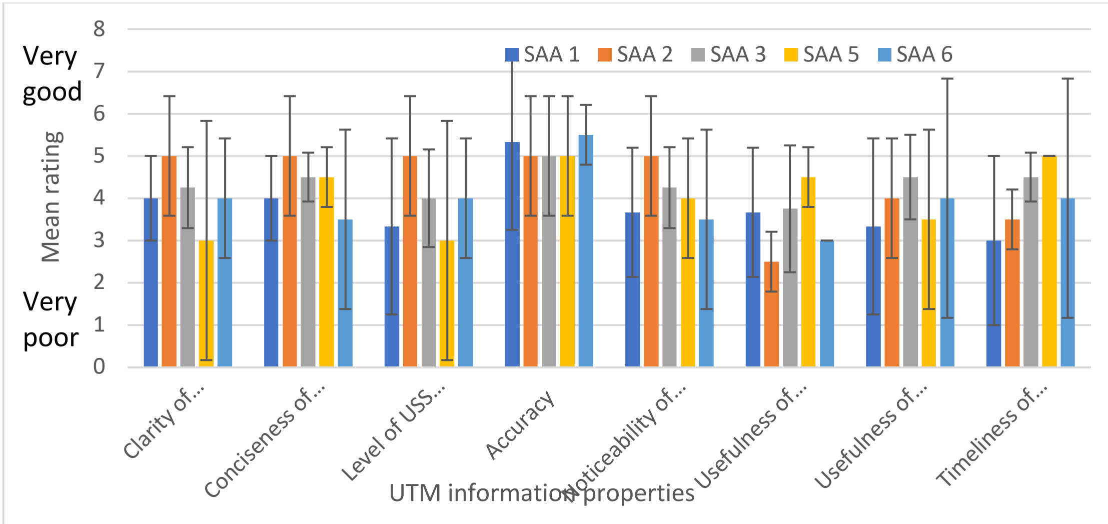

Figure 22. UTM information properties during SAA testing in TCL3 shown by type of SAA test (n = 13). Note: Rating scale was 1–7, y-axis is longer to show SD.

6.3.2 Methods: Operational Effectiveness

In the surveys, SAA participants rated their flight operations in terms of their efficiency, timeliness, and the degree to which they relied on UTM information to achieve them. Crews were positive about their operations but reported they relied on UTM information "less than half the time" ($\overline{x}$ = 3.4), although this degree of reliance varied between crews (Figure 23). On average, they rated the timing of UTM messages as "slightly later than needed" ($\overline{x}$ = 4.75, note the midpoint of the scale was the most positive option in this rating, labelled "right on time") and reported that their operations were "efficient" ($\overline{x}$ = 4.8).

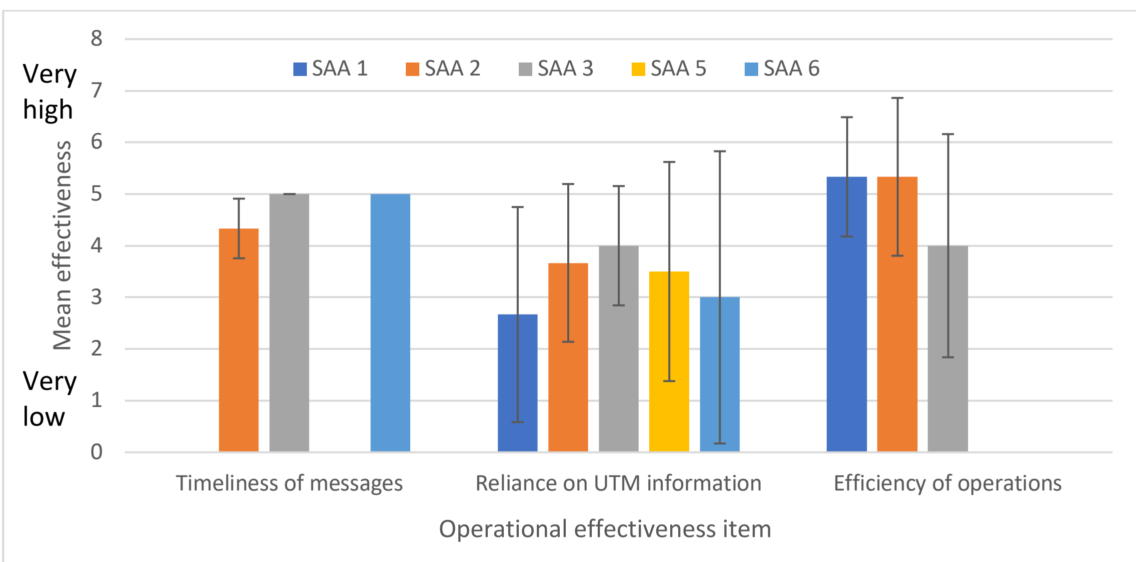

Figure 23. Operational effectiveness for SAA flights in TCL3 shown by type of SAA test (n = 8-14). Note: Rating scale was 1–7, y-axis is longer to show SD.

While participants had no concerns about the safety of their operations, only one person (out of 13) said they would be "comfortable" if they had no additional safety mitigations in place and were solely relying on UTM to provide their safety element during the SAA flight tests. The majority of respondents (53%) reported they would be "very concerned" with this situation. From the comments respondents made listed in Table 19, they were concerned both about the reliability of their USS clients and the reliability of some telemetry data.

Table 19. Reasons for Not Relying on UTM for Safety (n =13)

SAA Test	*Test Site*	*Comment about Relying on UTM for Safety*
1	6	The false alerts and "bugginess" of the USS makes me not inclined to trust it entirely. Most of the needed conflict mitigation constructs are in place or in progress but the software has not had time to mature to the needed level of quality assurance.
1	6	The XXX client lacked the features required for safe operation of the XXX aircraft. Additionally alerting was not implemented. There was a loss in usability and a lack of value in the XXX client. While it looked good in some places, it lacked basic functionality throughout.
2	1	Two streams of data relayed the aircraft's position to the USS client; both XXX GNSS position and GNSS position from ADS-B. ADS-B position relayed from the local ADS-B receiver showed latency issues when viewed from the client portal. If I was relying solely on position of other aircraft from ADS-B alone, I would be worried if I did not have a visual on mine or other aircraft.
2	5	Since we had a MAC in the air, yes absolutely I would feel concerned about the flight operation we conducted.
3	6	Due to the nature of testing and how the USS reliability was intermittent I would not have relied on it. Some connectivity loss experienced was only apparent when telemetry stopped updating on the USS client display.
3	6	At times it was difficult to determine a legitimate radar track from false tracks. This is mostly radar tuning related, not UTM related. Presentation of tracks could graphically represent and emphasize track age and confidence (as reported by the radar); this would make it easier for the operator to visually identify a track belonging to an aircraft vs. a false track.
5	6	App currently lacks enough functionality for pilot to develop trust in the system
6	6	XXX client provided no information about other aircraft or warning about conflicts

6.4 Crew Feedback from Debrief Discussions

In addition to general comments and survey responses from crews on the SAA tests, aspects of the debrief discussions will be examined below and organized as feedback on the SAA concepts, technologies, alerting, and operator experiences.

6.4.1 Concept

Concept: Participation

Participants discussed the approach of the different types of users who fly UAS. They noted that crews who currently comply with Part 107 are "good stewards" of the national airspace. They are the group who will file, and then fly, flight plans, and will comply with new regulations on SAA technology requirements. However, they argued that the hobby market, or even the Part 107 pilots who fly racing drones, may have a different mentality and take the position that they are having no trouble flying without UTM and they should be exempt. Crews felt, that this subgroup may be more skeptical and less accepting of having to add equipage to their UAV.

Other players who will affect how the rules for UTM airspace develop are manned aircraft and the regulators. Ideally, UTM airspace would be a fully cooperative national airspace (or at least have zones that are designated fully cooperative) integrated with the airspace above, but manned aircraft may not want to be cooperative at all times and may resist this, making SAA technology on UAVs necessary.

Concept: Airspace Definition

Regulations should determine which users can fly where, but crews did not think this is the way the UAS airspace will be defined. They see the rules of UAS airspace usage being defined by equipage requirements, where the level of access and risks that a mission requires determines the level of equipment that needs to be on a vehicle. For example, if you wanted to fly BVLOS, there would be a list of equipment requirements that you would have to meet to do this. Given the number of groups who will fly UAS, crews agreed that there needs to be a system like UTM in place, and that the separation aspect of UTM is the real benefit.

Concept: Vehicle Capabilities Procedures

Crews proposed that there must be a hierarchy of which type of vehicle should give way to others. As UAV are more easily maneuvered, and manned aircraft are easier to see (UAV are very difficult to see from a manned aircraft), the UAV should have to move to avoid the manned aircraft.

Crews debated the best maneuver for sense and avoid. They cited a case during one of their flight tests where the intruding aircraft was between the UAV and its GCS. This PIC thought that the safest maneuver would be to fly away at a 90^o angle because the other vehicle would not be able to turn to intercept him on that course, and therefore this would put the UAV well-clear of the other vehicle. Others argued that you cannot predict the flight path of the other/intruder vehicle, and if it was taking a curving course the two vehicles could meet even with a 90^o maneuver and felt that hovering in place would be safer.

Concept: Crew Procedures

One site wrote their own SAA procedures to guide their actions in their flight tests. In general, they advised their crews to stay in communication with each other and think ahead to try to resolve issues before they became problems. One of the procedures, in the case where an incursion has happened, stated that when an aircraft or target moves inside a warning area that the PIC defines during preflight, then the pilot, who has manual control of their system, has to give way and attempt to maneuver out of the warning area.

Concept: Risk Mitigation

Participants suggested that work on use cases is an important part of convincing the public to accept the risk of UAS flying in the urban environment. They suggested that, initially, the industry can mitigate the risks with other means, like limiting locations and flights, until the technology matures to where you can fly in the urban canyon. As technology develops, truly autonomous flights can take place. They suggested that the general public tends to immediately worry about privacy issues when UAS are mentioned and do not yet see the benefits of this technology.

Concept: Automation Toolset
Crews suggested that automation should be introduced to reduce their load, and in particular, for the pilot. The advantage of automation is that the pilot will be able to focus on the aim of their mission and they can hand the details of how to achieve that over to the automation. Ideally UTM would be transparent to the user, for example, it would automatically assign your mission a volume with all the required parameters, as the pilot completes flight path planning. More load would be relieved if UTM automation took over some of the flight decision making. If there is an issue, currently the pilot reviews the situation and decides whether there is a safe place to land nearby. This is one area where the transparency of UTM and more automation could reduce workload by identifying a safe landing area, like NASA Langley's "safe to ditch." Crews argued that, as flights go beyond VLOS, the system will need to have more of this kind of automation, including automated de-confliction, because the pilot will be one step removed and will find it more difficult to provide correction or evasive action.

Some crews said that UAS should need to have sense and avoid capabilities to be allowed to participate in BVLOS. They recommended that the SAA technology should be self-contained, automated, and require no human intervention, not only because humans are "slow and miss things" but also in case the GCS link with the UAV is lost. Crews argued that if you lose linkage, then your vehicle becomes rogue and, if it is a busy airspace, that can have serious consequences. So, the UAV has to be able to avoid another aircraft automatically. Others in the group disagreed, saying that the human-in-the-loop is important in the case of a lost link, but participants countered that there is very little chance of a lost link when crews have thoroughly planned their flight. Then the hazard is mainly someone else jamming the signals.

They reasoned that there is already an industry-driven standard autoflight software, a flight planning tool and ground control station tool, but what they lack is cloud-based C2 and multi-vehicle C2. These are the properties that UTM is bringing to the table. Participants pointed out that, as flight crews, they are "stuck in the middle," being invested in commercial off the shelf software (COTS) GCS tools and needing the feature set of their USS, which means they have to drive both softwares at the same time, and this is very challenging.

Crews said that it is good to have as much situation awareness as possible and that every new tool that can enhance your SA is a good tool. Having better SA is necessary, especially as the environment gets more complex. They liked the idea of being aware of the location of other traffic, noting that in manned aviation, it is possible to know where other aircraft are through ADS-B. Crews stressed that having situation awareness is critical when you are flying BVLOS particularly as UAS can fly at high speeds and can rapidly enter the area near your path.

6.4.2 Technology

Equipment: DSRC
In one discussion the crew said they did not think that DSRC added to UTM, as the user can already get telemetry data from other sources. Although DSRC may not add anything by being another source of position data, its advantage would be that the UTM community could leverage existing infrastructure put in place by other entities (e.g., Department of Transportation).

Crews thought the advantage of DSRC was the traffic and hazard awareness that it provided. They liked the idea of knowing the location of other UAS that may interfere with their mission. Crews noted that because it is their responsibility to see and avoid other traffic, they will always need to be on their guard and looking for UAVs that are not being flown cooperatively, that they will always have to fly as though they will have to see and avoid other traffic even if everyone is flying cooperatively. Technologies like DSRC that enable crews to see and avoid are important when flying BVLOS and will enable the pilot to choose a conflict resolution should they need to.

However, one participant noted that the full value of DSRC was not realized in their flight tests because the sensor data was being sent to the server first, processed through the collision avoidance software, and then back out to the USS client. They said that their GCS should also receive the raw DSRC data from their vehicle because this would provide faster alerting. Crews noted that the DSRC tracks were very clear and they could have used this information to make manual deconfliction decisions.

Equipment: ADS-B
Participants said that UAV are difficult to see when they are in flight. ADS-B was invaluable for flight identification, and crews used their ADS-B-fed displays heavily to see where target aircraft were. Even when they knew the general direction to look, participants said it was difficult to see the vehicle. Crews discussed one SAA flight where the manned aircraft flew straight at the UAS. Crews were surprised because they had not anticipated that the manned aircraft would be able to pinpoint where the UAS was just from its ADS-B signal. The direct line flight meant that the UAS-PIC was unable to execute the RTB avoidance maneuver that had been planned, and so made the secondary maneuver of descending.

It took one test site a little while to calibrate their ADS-B because the timestamp on the reports was incorrect, and initially one UAV looked like multiple vehicles. They filtered the incoming telemetry differently to overcome this. Another crew thought they had an intruder very close to them but it was resolved because the GCSO had not tied the vehicle's ADS-B readout to its GUFI in the USS client and so the client read the ADS-B as indicating a second, intruding, vehicle. They resolved the problem quickly because the ADS-B was tied into the UAV's tail number and they realized the issue as the client announced the "intruder".

Equipment: Radar
With respect to the purpose of the test, crews were happy to report that the ground-radar tracks they saw were close to their GPS-driven UAV tracks, and they confirmed this for multiple vehicles. However, the only information they received were the "blips," without any additional information. They were concerned because UTM/NASA did not see these tracks for all of the UAS, which meant that the USS client system was not reporting on all of the radar data it received.

Crews noted that radar inherently has false alarms for targets that are real, but not relevant, as radar tracks are shown for all airborne vehicles and entities (e.g., birds). While most of the tracks may not be potential conflicting targets, crews suggested that it is useful information to see everything airborne because it provides additional information about which altitudes have more traffic, and about areas the PIC might want to avoid because they are busier.

Automation: Sensor Trust Reliability
Crews noted that the reliability and availability of sensor data was key because for SAA you need to detect other airborne objects at suitable ranges in order to have sufficient time to maneuver. Being sure that the sensor data are reliable allows the user to have confidence in threat detection. Crews pointed out that pilots and GCSOs want to receive telemetry data and want to be able to trust it, but

that they did not care what sensor it came from and did not need to know the statistics per sample. They just wanted a general impression of the overall reliability of the data. That said, crews tried to compare DSRC to radar feeds and found it difficult to compare sensors because an active sensor, like DSRC, requires other UAS/aircraft operators to be using it (buy in) for others to receive any surveillance. Radar is passive, in the sense that it does not require on-vehicle equipage, which means you can receive surveillance of others even if they have low equipage or are not participating. One participant suggested that a graphical depiction of good/bad would be sufficient for this, and that it would be helpful if the good/bad rating was calibrated against an industry standard that characterizes the reliability of sensors. Another participant suggested that each (radar) track could be color coded to reflect the confidence-level of the data that had generated it.

Automation: "Safe Zone" Tools

The various test sites developed different approaches to depict "safe zones." For example, one site employed a spherical protected/ alerting zone for SAA on the USS client, defining a radius to generate the protected zone, which was applied in all directions around the UAV, and changed colors (from blue to red) as an intruder flew into this area. However, users commented that it was difficult to develop good situation awareness from a 2D display of the sphere, as they only saw the lateral protected zone out from the waist of the vehicle drawn on the screen. It was difficult to reconcile or calculate geometrical distances mentally while the UAV was in flight, as when a vehicle was just above or just below the ownship. It appeared that the intruder had breached the protected zone but actually was still outside the ownship alerting boundary, because the sphere was laterally narrower at that point. A PIC noted that this was unnerving, because they did not have a good altitude indication on the USS client, making it very difficult to judge whether vehicles were actually in conflict or not.

Using the working assumption discussed above—that SAA functions had to be either wholly or partly automated—another test site developed an approach for the way such technology would work and, although they could not build it fully, they emulated an automated avoidance function. Their concept for automated aircraft avoidance employed a display showing a cylindrical protected area, where one could set certain parameters of the cylinder to avoid other aircraft. They added SAA features to their UAS software—where the virtual cylinder could, potentially, trigger automatic avoidance maneuvers to avoid incoming conflicting aircraft that fly through the boundary. The current software development allowed the user to set a radius and altitude to the cylinder. The cylinder was color coded and when it turned red, the PIC knew that they had to start avoidance maneuvers. In addition, the intruding aircraft icons on the display went from green to amber to red as they traveled through the warning zone to the protected cylinder of the ownship. The test site tried to simulate automated avoidance maneuvers[11] by having the PIC do what they would have programmed the UAV to do, for example, a command to automatically go to a predetermined point on the map at a given altitude. There was also a 30 second buffer—that the UAV would execute a maneuver if the conflicting vehicle was within 30 seconds.

6.4.3 Operator Experience

Operator Experience: Situation Awareness

Participants talked about how they allocated their attention while flying. One participant said he was trying to maintain the best situation awareness he could, and the cost of that was that he was paying

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[11] The avoid action is where the avoidance actually occurs after the intruder has breached the warning zone or cylinder.

less attention to his tablet and tool interfaces and more attention to the sky and his remote-control pad (operations were VLOS). He wanted to keep an awareness of the other UAV while maintaining a visual on his own UAV. He said if something went wrong, being able to see the vehicle directly would be faster than the other pilot calling him on the radio.

Having tested out their conflict alerting software, crews noted that their UAS software did not provide as much vehicle information and sense and avoid parameters as they would like to know. Crews listed a number of USS features and functions that they thought would improve their situation awareness for conflict situations. They thought altitude, speed, heading, vehicle position on the map, velocity and their vehicle's protected zone would be useful. For the intruding aircraft (manned or UAS), they thought the target's position, altitude and having a longer length on the intruder's history tail would be useful, as would velocity vector, which they could calculate relative to a warning area. Ideally, the display would be a predictive vector to give some idea of the vehicle's forward flight path, but a history also provides good information. The crews stressed the need for the history tail to be long, so that if you have looked away from the display, there is still enough information on the screen when you come back to it to make predictions. One participant discussed that the pilot needs to know the difference between his/her ownship and the intruder regardless of whether the data is from airborne or ground sensors. This distinction was clearer through ground-based radar than through the airborne sensor displays (DSRC) they used.

Crews also stated the need for audio/ audible alerting because they could not watch one display the whole time (see earlier conversation) and having the tool annunciate conflict alerts would have assisted with pilot workload. During their flight tests, none of the participants heard audio-alerts for the conflicts they were flying, although they thought they had heard alerts in previous shakedowns and testing.

Operator Experience: Workload

A real challenge for pilots is that they are managing two sets of software while they are flying their vehicle—UTM software and their flight automation software. The chief test site coordinator noted that this created an unacceptable level of PIC workload. The UTM software supplies situation awareness, and not flight controls, but pilots are unable to capitalize on this because they are occupied flying their vehicles and looking at a different display.

Crews noted that, as pilot workload is an important thing to manage, having a very good alerting and a visual display is critical. Comparing the airborne (DSRC) and ground based (radar) surveillance feeds, one participant thought that there might be differences in pilot workload depending on the data source. For example, the pilot needs to know the difference between his own-ship and any intruder. As the ground-based radar reports intruder vehicle position relative to the radar rather than relative to the ownship, that might increase pilot workload because PIC will need to do a calculation to determine the severity of the conflict.

Operator Experience: Trust

Participants noted that using UAS in urban environments depends on users' trust in autonomous systems and the extent to which they have been proven to mitigate the set of potential contingencies that could be required.

Crews complained that their USS did not provide them with enough information about the status of their volume. On one client, status was shown through a text note on the side of the page saying “accepted” or “activated” or “rogue,” which crews said was not salient enough (note that this comment is for one particular client not for clients in general). On their other client, the status was noted on a separate window from the one used for flying and did not seem to change during flight. One piece of information crews would have liked, in particular, was whether the rogue state was due to vertical or lateral (or presumably, temporal) excursions. Another was to be given an indication of the direction the UAV needs to move to get back inside its volume. They noted that all their rogue statuses were unintentional drifts of the vehicle outside its volume boundary either because they were flying too close to the volume bounds or because the takeoff/ landing was difficult to judge.

Crews noted that they had also seen many false rogue states during their shakedowns and testing (where they could verify that their UAV was not rogue), to the point where they tended to ignore rogue status when it alerted on their USS client. The team was investigating why so many rogue states happened with the USS client developer but had not resolved the issue for the flight test. The chief test site coordinator noted that effort needs to be made to build pilots’ confidence in UTM capabilities.

Crews were concerned about accuracy of altitude measurement on the UAV, as discussed in reports for previous flight tests. They were concerned that if one UAV was using geometric altitude and another was using ADS-B pressure altitude that the vehicles could potentially climb into each other. Consequently, some avoidance procedures did not make sense under certain conditions when the altitude measurement method was unknown. Some argued that, to address this, the FAA will need to require one type of altitude measurement on UAS (probably barometric pressure altitude). Others said that avoidance procedures, like those that apply to manned aircraft, will need to be put in place. One pilot advocated that “stop and wait” should always be the first action that a UAS takes.

6.4.4 Automation

Automation: Issues using USS Clients

At one site, one of the vehicles was flown using a different client than the others. This client only had outbound data, which meant that this PIC did not receive any alerts or notifications. This PIC noted that it was frustrating during operations when other crews were seeing alerts and he had no indications. He worked with the developers to add a few features to his client, e.g., to show a lost connection with the server but, he said, that it was still not enough to give him awareness about when the alerting was operating.

Other crews reported having had some confusion regarding functions that seemed to both require manual activation and were automatic at some level. Pilots were confused that they had to manually activate their volumes but at the same time these were “auto-de-activating” (these volumes automatically expired). These issues arose when the flight was delayed and the crews did not realize they needed to resubmit their volumes with updated time parameters. Crews would have liked to be able to put a delay on the activation of the currently accepted volume, so that the volume did not expire and was available to be activated later.

Users from Test Site 6 commented about the functionality of their USS client. They had some issues with clutter when warning boxes popped up in sequence, scrolling down one side of the screen. Another issue they found disappointing was that alerts were meant to be annunciated aurally, but were not reliable. Some of the participants had heard the alerts when preparing the scenarios but during the test the audio did not work. They felt the visual alerting on the USS was good but would have been complemented by aural alerting.

Participants mentioned that knowing where moving cars were on the ground would be useful but that improvements in the USS client/UTM are more important for the usability of the system. They noted that the UTM system needs to improve in the following areas over the system they used in the flight tests: the USS client needs to work properly, it needs additional functionality, and the overhead to use it needs to be lower, which could be achieved if the interface was more transparent.

Users noted that they would like to see history trails or breadcrumbs (vectors) for other aircraft, that the pilot wants to make sure they avoid. They would prefer to be able to see other vehicles and plan their flight path to avoid them, rather than having to deal with collision avoidance (i.e., that tools are good at the sense-and-alert portion of sense-and-avoid). In general, users said that having to input data was undesirable and, as much as possible, UTM should work without users having to tend to it, providing information with less input from them. For example, the display currently requires that a mouse hover over the target to indicate altitudes, it would be nice if this information was automatically provided.

Automation: Tool Trust Reliability

One participant suggested they needed a predictive capability for SAA, given the current state information of aircraft in proximity to each other. He said it would be helpful if the predicted trajectory of both aircraft could be displayed and then updated in real time as the pilot is maneuvering. This would give the PIC a view of the closure rates and the distance to the closest approach.

During one series of flights, a crew noticed inconsistencies in the acknowledgement of the guided mode command when their UAS was flying in auto mode, which they thought was an autoflight software issue. However, the test site coordination team thought that it could have been too many people crowding around the display in the test site control location to see the radar and observe the test. They thought the people occluded the antenna and therefore the commands being sent from the station, i.e., the “go to guided” command.

Automation: Areas for Improvement

Crews pointed out the need for sense and avoid technology to be small and light is a limiting factor currently, as is the onboard computing power. They also noted the lack of readily accessible computer vision technology.

Crews frequently saw telemetry hiccups and small delays, where for a second or two no packets were received but after a couple of seconds the telemetry came through again. They discussed that these hiccups are acceptable with UAV that are traveling more slowly (e.g., at 6m/s) but are unacceptable for vehicles traveling faster (e.g., at 50m/s) because the closure rate is so quick that you need to be able to see the path of the vehicle at all times. They stated that for these situations, the protected cylinder would have to be very large to accommodate the closure rate of fast-moving vehicles if the PIC was manually completing SAA, likely so large that this approach may not work. Again, they noted that automated SAA may be able to overcome this issue.

As an alternative approach, one participant noted that having a leader line on every vehicle, that predicts its trajectory, would be very helpful when vehicles are moving quickly. They argued that a leader line may be more useful than a protected cylinder for SAA.

The flight tests revealed a number of small issues with the UAS and USS client software. Crews found that, initially, they could not see all the aircraft on their GCS automation displays because they had loaded a version of the software that was too recent. They also lost their GPS telemetry for a little while but were confused because they were locked on to enough satellites for the GPS to be coming through. One PIC thought that someone local to them was jamming the GPS signals.

As in all the tests where crews were exercising their software, one of the SAA test sites found a number of functions that did not work as expected and possible bugs in their system. One general issue with the automated logic was found when the test site was testing how the vehicle moved perpendicularly in its volume. On another flight, the GCS lost the telemetry link on their UAV, saying it "strangely disconnected," forcing them to land with a loss of communications.

Participants brought up the additional workload of having to monitor both a USS client and their auto-flight software. They lamented that the larger UAV manufacturers had not integrated UTM functionality into their auto-flight packages, and that working with UTM would become much easier if they only had one display to monitor[12]. If manufacturers were building UTM features into their products, then UTM integration would be more seamless. For now, USS developers are having to build USS components as tools separate from the autoflight software. Pilots felt they would utilize the USS more if it was integrated with their auto-flight software. They suggested integrating software the other way around—pulling auto-flight software into the USS client (but noted, that where this has been done currently the functionality on the USS is not as good as on the auto-flight software). They argued that, since integration of functions is unlikely, UTM needs to work on making its (UTM) functionality transparent to the user—essentially reducing the overhead of using UTM as much as possible.

Crews debated the utility of cloud-based servers. The benefits are the functionality that can be gained with a cloud-based system that allows users to revoke remote control, for example, for unintended UAS placement. The negative aspects of cloud-based servers arise if the server develops a fault, then all operations are affected. Crews advocated for an assessment to calculate whether the benefits of cloud-based systems outweigh the risk and, if this is situation-specific, the conditions under which you would take on that risk.

6.4.5 Alerting

Users of the spherical alerting zone noted that their alerting was "basic" (e.g., only being able to define one radius), and suggested having more than one alerting zone—a warning and then a protected region—with a sequence of alerts, or a variable sphere size based on the situation, which would make the system more useful. They noted a "hockey puck" (cylinder) shape for the protected area would be easier to use than a sphere, and that the saliency of the alerts and their ability to get pilots' attention in an appropriate way needs improvement. They also noted that integrating radar and DSRC feeds with the alerting logic would be nice but would be difficult to achieve.

The protected cylinder that Test Site 1 built for their SAA maneuvers had a height of 100m above and below the vehicle. However, crews felt that when altitudes are being measured in a number of different ways (geometric, pressure, etc.), that a 100m protected zone does not guarantee vehicle

[12] One participant noted that two of the major ground control station developers/ manufacturers are not developing UTM functionality.

separation. They were also unsure whether their UAV GCS software was converting altitude measurements accurately, leaving them with a degree of uncertainty that they found uncomfortable.

Alerting: Timeliness

Crews noted that the alerting they received was delayed—when their vehicle was within LOS, they could see that the display was "behind" the situation in the sky. Crews thought there was potentially a number of sources of the latency, but their critical point was that the lag was significant and they would not want to use it for sensing and avoiding. They argued that this implies that SAA needs to be automated and to originate in software on the UAV so that the reaction can be close to instant, as it will take the PIC too long to react. The added advantage, if the avoidance software was on-board, is that if the UAV experiences a lost link with the GCS, it would still complete SAA maneuvers.

6.5 SAA 1 and SAA 6

The SAA 1 scenario involved a test site flying one UAS towards another UAS, using DSRC technology on the first vehicle to sense and avoid the second. Survey questions asked about the USS information that displayed conflicts, its clarity and usefulness, and crew SA. Only six responses were received for this flight test. Debrief prompts focused on alerting and the usefulness of DSRC technology and discussion in the debriefs ranged more broadly to discuss the UTM concept (see above). The SAA 6 flight test involved a test site flying a UAS towards a ground vehicle (automobile) and using DSRC technology to sense and avoid the car. Survey questions asked about clarity and information in USS conflict displays, and the effectiveness of the resolutions, but only two responses were received for this flight test. The debrief was combined with the debrief for SAA 1 and prompts focused on alerting and the usefulness of DSRC technology (see Table 17).

6.5.1 Operator Experience: Situation Awareness

Participants reported using both position and volume of their ownship, and position and volume for the "other" vehicle, to identify potential conflicts and to plan resolutions. The on-site NASA representative observed that crews looked at their GCS tools, but sometimes flew their vehicles in VLOS and were always careful to be in a situation where one of the crew could see their vehicle. The crews used their USS client and a second data fusion display to find that "other" vehicle information. They gauged that they were "aware" of conflicts when they had sensor data available ($\bar{x}$ = 6) and that this sensor data gave them enough information to mitigate the interaction between conflicting flights ($\bar{x}$ = 5.3), Figure 24. However, although respondents thought the conflict alerts on their USS client were moderately clear ($\bar{x}$ = 4.5), they reported these alerts were only "somewhat effective" ($\bar{x}$ = 3.5). This may be because crews "received some false alerts when the well clear volume did not overlap" (Participant, Test Site 6). On investigation, the USS client developer representative suggested the false alerts could have been triggered by errors in the USS code.

Survey respondents reported that the USS gave them "some of the help" they needed to plan a resolution to the conflict ($\bar{x}$ = 3.6). Participants said they had "enough time" to take effective action to solve the conflict ($\bar{x}$ = 5.5) but they were less certain that these solutions were effective ("somewhat effective" $\bar{x}$ = 3.75).

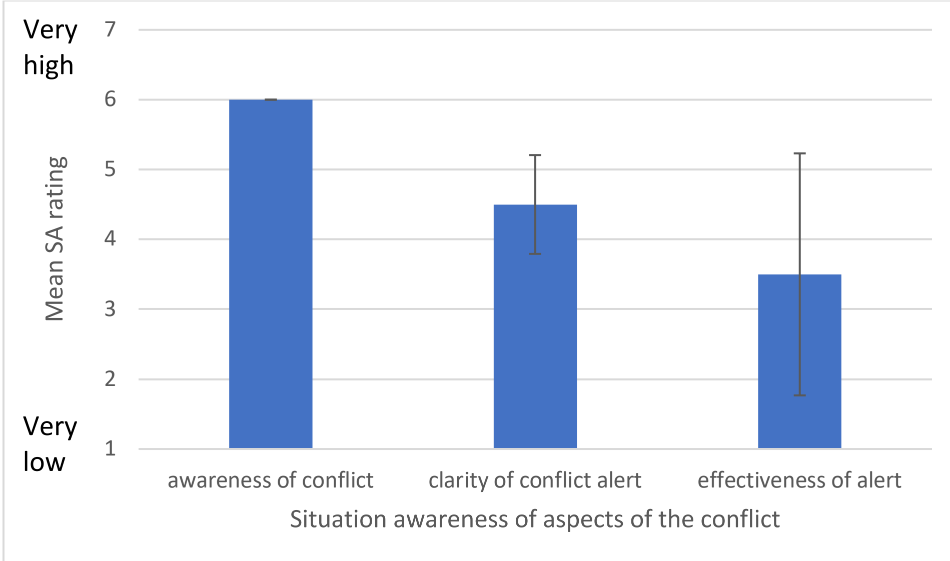


Figure 24. Awareness of conflict situations during SAA 1 flight tests (Note: n = 2-4).

One of the two respondents said s/he could see the ground vehicle's DSRC messages through the USS client, which showed him/her "a little information." The other participant could not see these messages, as their USS client display did not show any information about the ground vehicle. This meant that the two participants gave different answers to the questions that followed about how clearly overflights were displayed and how effectively they were alerted by the client to trajectories over the ground vehicle.

6.6 SAA 5

The interoperability between all the mitigations discussed above was the focus of SAA 5, with test sites looking at USS to USS interaction. Survey questions asked about situation awareness, the timeliness and clarity of messages and the resolution maneuvers made. Only two responses were received on the survey for this flight test.

One of the two respondents to this set of survey questions said they were informed about intruding vehicles by their USS Operator, and the other did not receive any USS information. The participants were not aware of the USS message stream, as neither of them were USS Operators, however, they reported they were "somewhat aware" of their vehicle. Because they could not see a USS client, participants reported rogue states were "not at all" clear to them. They did have a more favorable view of their operations, estimating that their replanning was "reasonably effective" and that their resolutions to airspace intrusions were "very effective."

6.7 SAA Test Summary

SAA testing was exploratory, with test sites using new equipment (to them) to sense and avoid a variety of vehicles. This experience not only highlighted features and issues with SAA tools but also helped crews to reflect on how they are using their GCS, USS clients and the UTM concept. Some of the major points included:

- The telemetry that provides additional situation awareness can come from a range of sensors, one type of data was not clearly better than another, when comparing across tests. But, the data *does* need to be reliable and consistent.

  – Reliability: Some SAA data had uncertain reliability, making those crews unsure about all of the data they received. Implication: As above, this suggests continued progress to improve the reliability of SAA data.
  – Trust: Users did not always trust the telemetry and sensor data enough to rely on it. Implication: The accuracy of information provided through UTM would benefit from improvement to make it as consistent as possible.

- Test sites liked the additional sensor tools they had that provided increased situation awareness about the airspace they were flying in.
  – SA: Some crews were not confident enough to fly SAA tests while BVLOS, suggesting they did not trust their tools enough to move away from visual contact. Implication: Continued progress is needed to improve the reliability of SAA data.
  – Trust: As BVLOS is a higher risk environment than VLOS, this is the type of flight where SAA will be needed most and can be most informative. Suggestion: Continue work to improve both training and the reliability of SAA data, which may counteract the lack of trust experienced by some of the crews in this study.
- Test sites liked the idea of SAA tools to alert them when intruders were approaching their vehicle too closely but reported a number of issues with this new-to-UTM technology, ranging from telemetry reliability issues to interface interaction issues. They concluded, in general, that these tools need more development to become truly useful.
  – Usability: Some USS displays either lacked SAA functions and/or were cluttered. Implications are that it could be advantageous to continue to improve USS GUIs.
  – Functionality: SAA technologies were all good for awareness, but some users were just getting to know how to use them and which were best for what situation. Implications are that continued testing of SAA technologies could be beneficial.
  – Workload: Crews commented on the level of workload required to monitor all the displays in a GCS. Moving forward, in addition to addressing the items above, consolidating data onto fewer displays could alleviate workload.
- An area where crews were uncertain was how to react to SAA events. Discussion highlighted the variety of approaches crews had considered that could be used to respond to conflict situations.
  – Procedures: Crews created their own procedures for avoiding conflict and giving way. Moving forward, a consistent set of procedures should be tested and evaluated.
  – Public and Hobby Users: From their experience of flying SAA, crews noted that having operators outside the UTM system will be problematic for SAA. Suggestion: Offer hobbyists incentives to encourage full participation in UTM.

7. Communication Navigation Surveillance Tests

Three CNS tests were conducted to examine technologies for communication and navigation by measuring data elements, such as the accuracy, latency, and switchover effectiveness. For the first test, CNS 1, the test sites attempted to maintain positive control of the vehicle during a scripted primary C2 link failure, and subsequently switchover to a backup link. To assess whether the redundant C2 was successful, a maneuver command was sent to the vehicle, and the vehicle's response was confirmed. The ability to remain within a flight geography using GNSS navigation was the focus of the CNS 2 test. The test sites were encouraged to utilize manmade structures to naturally inhibit or block signals between the vehicle and GPS satellites, or create a multipath effect. For CNS 3, vehicles were equipped with a radio frequency (RF) sensor payload, and gathered data at three different altitudes to characterize the RF environment and inform the impact on C2 communication in low altitude.

Five of the six test sites were awarded two or more CNS tests. In total, 12 CNS tests were awarded, and these awards were distributed so that each CNS test was performed by three to five test sites. Test sites conducted these 12 sets of tests over 18 calendar days, across two months. For some of the tests, an AOL observer was present in the field and took notes. For all the tests, participants completed a survey at the end of the day. Also, at the end of a number of flight days, crews took part in a debrief, either with the onsite AOL representative or over the telephone. These discussions and responses are reported below.

7.1 Method

7.1.1 Surveys

There were 30 questions in the CNS survey, with the questions preselected to show only between 10 and 25 of these questions depending on the test. All CNS tests received 10 general questions, and only CNS1 and CNS2 received additional test specific questions, 15 and 20, respectively. Many items asked the participant to rate their answers 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. Ninety surveys were started in total across the five sites. All 90 surveys had some data entered but not all were complete. The greatest number of surveys started at one site was 25 and the fewest was 11.

7.1.2 Debriefs

There were nine debriefs that focused on the CNS tests that were hosted across the five test sites. Eight were specific debriefs focused on one CNS test while one touched on all three CNS tests (see Appendix 15). Numbers of discussion prompts varied, as researchers wanted crews to discuss and explore the topics within the time available. Prompts focused on operator situation awareness, the UTM concept, usefulness of sensor data, and technical issues of concern.

7.2 CNS Metadata

There were 134 operations submitted to UTM by the test sites to support CNS testing. Sixty-four operations were submitted for CNS 1, 14 for CNS 2, and 55 for CNS 3. See Table 20 for a further breakdown of submitted operations.

Table 20. Number of Live and Simulated Flights Providing Data for TCL3 by CNS Test

	NASA	*Site 1*	*Site 2*	*Site 3*	*Site 4*	*Site 5*	*Site 6*	*Total*
CNS 1		21	8	19	15	1		64
CNS 2		6	4			4		14
CNS 3			3	21	25	6		55
All CNS		27	15	40	40	11		133

7.3 General CNS Feedback

A standard set of ten questions were asked at the beginning of every CNS survey. Participants were asked to rate the information they used, timeliness of actions, their opinions of the information they received through the USS clients, and their safety concerns.

7.3.1 Methods: Operational Effectiveness

In the surveys, CNS participants rated their flight operations in terms of their efficiency, timeliness, and the degree to which they relied on UTM information to achieve those (see Figure 25). Crews were cautiously positive about their operations. On average, they rated the timing of UTM messages as "right on time" ($\overline{x}$ = 4.4, note the midpoint of the scale was the most positive option) and reported that their operations were "quite efficient" ($\overline{x}$ = 5.3). To do this, they relied on UTM information "about half the time" ($\overline{x}$ = 3.7), although this degree of reliance varied between crews, and was higher for CNS1 than the other two tests.

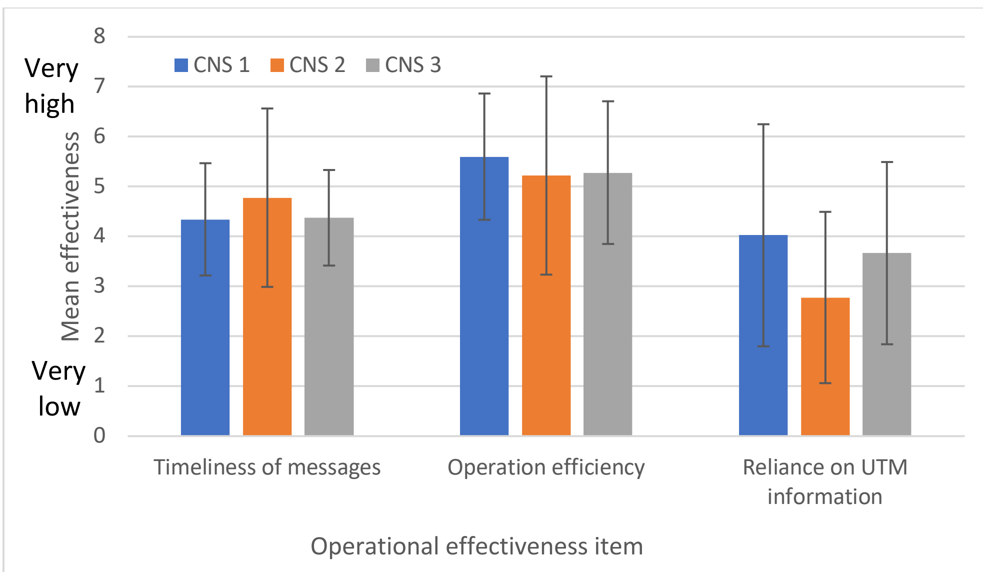


Figure 25. Operational effectiveness for CNS flights in TCL3 shown by type of CNS test (n = 44–70). Note: Rating scale was 1–7; y-axis is longer to show SD.

7.3.2 Information Properties

Participants were invited to rate eight properties of the UTM information they received through their USS. On average, participants rated all the UTM information they received as "good" with means varying from 4.6 for usefulness of information for planning to 5.3 for level of detail in the client (see Figure 26). Participants gave the highest ratings (on average) after CNS 3 and the lowest after CNS 2, especially for "noticeability of needed information."

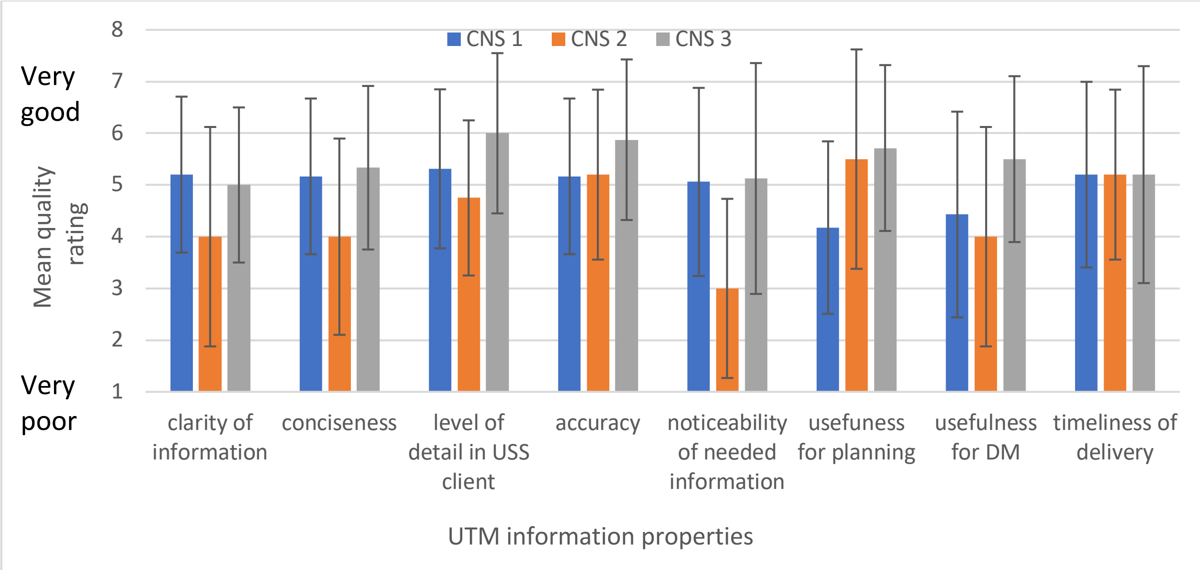


Figure 26. UTM information properties during CNS testing in TCL3 shown by type of CNS test (n = 26–35). Note: Rating scale was 1–7; y-axis is longer to show SD.

Participants were asked about their experiences as operators after every CNS test, specifically their level of workload and perceived awareness of UTM states, e.g., rogue or non-conforming, or active (Figure 27). Participants felt that they had good awareness of UTM states, on average ($\bar{x}$ = 4.9), reporting the highest level of awareness during CNS 3 and the lowest during CNS 1. On average, participants rated their workload as "moderate" during the CNS flight tests ($\bar{x}$ = 4.2), with CNS 2 having the highest ratings. Crews' lowest workload ratings were during CNS 3.

Participants were also asked how concerned they were about the safety of their operations and reported they had "no concerns" about safety 88% of the time (n = 74). There were only two responses indicating a crew was concerned about safety "many times" (2.3%). The reasons participants gave for being concerned were most often changes in the weather (30%) or an aspect of the testing (30%). Only once was a participant concerned during an unplanned off nominal event, where a manned helicopter intruded into the test area. However, twice participants reported their concerns were due to adding the USS client to their suite of tools, because it was distracting, e.g., "the distractions and inaccuracies of the current USS cause unneeded confusion in the GCS" (CNS1 participant, Test Site 2).

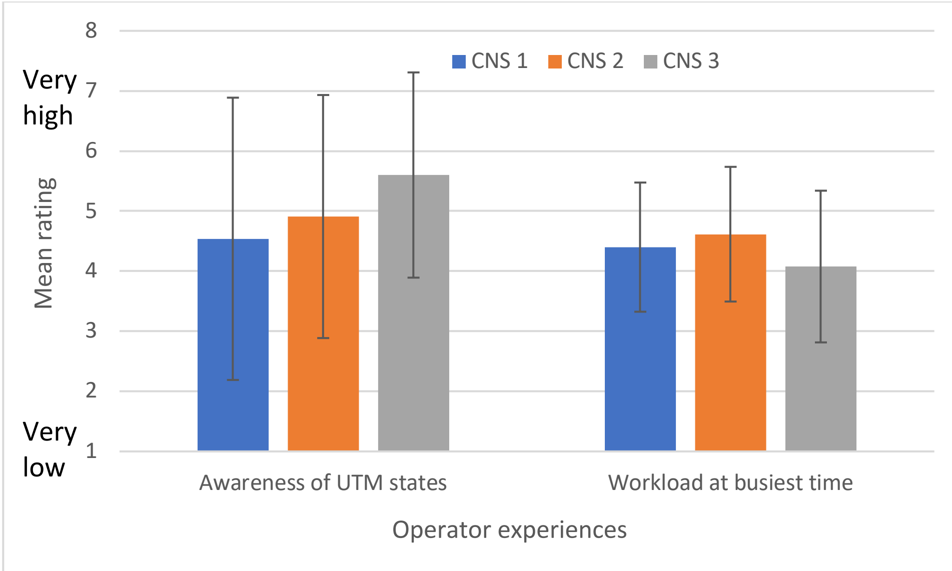


Figure 27. Operator workload and UTM awareness during CNS testing in TCL3 shown by type of CNS test (n = 49–75). Note: Rating scale was 1–7, y-axis is longer to show SD.

7.3.3 Technology: RF Spectrum

Participants debated which portion of the RF spectrum UAS are going to use in the future. Crews predicted that in the future, when there are many UAS in the airspace, then the RF bandwidth will be over-taxed and the command for one aircraft will possibly overlap onto another aircraft, which could lead to un-commanded movement. They noted that encryption will help but also that crews may need to declare the frequency they are using, which most will not want to do for privacy and security reasons.

Currently UAS use industry, scientific and medical (ISM) bands but they predicted that with the number of UAS flying these bands will become overloaded. One participant noted that this situation will improve when an aviation grade spectrum is available for UAS, but the team speculated there will still be a question about whether long term evolution (LTE) or the ISM band might still be used by smaller UAVs.

7.4 CNS 1: Effectiveness of Redundant C2 in Maintaining Operational Control of UAV

The CNS 1 test was designed to evaluate the effectiveness of redundant C2 tools in maintaining operational control of UAS. Crews were required to use two C2 tools on their vehicle (e.g., two point-to-point radios or a radio and a cell network), send a UAV maneuver command using their primary link to verify execution of the sent command via vehicle telemetry, and then to turn this link off (simulating a failure of the primary link) and re-execute the maneuver, again collecting telemetry data. In some cases, the test sites performed a natural link transition, where they would fly to a point where the primary signal was degraded enough to trigger an automatic switchover. It should be noted that the impact of a real failure varied across different UAS. For those whose systems were redundant, CNS 1 was a test of the auto-switch capability on their UAS to just use one radio, rather than two. This should not result in an interruption in telemetry, and was not an event that represented a failure for the crew. A failure would have been for the second radio to fail as well. For those crews who were using a single-link system, CNS 1 *was* a C2 failure, in the sense of an interruption in telemetry, with a switch to the back-up radio/network restoring the telemetry. This functional difference gave crews different perspectives and led to them responding differently to survey and debrief questions.

Survey questions asked about the process of switching C2 links, crew procedures and users' situation awareness. In debriefs, crews discussed alerting, GCS functionality as a model for USS clients, and C2 awareness (Table 21).

Table 21. CNS 1: Discussion Topics and their Notional Categorization into Information Themes

Debrief Topic Category	*Site 1*	*Site 2*	*Site 3*	*Site 4*	*Site 5*
Information property		7		11	
Information meets user		6	1	9	
Operator status		1		11	
Methods		1	2	2	
Automation		8	6	6	
Concept		5		3	

From the survey, 86% of the respondents reported that the UAV they were crewing automatically switched to its back up link (see Appendix 14 for details). Six respondents indicated that the C2 failure was shown on their GCS auto-flight software, through a message or icon, five reported that nothing was flagged, and a sixth had a manual system. One person noted that their USS client showed an alert message, while another reported that their USS client did not receive C2 link-messages. Forty seven percent of respondents indicated that their system automatically executed a contingency flight plan when it lost its primary C2 link, and 72% of respondents also reported that their UAS automatically continued on its original flight plan after switching to a back-up C2 link.

7.4.1 Methods: Management of Failure

Participants were asked a number of questions in the survey to establish how they were managing the C2 link failure. Sixty-six percent of survey respondents said they were monitoring the health of their ground-stations' C2 links with their UAVs. However, only 9% used the USS client to do this (confirming their USS client showed the C2 link failure), everyone else reported using their GCS auto-flight software for this. The 33% who were not monitoring the C2 link reported that it was not part of their role to do this, with one PIC explaining that he was not monitoring the C2 link because he was relying on his GCSO to tell him if they were switching between links. When the C2 link was failed, only 9% of the respondents did not know it had failed, and 27% reported they knew of the failure because they were told by a teammate. Surprisingly, of the 53% of respondents (n = 21) who said they became aware of the failure through their tools, 80% of this group (n = 17) reported they were made aware of the failure via their USS client specifically. (This is only surprising because relatively few people reported they were monitoring the USS client for system health *and* reported failure messages coming through on their GCS, see above and discussion below.) They explained that the display showing them the C2 failure, provided "a lot of the information" they needed about the failure ($\bar{x}$ = 5.5; n = 30).

CNS participants were also asked about how they managed their C2 link failure and switched to back-up in terms of their efficiency making the switch, the timeliness of their response and, the completeness of the information they received about the failure. Crews reported their failure response processes were good overall. They were starting from a good position because they reported having "a good amount" of the failure information they needed, on average ($\bar{x}$ = 5.5; Figure 28), with Test Site 4 responding that they thought they received the most information. Test Site 1 participants had the most varied opinions within their group. On average, crews estimated that their response to the C2 failure took "very little time" ($\bar{x}$ = 1.8), with all test sites being in agreement on how quickly they resolved the issue. They argued that they should not have to share information about the amount of time it takes them to complete the C2 switch with other crews through the UTM system, but then debated whether they should have to if this process took a long time (e.g., more than 10 seconds, see below for a discussion on 10 seconds to alert). Supporting this, they also estimated that their C2 link switch to the back-up link was "efficient" ($\bar{x}$ = 6.1).

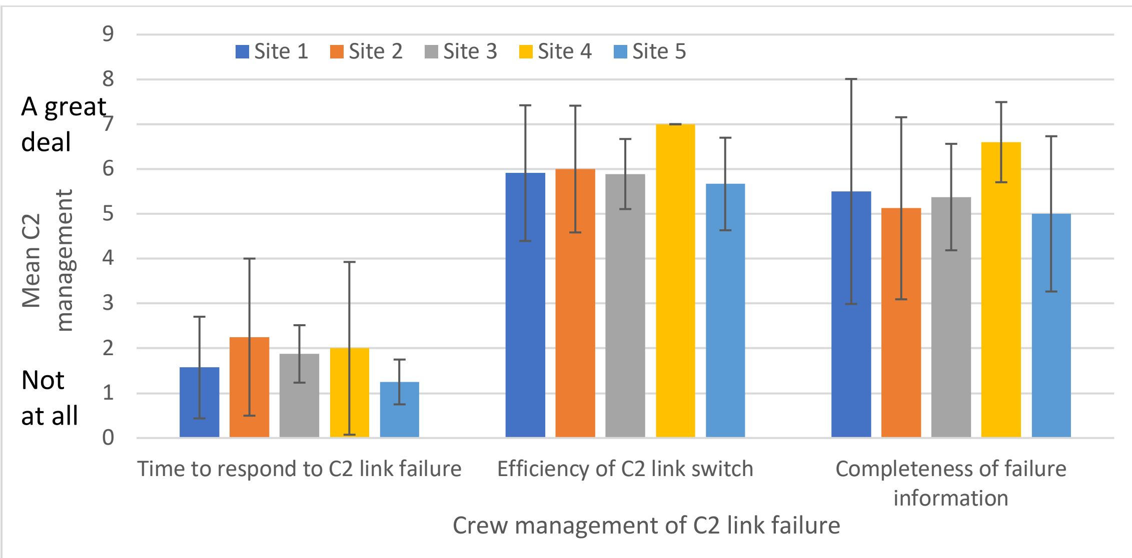


Figure 28. Crew management of C2 link failure during CNS 1 test shown by site (n = 25–35). Note: Rating scale was 1–7; y-axis is longer to show SD.

7.4.2 Operator Experience: Situation Awareness and Workload

A primary C2 link failure might seem like a busy time for flight crews, but the participants in the survey reported a lower than average level of workload ($\bar{x}$ = 2.5) during the CNS 1 tests (see Figure 29). Participants at Test Site 4 reported that their workload was "very low" on average ($\bar{x}$ = 1.4). One reason for this may have been that their UAV automatically switched to a backup link and continued with its flight without crew intervention.

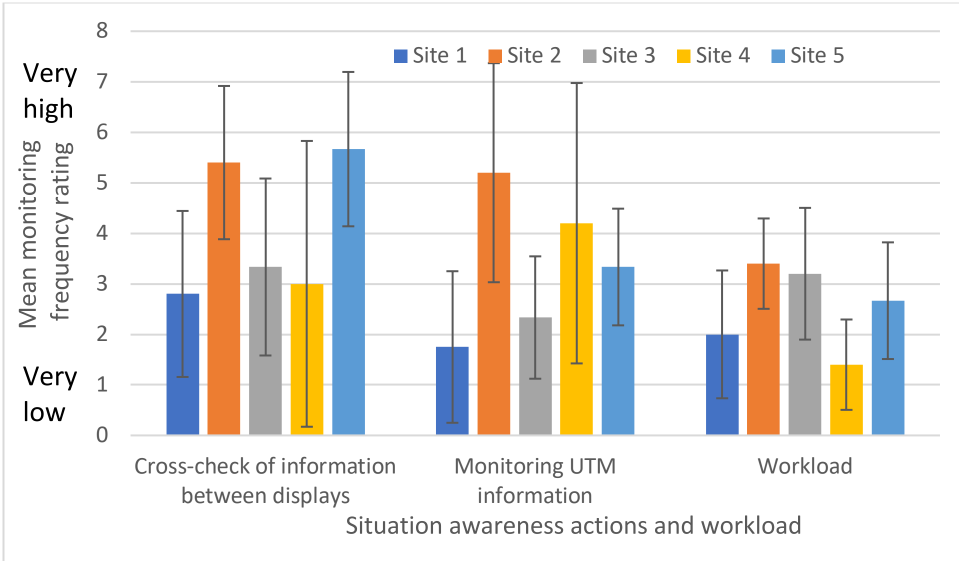


Figure 29. Operator monitoring and cross checking (situation awareness) during CNS 1 testing in TCL3 and operator workload shown by test site (n = 16–24). Note: Rating scale was 1–7; y-axis is longer to show SD.

Also shown on Figure 29 are participants' estimates of the degree to which they monitored UTM information and cross-checked their USS client information with other sources, reflecting their comfort level with their situation awareness. The degree to which crews reported they monitored their USS ranged from "hardly at all" to "quite often" depending on the test site, with those at Test Site 2 reporting they "monitored quite often" on average ($\overline{x}$ = 5.2) and crews from Test Site 1 reporting that they monitored the USS client "hardly at all" ($\overline{x}$ = 1.76). Participant ratings were dependent on the UTM role organization within the team and also dependent on the role individuals were in. Respondents varied a great deal in the frequency with which they reviewed their USS information with other sources. On average, participants reported they reviewed information "sometimes" ($\overline{x}$ = 3.7) but individual reports varied from "never" to "constantly" and, again, ratings varied from site to site. For example, Test Site 5 reported they cross-checked information "often" ($\overline{x}$ = 5.6), whereas Test Site 1 "intermittently" cross-checked their USS client with other sources.

Crews discussed which information should be available through their USS client. They said everyone should see the positions of all the aircraft that are connected to the local USS network. In the case of lost link (or stoppage in position reporting for other reasons), all those in the area should receive an alert to the possibility of a conflict with that flight. Others thought last known heading, altitude, and airspeed should also be broadcast to help other pilots estimate which areas to avoid. One participant suggested that UTM should build a caution area around the last known position of the vehicle to assist other crews. A second PIC noted that if you lose link, you have low SA and uncertainty about your own vehicle.

7.4.3 Information: Alerting

The discussion, about what crews with a C2 failure needed to know led to a discussion about the number of alerts a neighboring crew might receive due to this event. Crews were concerned about being flooded with alert messages and being distracted by too much information, both from their own UAS and from others. Even for their own UAS, one PIC said they would not want to receive pop-up messages for a temporary lost link event, and definitely not for other vehicles. As an example, at one test site, there was a visual indicator on their GCS toolkit that simply turned red when there was a C2 failure of that vehicle. Another crewmember suggested a lower time limit for reporting lost link, and that one second telemetry drops should not be reported (see below that systems follow this suggestion to some degree).

For other UAS, another PIC emphasized that he would want an extremely low false alarm rate if every lost link was going to be broadcast as an alert. Crews pointed out that it is not worth broadcasting information that does not affect anyone else, and this would avoid unnecessary distractions. Participants argued that, if you still have one C2 link, are in control of your vehicle, and are inside your volume, other operators do not need to know you lost your primary radio. Crews said they only needed to know about others' lost link if that operation is not being tracked in any other way, or if it would affect their airspace, or the UAV was having trouble (presumably loss of control). In the case where the other UAV with the lost link would affect local operations, crews said they would want to know as much as possible about that flight. For example, it would be important to know if a lost-link-UAV is executing a total loss of link procedure, as this state would make the aircraft position uncertain and it would be unable to react to commands. One site said that lost link situations may be best shared USS-to-USS, rather than directly to the UAS operator, and then have the information filtered down to the appropriate users. They specified that might it be helpful to define a level of priority or criticality to avoid clutter arising from C2 link issues of other operations.

7.4.4 Information: SDSP

One suggestion for our SDSP was a strength-of-signal heat map showing the spot where radio coverage is good and poor within a wider area**.** Crews noted that a large operator or dispatch position, deploying many UAS, might find information like this very useful. Participants also said that service providers of the C2 link, as a service that UAS operators will subscribe to, should have a way of showing their users when a link is down or impaired.

7.4.5 Automation: GCS

GCSs contained the primary tools through which crews monitored their lost link status. Crews described both the representation of lost link status and when this was triggered on their GCS. Many crews have a redundant C2 link, where all telemetry sources are connected and the crew is able to see the health of each link, sometimes as the number of satellites acquired or as a general rating of overall signal strength, depending on the system. Some systems have an auto-switch capability where the UAS switches itself to use the best signal available. Systems also vary in their time threshold for a lost link alert, e.g., 3 or 10 seconds. If the link is lost for less than 10 seconds (or 3), the system does not show an alert to the user. The PIC in the debrief agreed with a lower limit to alerting, saying they definitely do not need to be told about lost links less than a few seconds long. However, in a situation where a crew needed to reboot a system, which would take a relatively long time (e.g., 45 sec), this should be alerted to other operations that are in close proximity. All these features reduce the number of alerts presented to the user and led to the crew reports, noted above, that they were not aware of the primary radio failure. For those whose systems did not automatically switch, crews reported knowing they had successfully switched to their back up radio when the telemetry data on their GCS re-started.

Crews described that the strength of their C2 link was shown as a colored bar on some GCS. A good connection was represented in green and it turned a series of colors and then to blinking red as the signal degraded. Others reported that their systems had signal-strength icons, that changed color with the link strength, and pop-up windows to alert its status. Crews suggested these features should be copied in USS clients, then lost link alerts would display through a USS client as a color change in the aircraft icon or a message.

7.4.6 Automation: USS Client

Crews from more than one test site reported that their USS client did not provide them with enough/ timely information to be useful in CNS 1 testing. Crews reported a large lag when they were using the USS for their UAS to switch from the primary C2 link to their back-up, noting that when they conducted flight operations through their GCS alone, without the USS involved, the switch-to-backup was a matter of seconds. With the USS in the loop, it took much longer. Crews speculated that the amount of telemetry data flowing through the UTM system when many UAV had two radios on board and reporting out was enough to slow the USS (UTM) down.

Two additional general issues with their USS were also reported by some crews. At Test Site 2, crews noted that their USS client showed them a view that was too high-level (zoomed out) to be useful. The UAV icon was larger than small volumes and they could not see its movement within the space, so they consulted their GCS for all the information they wanted. At Test Site 4, the issue was different. This site had multiple USSs covering in the same area and those USSs did not share information, so crews using one USS did not know when UAV on another USS network had experienced lost link. USS Ops reported feeling isolated and listening to the radio to try to glean information.

7.4.7 Automation: USS Issues

Crews reported a number of issues with their USS that were revealed during their CNS 1 testing. One was a NASA issue: that the NASA side of the UTM system had too many teams wanting to make data connections and could not support all of them. This resulted in crew submissions being rejected but not for a reason they could address. This issue was resolved during TCL3 testing. A second issue was the UTM limitation that it could not accept more than ten volumes (see footnote 5 above).

7.4.8 Concept: Privacy

There are two threads to the C2 lost link test. The first is how much crews wanted to know about their own UAS, and the second is how much they need to tell other crews. Keeping others informed of your C2 link status potentially entails revealing a good amount of data about your operation, and many crews were uncomfortable with this. Participants debated about the amount of privacy UAS operations should be afforded. One PIC thought it would be okay to show the position of the aircraft but not operator details, and suggested using randomized callsigns to protect operator identity. When asked specifically about whether they should be required to report a loss of C2 link to the community, the group was divided, saying that it depends on the specific situation (as discussed above). If you have a secondary link or seamless back-up mode, so there is little to no effect on your performance, PIC asked “why would I share that?” But, they agreed that if the failure impaired your vehicle’s performance, then you should broadcast this (and will have to follow a public network’s rules). Others thought that, regardless of the situation, you would want to broadcast a reduction in capability. One participant suggested that UAS could report, along with their position information, whether their system is operating in dual-link mode or single-link mode. If the dual-link switched to a single-link mode, then other users would be able to infer that the vehicle had experienced a lost link. Other participants supported an idea like this because it would provide information but not create alerts. (See also discussion above about alerting.)

7.4.9 Concept: Participants

PIC asked how manned aircraft are going to be informed of UAS that are having difficulties, e.g., lost link. They argued that helicopter traffic, in particular, either need a way to monitor UAS traffic or to be told about unexpected behavior from UAS traffic.

An issue arose when a site had multiple USS covering the same area. Crews experienced their flight volume closing without warning midflight. They had no indication on their USS client that this was going to happen or why. It became apparent that crews using another USS covering the same area were able to close the volume on the first USS, which enabled them to submit, and have accepted, a volume for their vehicles to fly in that same area. These "second USS" crews were unrepentant because, in the time it took the teams from the first USS to troubleshoot the issue and then resubmit volumes, the second USS crews had completed all their test flights.

7.4.10 UTM System

Participants varied in their opinions of the usefulness of UTM. Two opposing perspectives were an argument that all UAS operators should have to participate in UTM because having an operator who can decide to not be part of the system and then fly in contravention to all the rules of the UTM system will defeat its purpose and make the airspace unsafe. The opposing view was that there is no benefit to UTM other than a "no guarantees" assurance that the airspace is clear for you.

Participants want the UTM submission procedure to be more user-friendly. One particular case they discussed was moving the window for time of flight, noting that, if they flew before the window opened, telemetry was not sent through the system. For example, in the case where the crew needed to take off early, due to weather or other constraints, they needed to either make extensive edits in UTM or create a whole new operation.

7.5 CNS 2: Remaining within Flight Geography using GNSS Navigation

The CNS 2 tests explored the impact of GNSS navigation errors on the ability of UAS to stay within their UTM flight geography. To achieve this lack of coverage, one site flew their vehicle in close proximity to a structure, which increased the level of safety concern for all involved. A second site used a shroud-collar on their UAV to mask the GPS signal and flew in an open area. They also had radar surveillance as a second source of telemetry and (as the test specified) wanted to see how closely the radar signal aligned with their GPS telemetry with and without the shroud. The third site flew into and out of a building.

Test sites reported very different experiences with GPS degradation. At the second test site, the team reported that it was difficult for them to degrade their GPS signal during the flight tests, and they saw no noticeable difference in telemetry between using a collar on their GPS and having no shroud. However, the third test site reported that they had trouble staying in their volume because they experienced a large GPS drift. This resulted in the UAS going both rogue and non-conforming during their CNS 2 tests. They observed high horizontal dilution of precision (of GPS signal) (HDOP) values and high horizontal and vertical position variance and one PIC reported he lost GPS lock multiple times during the tests. Survey questions asked about the reliability and quality of the Global Navigation Satellite System (GNSS) back up source and users' situation awareness during these maneuvers. Debrief prompts focused on use of the USS client and navigation data availability (Table 22).

Table 22. CNS 2: Discussion Topics and their Notional Categorization into Information Themes			
Debrief Topic Category	*Site 1*	*Site 2*	*Site 5*
Information property	6	5	
Information meets user	2		
Operator status	2		
Methods	4		
Automation	6	1	3
Concept			

7.5.1 Operator Experiences: Situation Awareness

Participants were asked about the frequency with which they refreshed their situation awareness, by monitoring the USS client or cross-checking it with other sources when their vehicle was flying using different navigation GNSS (Figure 30). The degree to which crews reported monitoring their USS was site dependent, with those at Test Site 2 reporting they "monitored quite often" on average ($\bar{x}$ = 4.6) and crews from Test Site 5 reporting that they monitored the USS client "sometimes" ($\bar{x}$ = 2.5). However, participant ratings were also role-dependent. Respondents varied a great deal in the frequency with which they cross-checked their USS information with other sources. On average, participants from two sites reported they cross-checked information "sometimes" ($\bar{x}$ = 4.3) but individual reports varied from "never" to "constantly."

Crews were asked whether they needed to know details about GPS signal strength. They all agreed that they did, and liked that this information, e.g., number of satellites acquired, was available on their auto-flight software (GCS). Crews explained that some of the UAS flight modes are dependent on GPS availability, and so knowing how many satellites are in your HDOP gives the crew an idea of how reliable these modes will be.

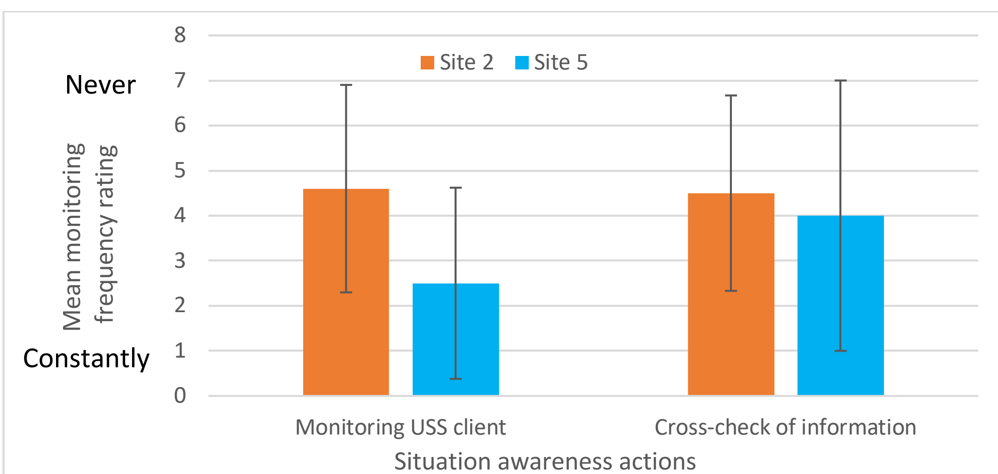


Figure 30. Operator monitoring and cross checking (situation awareness) during CNS 2 testing in TCL3 shown by test site (n = 7–8). Note: Rating scale was 1–7; y-axis is longer to show SD.

7.5.2 Automation: Technology

Participants rated their GNSS back-up source (various technologies) as “reliable” on average ($\bar{x}$ = 5.7) and the discrepancy between the sources as “manageable” ($\bar{x}$ = 3.7). The change of GNSS source caused the test sites some difficulties with staying within their flight boundaries, but also, those flying near structures found the vehicle position reports were inconsistent as both position and heading were affected by the obstacle providing the navigation shadow.

Ground radar is another safety tool employed by some sites and used in tandem with their on-board sensors. Crews noted that the radar indicated a divergence from the last reported GPS position if the GPS signal was very weak, and that although this radar lacked precision, it provided general course information if you had nothing else.

7.5.3 Automation: USS Client

One test site compared their USS client to their vehicle auto-flight software. They bemoaned the lack of development/functionality on their USS client, saying the client told them nothing—yet. Issues they listed were that the USS map view was the whole flight area and their UAV icon was bigger than their volume. There was also no alerting. By comparison, their auto-flight software showed them position, speed, how many satellites were forwarding telemetry, and had a range of visual alerts.

Another test site noted the complexity of flying UAS from remote sites. They listed all the connectivity they had to ensure, first for telemetry then to keep personnel in touch, and the difficulties setting up reliable hotspots, linking GCS and then linking to UTM.

7.5.4 Concept: Safety

A central concern for the CNS 2 tests revealed during crew debriefs, was the strength of the telemetry signal that their vehicles were receiving. Signal can be degraded for a number of reasons—RF interference is one and also overload on the RF circuits (see Section 7.6).

PIC at Test Site 1 pointed out that the impact of signal degradation depends on how you are flying your vehicle. For example, if the GPS is degraded, the UAV autopilot may be unable to land the vehicle, as it is not designed to do this when the horizontal and vertical positions of the UAV are unclear. If they do lose the GPS signal from their UAV, crews reasoned that they have fail-safes they set before flight, usually commanding the UAV to loiter, to give the system time to re-acquire the signal. At another site, when a crew lost GPS signal, their GCS display froze, and position reporting was lost, but when the GPS was re-acquired, the display un-froze and began re-showing positions.

PICs were comfortable with the layers of safety they had supporting them if they lost GPS signal, noting that they had a VO, personal awareness of the vehicle location, the ability to take manual control, and the comfort of knowing the UAV has fail-safes programmed.

7.6 CNS 3: RF Interference Baseline Monitoring

The CNS 3 tests asked test sites to characterize their radio frequency (RF) environment and evaluate its impact on their UASs’ C2 links. Crews clarified that they were concerned with both frequency overload and magnetic interference, such as the interference they have found around metal towers or power lines, during these tests. Four test sites performed RF baseline flight tests (a total of 56 recorded data collection flights) and, by design, only the general section of the surveys was asked as there was not a human factors component to these tests. The discussions reported below are from the debriefs that followed some days of CNS 3 testing. Debrief prompts focused on the quality of telemetry, what information a crew can glean from a degraded feed and crew situation awareness (Table 23).

Table 23. CNS 3: Discussion Topics and their Notional Categorization into Information Themes

Debrief Topic Category	*Site 2*	*Site 3*	*Site 4*	*Site 5*
Information property	3	3	4	
Information meets user			1	
Operator status			1	
Methods			4	
Automation		7	5	
Concept	1		1	

7.6.1 Technology: RF Interference

Crews at different test sites reported different levels of RF interference in their testing. Those at Test Site 4 said they saw no interference, although they noted that they have experienced interference before when using the 2.4 GHz band. Test Site 4 also saw a drop in LTE coverage, but the USS Op confirmed that the drop was the LTE on the RF not related to position updates. Test Site 2 reported they did not see any unexpected RF frequency interference, as they were very familiar with the area and knew where they would see a decrease in signal on their flight corridor.

In general discussion, crews reported having RF interference problems (in the 2.4 GHz band) when they have been flying next to cell repeater towers and have found magnetic interference around metal towers and power lines. They described magnetic interference, noting that the GPS fades first, then the compass fails, and at that point flying gets “sketchy.” Overload, crews described as cyclical, as cell phone usage is higher at some times of the day. They discussed whether the 2.4 gigahertz band may suffer from being drowned out by Wi-Fi, but crews thought that the Wi-Fi signals coming out of a building are too weak to cause disruption. Crews noted that they are more concerned about RF interference than they are about loss of GPS. If they lose GPS, then the UAV has RTB commands in its software, so there is not a problem with getting the UAV back to the GCS, but with RF interference, you are not sure which commands are getting to the UAV and which are not.

One test site discussed a few possible sources for RF interference with the on-site NASA representative. In addition to external interference, ownship payload or electronics equipment could potentially also cause issues. Even during this TCL3 testing, the crews cited jammers that caused unexpected GNSS interference as a concern that could affect their navigation capabilities.

7.6.2 Automation: Issues

Crews reported issues they had with their USS client during their flight testing. One test site had an issue where their flight geography closed abruptly. Their complaint was that the interface did not give them any warning before the closure, nor any information that told them why. Their second concern was that their system stopped reporting telemetry when the volume closed, which meant their vehicle disappeared from UTM. For later tests, they ensured that their system kept recording if the volume closed, but it still did not live-transmit to NASA.

Two test sites had issues with their volume submissions being rejected by the UTM system. One test site did not know at the time of the debrief whether it was an issue they had with not sending data in the correct format or time limit, or whether it was an issue with UTM. It caused them to spend some amount of time looking through their USS client logs to find “hiccups” and developing a trouble-shooting plan. The second site was aware that the issue was with UTM, and it was because two sites were trying to use the NASA server at the same time and the USSs were both in the other’s LUN.

In addition, crews reported some connectivity issues related to moving locations, because the port connections between the USS client and UTM were not always maintained as they moved, so they had to recycle the connections. They said that to all the other USSs, they just blipped off their screens.

One participant argued that the time constraint to the flight geographies should be removed. Flights are delayed all the time, so the UTM system should just recognize when a UAV takes off, automatically activate the volume and start sending telemetry, and should automatically close when the UAV lands.

7.7 CNS Tests Summary

Test sites were interested in these C2 TCL3 tests, as all their crews had experienced telemetry faults and weaknesses during past missions. However, apart from known locations, the C2 link was reported to be stable throughout the TCL3 tests. Awareness of C2 status and data health was generally high, often with team members tasked to specifically monitor system health.

- Safety: Feedback indicated that operators were generally happy with the safety of their operations during CNS testing.
- Technology: Some crews noted a lag in their C2 data. Moving forward, crews made suggestions for more direct vehicle to USS connections in an effort to speed up data arriving to the user from the sensors.
- SA: Discussions focused on what operators need to know about other flights. Moving forward, operators suggested continued progress to identify what they need to know about other operators in UTM and providing that information.

Discussions focused on the human-technology interface, not only what tools and displays were available in their GCS, but also what features they would like their USS clients to have. As well as clear and timely alerting, crews wanted to be aware of their telemetry strength, but not be distracted by it. They were concerned about being flooded with alert messages, both from their own UAS and from others, if issues internal to one UAS were broadcast to all others in the area. They were also concerned about privacy if they had to report out all issues with their systems.

- Usability: Crews emphasized that C2 link displays needed to be simple, and could be situated on the USS client in this case. Moving forward, indication of the strength of the C2 connection might be added to USS displays (simple gauge only).
- Distractions: Users were concerned about being flooded with messages if every lost

link was to be broadcast to the community. This led to a wider discussion of how much is “too much” for all types of alerting. Moving forward, crews suggested that the community specify some lower limits on what needs to be broadcast, e.g., “lost link” of one or two seconds does not need to be broadcast.

- Privacy: Users do not want to share their data or information, but agree that some level of sharing has to happen to make UTM useful. Implications are, as stated earlier, that the community should specify lower limits on what needs to be broadcast, outlining information that must be shared and when.
- Procedures: Reports from crews indicated that they had no issues with their CNS procedures, possibly as these seem to be more clearly specified for CNS loss than other areas.
- Design: UTM users were able to “step on” each other to reserve airspace, some did this accidentally, others gamed the system to gain an advantage. Moving forward, is the recommendation that these loopholes should be identified and solutions considered.

8. TCL3 Conclusions and Recommendations

Six test sites participated in the TCL3 testing from March through May of 2018, flying a subset of 20 tests with one of four foci—CNS, DAT, CON or SAA. The mainly qualitative data discussed above was collected by on-site and remote NASA researchers. The data consisted of end-of-day debriefs, end-of-day surveys, observer notes, and flight test information, submitted as part of the data management plan. The TCL3 flight tests were successful, and more was learned about operators, the information they need to fly within UTM, and procedural requirements in a TCL3 environment. The findings presented above complement data previously collected for TCL2nc (Spring 2017) and TCL2 (Reno, 2016). Test-sites, again, markedly improved their tools and organization with respect to UTM, but also identified further areas that would benefit from more consideration.

Taking general account of the 280 individual survey responses and 40 debriefs with crews at test sites that reviewed the 831 test flights made, the feedback from participants was positive in a number of ways. Data from CNS and DAT tests were very helpful, and the tests went as expected. The tools investigated with the SAA tests were well-received by operators and helped with their overall situation awareness. CON tests were interesting and varied and generated a good deal of discussion at both a detailed level of flying during different events and at a broad concept-level.

In addition to items already addressed from previous flight tests, certain themes consistently surfaced in many discussions regardless of the particular test site or specific test being discussed. These themes relate directly to one of the six overarching categories that were pre-defined (Table 4) by the AOL and guided the data collection process to inform the question: “What information is required to successfully fly in a UTM environment?” All of these themes together help us understand how UTM was used, what went well and should persist, and how the UTM experience can be improved.

1. Information Properties

- *Alerting Information.* Crews discussed UTM-specific alerts at length, including rogue states. They discussed aspects of alerting triggers, distance from target, priority operations, balancing alerting frequency between too often and too seldom, what information should be broadcast, and procedures for responding to alerts. Moving forward, alert characteristics, including information required, and expected proper responses need to be further defined.

- *Usability.* Under-developed user interfaces contributed to users not accessing UTM information, and instead falling back on LOS techniques to ensure the safety and compliance of their vehicles. Examples of this included on-screen clutter caused by too many consecutive and repeated alert messages, and clutter from multiple (and sometimes too-sensitive) track sources being displayed simultaneously. Moving forward, standards could be developed for displaying relevant information to increase the usefulness of information offered while engaging with the UTM environment.

2. Information Meets User

- *Trust and Reliance.* False alarms and/or inconsistent responses from their system led users to rely on UTM information less because they could not trust that everything relevant was being detected and reported. Moving forward, the reliability of detecting and reporting information should be improved in order to increase trust in the systems, and therefore user reliance and buy-in to UTM.

- *Transparency of Tool.* Interfaces showing UTM information did not always give enough information to the user about why automated actions took place. This led to longer times for the operators to diagnose issues and troubleshoot problems. Moving forward, tool transparency and information clarity need to be improved along with user training/experience on the system.

3. Operator Status

- *Situation Awareness* was influenced by the usability of the information presented by crews' USS client, but also by how aware they were of what information was accessible. Operators who understood how UTM works, their part in the system, and how to access the information applicable to their tasks, had positive feedback about their UTM situation awareness. In addition to further GUI development, more training before the tests begin can help users understand how to utilize their tools and interpret the information meaningfully.

- *Workload* reports were estimated at low or moderate, a very manageable level, even during flight tests that included off nominal events, suggesting that crews were able to manage the addition of the UTM role and the extra information load that brings within their teams.

4. Methods

- *Procedures or "Rule Book."* Throughout the TCL3 testing, there was evidence that further development and research on procedures, standards, and/or recommendations are needed. For example, if two interacting vehicles were operating under different assumptions or guidelines, their responses to situations would not be predictable enough to support trust in the system. Defining proper responses for an array of theoretical situations, and then assessing them, can help users feel more comfortable with overall knowledge of their own and others' operations.

  Example procedure/recommendation areas include:
  - Altitude reporting standardization (AGL/MSL)
  - Operational limits that define a rogue state and the reporting that goes along with that state change
  - Actions required in the event of a USS failure

– Actions required when interacting with a TFR
– When and what information to show to other players
– Guidelines for USS client displays
– Cooperative planning between users of each USS to avoid “gaming” the system.

5. Concept: Operator Buy-In

- *Training.* As mentioned above, more training is advised to increase operators’ situation awareness, but training may also increase acceptance of the UTM concept and operators’ willingness to participate in this environment. Users with broad UTM knowledge were able to interact with the systems purposefully and provide a great deal of feedback regarding what they liked and disliked about both UTM concept and specific tools used.

6. Automation

- *Level of Automation*. There were many, varied, levels of automation available to the participants of TCL3 that affected their experience with, and opinions of, UTM. Some crews used tools that were nearly entirely automated, with very few tasks allocated to the human operator. Other crews had human operators manually flying their vehicles with little knowledge of the automation that was interacting with UTM on their behalf. Most crews used a system somewhere in between, making the TCL3 testing a good representation of what is anticipated in the future for automation integration. As would be expected, crews that relied on automation, and had everything go well, were more receptive to UTM, while crews that experienced issues or bugs, had a less positive response. Generally, operators liked the tools that were presented to them clearly and reliably.

- *Tools*. Although tools, like those for the SAA tests, were very well-received, participants suggested additional features and functions, which, if not already supported with the current configuration, may be helpful additions in the future.

  Example features and functions suggested include:
  – Better feedback on USS clients
  – Ability to categorize a UREP
  – Arrival alerts for UREPs
  – Recoverability from a rogue state
  – Dynamic volumes
  – Two or more vehicles sharing launch locations
  – Ability to compare overlapping volumes and make suggestions
  – Ability to add a delay to an accepted volume
  – Integrating USS clients and auto-flight software
  – Severity component to alert messages
  – Always reporting key information with an incoming conflict
  – Audible alerts
  – C2 link-health status indicators
  – Auto-switch to secondary C2 link
  – Redundant sources for critical information in tools
  – Safe landing area identification
  – Automated de-confliction
  – Predicted vehicle trajectories with closure rates

9. References

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

Kopardekar, P., Rios, J., Prevot, T., Johnson, M., Jung, J., & Robinson, J. E. I. (2016). *Unmanned Aircraft System Traffic Management (UTM) Concept of Operations*, AIAA Aviation, Technology, Integration, and Operations Conference.

Martin, L., Wolter, C., Gomez, A., & Mercer, J. (2018). *TCL 2 National Campaign Human Factors Brief, NASA/TM-2018-219901*, NASA Ames Research Center, Moffett Field, CA.

Rios, J. (2017). *UTM TCL3 Statement of Work*, 27 July, 2017.

Rios, J., Mercer, J. & Martin, L. (under revision, 2018). *Use of UAS reports during TCL3 field testing*, NASA/ TM, NASA Ames Research Center, Moffett Field, CA.

Appendix 1: Days of flying for TCL3

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
5-Mar						
6-Mar						
7-Mar						
8-Mar						
9-Mar						
22-Mar						
27-Mar						
29-Mar						
3-Apr						
5-Apr						
6-Apr						
9-Apr						
10-Apr						
11-Apr						
12-Apr						
15-Apr						
16-Apr						
17-Apr						
18-Apr						
19-Apr						
23-Apr						
24-Apr						
25-Apr						
26-Apr						
27-Apr						
4-May						
7-May						
9-May						
10-May						
11-May						
15-May						simulation only
16-May						
17-May						
18-May						
23-May						
25-May						
30-May						
Shakedown days	1	1	4	0	3	1
Test days	11	4	6	9	13	8
Total days in field	12	5	10	9	16	8

Key: orange background = a shakedown day; green background = a data-collection day; blue background = a simulation only day

NOTE: one site retested some of their data collection in the lab – hence there were 51 days of testing for data collection with 50 of these flying vehicles in the field and one simulating all flights in the lab.

Appendix 2: Crew Size and Composition

GCS and flight crew information.

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Most common number of GCS	Up to 5	4	2 (note TO site is different, there was 1 of these)	2	1	5
Number of crews flying	Up to 5	3 real, 1 simulated	2	3	2	5
Most common number of personnel in a flight crew	3 (not co-located)	3-6 (co-located)	6 (not co-located)	2-3 (co-located)	4 (not co-located)	1 to 3 (co-located for some crews)
Common crew positions	GCS op, USS client op, PIC, engineer, VO	GCS op, USS client op, USS manager, PIC	PIC & GCSO, VOs	PIC, GCS/US Sop	GCSO PIC, VOs = shared by both crews	GCSO/PIC, USS Op, VO/ safety rep (other configurations were used)
Additional crew positions	test manager	Integration manager, engineer	Additional collocated = UTM specialist, data engineer and at an alternate location: UAS ID field personnel = shared by both crews		Additional = UTM operator	flight manager, test coordinator, package loader

Appendix 3: Vehicles Flown in Flight Test

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Number of UAS models	6	3	2	4	5	8
Type of UAS flown	6 multi-rotor	1 multi-rotor 1 fixed-wing, 1 hybrid	2 multi-rotor	1 multi-rotor 2 fixed-wing 1 helicopter	3 multi-rotor 2 fixed-wing	1 hybrid 5 multi-rotor 2 fixed-wing
Model of UAS	S1000, S900, F450, Matrice 100, inspire, ptarmigan	VTOL Savant, NAV-X, T-master	S1000, Matrice100	F7200, F6500, vapor, Sharper A6,	UASUSA Tempest, F7200, Solo, Matrice 600, AR-180	eBee, Aero, Hummingbird, Intel Aero, Inspire, S1000, Eagle XF, Phantom 3

Appendix 4: List of Flight Tests

Test identifier	Title
CNS	**Communication, Navigation, and Surveillance**
CNS1	Maintaining control of UA with Redundant C2
CNS2	Remaining within Flight Geography using GNSS Navigation
CNS3	RF Interference Baseline Monitoring
SAA	**Sense and Avoid**
SAA1	Air to Air Conflict Mitigation Cooperative Technology for UAS-UAS Interaction
SAA2	Air to Air Conflict Mitigation Cooperative Technology for UAS-Manned Interaction
SAA3	Air to Air Conflict Mitigation Non-Cooperative Technology for UAS-Manned Interaction
SAA4	Air to Ground Conflict Mitigation Non-Cooperative Technology for UAS-Manned Interaction
SAA5	System Level Assessment and Off nominal conditions
SAA6	Air to Ground Remote Identification and interoperability with automobiles using Cooperative Technology
DAT	**Data and Information Exchange**
DAT1	End-to-end UREP
DAT2	FIMS failover
DAT3	USS failover
DAT4	UAS ID
DAT5	USS-USS Negotiation
DAT6	Wx Service
CON	**Concepts**
CON1	BVLOS Landing
CON2	Contingency Initiation
CON4	Multiple TCL-2/3 operations for a sustained period
CON5	FIMS/USS interaction when vehicle heads towards Controlled or unauthorized airspace

Appendix 5: Debriefs Conducted

Debrief Interviews: Location and test discussed.

✓:

Test	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	ALL
DAT1		1 ✓		✓	✓	✓	1
DAT2				✓			
DAT3		✓		✓	✓		
DAT4			2	1			3
DAT5		1 ✓		1	✓	✓	2
DAT6		✓					
DAT multi test		1		1	1	2	5
CON 1			1				1
CON 2	✓				1	✓	1
CON 4	1 ✓			1	1	1 ✓	4
CON 5	2			1			3
CON multi test	1					2	3
SAA 1						✓	
SAA 2	1						1
SAA 3						1	1
SAA 4	1						1
SAA 5							
SAA 6						✓	
SAA multi test						1	1
CNS 1		✓	1	1			2
CNS 2	1	✓			1		2
CNS 3		✓	2	2			4
CNS multi test		1					1

Check marks denote that this test was covered in a debrief that discussed multiple tests. The number of multi-test/ multi-topic debriefs is listed in the “multi-test” rows.

Appendix 6: Flights Made by Test Sites to Fulfill each Test

Flight activity by Test (includes GUFIs with or without valid positions).

	NASA	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	ALL
CNS1		21	8	19	15	1		64
CNS2		6	4			4		14
CNS3			3	21	25	6		55
CNS		27	15	40	40	11		133
SAA1							8	8
SAA2		8				4		12
SAA3						2	5	7
SAA4		3				6		9
SAA5						2	2	4
SAA6							1	1
SAA		11				14	16	41
DAT1			12		8	6		26
DAT2			9		4		1	14
DAT3	3		21		6	5	3	38
DAT4				14	5			19
DAT5	13		38		17	7	53	128
DAT6			10					10
DAT	16		90	14	40	18	57	235
CON1		4		4			5	13
CON2	10	8					14	32
CON4	5	34			25	2	250	316
CON5	12	18	1		6	3		40
CON	27	64	1	4	31	5	269	401
ALL	43	102	106	58	111	48	342	810

Appendix 7: Examples of Topics Discussed in DAT Interviews with Flight Crews

A selection of excerpts from field debriefs with test site crews for DAT tests and the corresponding topic category.

DAT 1		
Information: Usability of information	7	We need to see the heading, speed and altitude information in an easier to read format—during our time in the air we did not see any of the other aircraft, real or simulated on the screen. If the system is going to deconflict two aircraft it needs to be very clear as to what we need to do and what the other aircraft has been told to do. This could be shown as a warning box and a suggested path/heading with countdown timer.
Information: Accuracy	9	The distractions and inaccuracies of the current USS cause unneeded confusion in the GCS
Methods: Procedures	4	Our flight operations with our GCS worked according to plan. No surprises—the addition of the USS was distracting, our USS manager worked to insulate us (the flight team) from having to deal with its inconsistencies. We attempted to use the USS in conjunction with our GCS but it became a workload safety issue so instead we received real time reports from our USS Manager.
Automation: Functionality	4	So the system was doing automatic UREPs for the weather, it was doing automatic UREPs for traffic that was ID'd from different sensors, and then the manual UREPs were submitted by basic crew.
DAT 3		
Information: Usability of information	4	The only way in our system you wouldn't know it's not fully functioning is that on our big map display your own stuff doesn't get updated anymore or you don't get any updates. Just a static screen. I think that's a function of the map.
Information meets UTM: Decision making	3	If you had just the UTM part of it go out, you might still have access to things like the TFMS feed so you'd know where other manned traffic is. You'd still have your links into, you know, like supplementary ground radars, ADSB receivers, anything else. The person who's in command of the mission would have to make decisions about "what do I know" and "what does that mean for me right now?"
Operator experiences: Situation awareness	7	When you come back up, it's not like instantly you see it, right? You need to wait for a little bit for things to catch up, 'cause there's nothing that, um, necessarily tells you right away what messages you've missed.
Methods: Rules	10	Not if already in the air. If in planning it would let you submit the plan. If flying under normal 107, no need for UTM so can continue without UTM as a normal 107 operation. If flying

		with UTM is a requirement for your operation (say a requirement of your 107X waiver) then you would be unable to fly.
Automation: Design of system	5	Because when the network link would come back up, our USS because it didn't know it failed didn't know it missed anything.
Concept: Requirements	4	Some of the scalability issues with positions reports for USSs that are unresponsive. So, if you have to reach out to every other USS who's subscribed in your positions, once every second, for every operation you have, that's already a decent amount of independent HGTD (?) calls to be making. If one of the USSs is out, every single one of those to that USS for every single operation you're sending every second is gonna be timing out. So, you add a lot more strain on your system waiting for the time-outs for every single position report for the operation.
DAT 4		
Operator experiences: Situation Awareness	15	I didn't really have good visibility into what the ping station, which was mounted on top, searches as far as the receiver. I didn't have good visibility to what it was doing, um, I was only looking at the hand-held receiver piece of it. Um, and the, yeah – like I said, I could – it was detected long before I could see or hear it. But again, we were behind trees and a water tower and all that other stuff, but, it was kind of good that I could see it quite a while.
Methods: Roles	8	You can have a team of operators and a, because for example, they found that the workload was too high for the command and control operator. They separate roles but then shared a similar space so they can communicate better.
Automation: Design of system	12	We're very much focused on automation being the answer to safety rather than additional knowledge that actually told us to take data away because they don't need it because it doesn't make a decision.
Concept: Privacy	11	And for us to have balance between transparency and privacy is the distance to be able to handle it on demand, not store data, feed it in a particular way that's needed for that.
DAT 5		
Information: Usefulness of information	8	From what I observed I think a key piece of information is some context or information not really the intent that can be embedded in the operation or put somewhere that can be called for a negotiation so that can inform the mission.
Information: Trust	10	There is a lot of trust in the system, there's trust that when you're asking for a negotiation that you actually need it, and there's trust from the other side that when I ask you for a negotiation, that we're trusting that you'll like actually try, and we're trusting that what you get back is actually valid and de-conflicted.

Operator experiences: Situation Awareness	20	Everyone likes having the display with ADS-B because it's just another level of situational awareness. If this is the display they're using for situational awareness.
Methods: Procedures	3	And so, you know, like "I got battery, and I got everybody sitting here," so there does need to be some rules of the road, I believe, so that if it's X-amount of time before the window then you're locked out, or you know, there does need to be consideration that there are certain times where you don't want your plan pulled out from under you.
Automation: Design of system	21	I think it's important to have APIs that scale across multiple interfaces.
Concept	3	We think it's important to have small operators be able to participate in a USS in an easy way because that's the way we keep the whole of the system safe.
DAT 6		
Information: Usability/Usefulness	3	Yeah, you actually had to click each one and then see where it came from or what type it was, but it was just essentially a list of time stamps.
Information meets UTM: Input demands	3	We're trying to make it so you had to fill out the least amount of information when you had it…Which is good because then it also can be more accurate, right, because you already – well, if you did like a weather report in the air, but like if we did the ground one, the aircraft might be over there, you know . . .
Methods: Procedures	4	We have a weather overlay of ER and apps on our screen but our pilots also have their own checklist and I think that once they are done getting their route, they still go through besides the USS screen. They have their own checklist and they would also get it on the plane. Commercial airplane pilots already have their own source of weather data that they are used to getting it from and at the moment they trust.
Automation: Data rates	2	We're very much focused on automation being the answer to safety rather than additional knowledge that actually told us to take data away because they don't need it because it doesn't make a decision.

Appendix 8: Examples of Notes from DAT Observations

A selection of excerpts from debriefings and NASA representatives' field observation notes and their corresponding topics.

DAT 1	
Information: Transparency of tool	It was easy to send UREPs but the search for new UREPs was not intuitive.
Information meets UTM: Quality of alerts	UREP received, but only see Air temp, wind speed. No aircraft sighting info.
Automation: Design of system	UREPS are .JSON files that come through. Can display graphical information as well as text. Issues with the [USS] "listening" for the message every # of ms, and then ignoring messages in the past. And if [USS] sends the message in between the "listening" time then they don't get it.
DAT 3	
Methods: Procedures	Q: How did it "fail" and how did each crewmember react? A: We simulated some USS failure by resetting [USS1] while in-flight. In parallel, [another crew] was flying some mission. Crewmembers reacted by checking the expected "503 service unavailable" status codes returned by [USS1] during the USS failover.
Information Required/Desired	Q: What information do you need when your USS fails? A: We just need our USS to restart and to catch up with what happened in the UTM while it was failing.
Automation: Design of system	Ultimately, USS should be fully automated. We should however persist USS failure events so that we can inspect what happened.
Information: Required/Desired	Additionally, there currently was no alert in the GCS for the pilot to know that the GCS is down.
Information: Required/Desired	Q: What information do you need when your USS fails? A: The pilots need to know what that failure means for them. Should they land or should they keep flying on their flight plan? Should they activate a contingency? The GCS operator needs to know the failure (on his end, on the USS end?) and if there are any debugging steps s/he should take. Also what s/he should communicate to the pilot (if anything).
Methods: Description of operator roles	Q: What were the individual responsibilities of each person? • USS client operator: Monitor the airspace in real time and communicate any USS alerts to the GCS operator. • USS manager: Coordinate testing with other USSs so that we can execute the tests. • GCS operator: Communicate with the pilot about flight plan approval and connectivity and telemetry. Monitor conformance. Communicate with USS operator if needed.
Operator status: Workload	USS op was also in charge of slack, has to hand off task to mission command because of workload.
DAT 4	
Operator status: Workload	Both crews are hurrying.
Other	[IR beacon detection] device only detects with an active flight plan.
Information: Usefulness	Flight crew thinks remote ID is useful in real time to help a flight crew have better awareness of the UFO (i.e. looking up the vehicle type is useful, looking up the created information the registered owner is not).

DAT 5	
Information: Timeliness	Q: Did you receive the negotiation information with enough time and enough information to safely mitigate the conflict? A: Yes. The USS and the GCS interfaces notified users immediately if their proposed route was in conflict. If incoming route from another USS were in conflict, the USS screens would notify the user.
Automation: Design of system	Q: Do you think the USS-USS negotiation strategy was effective? A: Somewhat. Because some USSs took up the entire airport instead of trajectory-based reservation, it was hard to find alternatives that weren't in conflict. Also, the manual nature of negotiation made it cumbersome to figure out alternatives. It was much easier to just call and talk.
Information: Usability	Q: If you were instructed to make changes to your plan because of a higher priority mission coming into your airspace, did you have enough awareness or were you provided with enough information of the surrounding operations to do this safely? A: Yes. There was a map with pictures showing where the conflicts existed and where other operations were and it allowed us to visually figure out how to re-plan the flights.
Automation: Design of system	A NASA representative noted that the highly autonomous nature of the operations made the crew irrelevant, or not existent.
Methods: Procedures	One site flew three versions of this test. To begin, the second operation's USS initiated negotiations with the other USS and their request to replan was granted. In another scenario, they requested a manual clearance, which was denied, and then a third scenario, where they requested a manual clearance, it was granted, and the operators continued with manual/visual deconfliction. Our NASA representative asked, "What if pilots or GCSs weren't close enough to each other to verbally chat. Would that change a response to a request for clearance to fly in the same airspace?"

Appendix 9: Concerning Nearby Operations

Nearby operations that were the most concerning to the survey respondent, n = 18.

Test Site	Theme	Comment about Most Concerning Operations
1	BVLOS	BVLOS landing flight from the S1000
6	BVLOS	Simulated BVLOS
6	BVLOS	BVLOS operations due to the large area and no single observer.
3	No UTM	The last flight of the day was an intruder flight, and not within the UTM system. We could not actively determine the bounds of the flight, alt, heading, etc. This increases awareness of our operations because the aircraft is less predictable without the assistance of UTM.
4	Altitude	The other two operators were at altitudes of 100 ft above and below our location. The altitudes planned by each operator were done by AGL. This ended up causing some concern from a fixed wing hovering close you our take off location. Since it had launch at the lake bed which is approximately 50 ft lower than our location, it was only about 50 to 60 ft above where we were going to climb to. The other operators appeared lower than us since they were launching from another ground location. If all operators were required to figure out their MSL location, then the altitude separation and future segmented operations would be much more seamless to plan and accomplish.
6	Altitude	The nearby operation most concerning were XX because their flight path was right above our launch location.
4	Over-reserve	The difficulty was the operators were reserving large airspace and it was difficult to fly multiple aircraft. 2 of 3 clients could not handle multi-segment ops. That would have reduced the conflict although not eliminated it.
4	Over reserve	Those who just grab the entire base for the whole day as their op when in fact they just need a small part for a short time.
4	No reports	Last with an aircraft not reporting.
4	No report	Last for flight watching for the non-ID aircraft.
4	No report	During the last flight another aircraft was orbiting nearby and was not broadcasting its position in the UTM map.
4	Rogue Close by	Rogue ops and ones in close proximity are the most concerning as they are most likely to affect me.
5	Close by	Ops in my Landing zone
6	Close by	Other XX operators, because we launch very close to each other so need to pay attention during launch and land.
6	Close by	Most concerning were operations adjacent to my launch/landing zone. Reason being due to ascending and descending through their flight level after launch and before landing. There was good separation and no need for concern, but in my opinion required heightened situational awareness despite USS automated deconfliction.
6	Public	Non-participants in area.

Appendix 10: Examples of Topics Discussed in CON Interviews with Flight Crews

A selection of excerpts from field debriefs with test site crews for CON tests and the corresponding topic category.

CON 1		
Information: Quality of alerts	3	There are like 2 uses for those sensors. One is so that the aircraft does not run into something in the building and the second is also situational awareness.
Information meets user: Speed of data transfer	6	I think that is really critical as fast as you can tell us where is and how fast and what it is doing so we can take some manual action to avoid it.
Operator experience: Situation Awareness	6	We have live tracking we know where it is and we are confident we know where it is as long as your get positive affirmation that there is a person somehow responsive and I think that is the whole idea of the UTM client make sure still alive and functional.
Method	1	
Automation: Status	7	Like last year when we did dynamic replan we trying to do specialized cases the same points potentially we didn't run across but the fact that if you go rogue you can never go back and it's nice to have alerts but we also can go back.
Concept: Design of concept	4	So, you can have another aircraft following a little ways behind you, your track is closing behind you so he is good to fly behind you but your next track would involve going backward so you would not get clearance to [go] there.
CON 2		
Information: Sharing information	8	The main information for us in terms of sharing information amongst USS is that if an operation has gone rogue to be alerted to that, that, or be alerted to that event so that we can you know, inform or, or educate any of the, flights that are handled under, under our USS.
Information meets user: Confidence in information	14	If I, in the event of a non-planned emergency where I need to, I know the aircraft is returning and I'm concerned I'm a potentially in the way, so I need to have a way that I can look at it at glance and see that, uh, that I need to clear or that I need to change what, what I'm doing.
Operator experience: Situation Awareness	4	I think that positions are very important. That tells you exactly where on the aircraft is that and allows you to make sure that you maintain your separation from each other.
Method: Procedures for operations	5	We have to generate airspace for it, which we do. That airspace is now at an increased priority. So it always made any other vehicle that was maybe nearby, would make it rogue because you were conflicting with a priority airspace. So just because I'm a guy who's misbehaving...is kicking everybody else and making them go rogue, is that really a fair thing to do?
CON 4		
Information: Usefulness	25	My map is like super open and I know it's not cluttered, so planning a map for emissions for me was super easy until the negotiations started and I couldn't see my own plan. 'Cause I couldn't click on my own plan.
Information meets user: Desired information	14	I would like back from the USS about how close to compliance I am. So that if I'm slow I could speed the craft up and get back in compliance with my plan or if I'm going to fast I could slow down.

Operator Experience: SA (lack of)	11	We couldn't communicate with anybody, we had no contact information. So, basically, we would put a plan it, we'd get rejected, we'd change it, and we could see what others had planned or tried to plan, we couldn't tell what, so then we'd just make a boundary that would intersect with the fewest lines ... We could see other operations, but like we were in very small areas, so we only grabbed just small chunks of pie, and that seemed to work better.
Method: Gaming the system	23	The other thing is, cost … So, if we want to go and inspect the water tower and we're making money here, we have to do this, and there's somebody that just has a huge area … in real life, we would have just flown that 107 and we would have just avoided it [the other vehicle].
Automation: Display conventions	25	All users should kind of appear the same to the UTM. The UTM shouldn't necessarily know if it's a human operating or an autonomous system right, it's getting the same information. And then on the other side it should be given the same information out, and then however the user as sophisticated as they want to be with it, they can do.
Concept: Usage rules	15	The system is really vulnerable to somebody just being like "I want this whole county for all day." Like you could easily have done that. Be like "Oh, I guess that's what we do!" And so, some kind of incentivization to be as efficient with your flight plan as possible is good.
CON 5		
Information: Usefulness	29	I was pretty impressed by the notifications on just our restricted airspace. Um, just with the proximity warning and then actually crossing it was dead on and seemed to work pretty great.
Information meets user: Alerting	10	Yeah, a reminder while you are submitting the flight plan would maybe be nice, but I don't need the 30-second reminder the whole time because I already knew it.
Operator experience: Situation Awareness	18	Like you said, you announce that there's a rogue aircraft, but you won't tell people where. I guess if it was me operating, if you announced that there's a rogue aircraft, I want to know where it's at. If it's not going to be a factor for me, then I don't even want to know it's rogue, because you hear that and you're constantly………just announcing rogue isn't necessarily beneficial.
Method: Procedures for event	5	We have a two-minute, an arbitrary but a two minute period for you to vacate the airspace. So, um, so there's actually kind of hard to tell, but there's actually two volumes. Is the larger volume, the original one still stays in place and, but it's end time gets shortened, but it's still two, you still have two minutes of time in there.
Automation: Functionality	13	The goal, you know, a lot of folks want full automation, so if you do more of that, we've got to add more smarts into the system to actually be able to make those, I'd say pilot kind of choices.
Concept – Airspace rules	17	You can't cross out – so, that goes back to how big of a performance geography do you need, because you can't – even if the pilot crosses out of their protective geography, what's kind of reserved for them, that impacts others. So, just saying "Hey, the pilot understands and is going to try to rectify," that could impact somebody else so, that part, you know .... That's just gonna lead to people requesting a larger amount of airspace for a longer amount of time.

Appendix 11: Examples of Notes from CON Observations

A selection of excerpts from NASA representatives' field observation notes and the corresponding topic category.

CON 1	
Methods: Description of operator roles	The PIC, the GCSO, the UTM Operator, and the Mission Manager were all located [inside]. Outside, there were always VOs, and for CON1 flights, a RC safety pilot was also stationed with them.
Methods: Procedures for flight/event	CON1 for [the test site] includes taking off from within a hangar using a laser rangefinder to navigate through guided waypoints, exiting the hangar, loitering and switching to Auto mode, flying to a further BVLOS location (behind trees in the triangle at the compass rose), landing in auto mode, then taking off again automatically, traversing back to the hangar, and landing inside in that same automatic-type mode. PIC, GCSO, and UTM Op are all co-located, BVLOS of the operation. For CON1 only, there is an RC safety pilot at the original takeoff location/2nd landing location to take control if necessary.
Information: Saliency, Other: Operator buy-in	UTM Operator is the only/first person to recognize that during a power cycle, the position reporting would stop and they'd go rogue. The sole concern of the PIC GCSO is the safety of the vehicle.
Information: Transparency of fool	Terrain data is still missing. Crew can't yet figure out the problem.
Information: Reliance, Trust, Confidence in maneuver	GCSO begins glancing at video on the return @ waypoint 4, PIC starts @ waypoint 5. GCSO starts tracking the video (80% of his focus) at 70 feet from the hangar doors, the PIC starts tracking the video (with 100% focus) at 80 feet from the hangar doors, and also with his mouse hovering over "LAND."
Information: Saliency, Reliance	No one is worrying about [the USS client}. They've never had a state problem that I've seen so far.
CON 2	
Information: Usefulness, Interpretability	Not only are there visual tracks, but they get text notifications that persist on the screen for a period of time. Because of number of false notifications, the text was covering the majority of the display. Rendering it useless.
Other: Confounds	The secondary ground radar was having trouble with the birds in the area. They system was smart enough to exclude individual birds, but flocks of birds were large enough to be considered a target. This made it difficult to calibrate the radar. Mission manager/UTM op decided to calibrate the radar using [a] vehicle. They had the pilot fly various encounters to calibrate. They noticed that the [vehicle] would show up accurately but then unexpectedly show a negative value for its altitude. Crew continued after a little bit of calibration/code work
Automation: Design of system or hardware	XXX client isn't processing the data very well (fusing the tracks). Tempest crew can't use tool successfully.
Information – Transparency of fool	USS to USS notifications for contingency don't include a code for "altitude contingency," so they used the loiter identifier. Execute same procedures as above, but change altitude by 100ft upon intruder notification instead of loiter. Since, vehicles were already altitude separated, 100ft change didn't seem to affect much in the DAA software.

Operator status: Situation Awareness	This led to discussion on how the DAA software works. There is a "preventative DAA" and not and the crews admit they don't fully understand the state changes for the DAA. They know it has to do with range proximity, but the state changes are so quick and erratic that it's hard to nail down cause and effect.
Automation: Functions	XXX client display has 4 levels of "vehicle interaction". ○ Clear of conflict ○ Preventative ○ Corrective ○ Warning
CON 4	
Information: Timeliness	[Vehicle] went [non-conforming] because it switched radio links.

Appendix 12: Examples of Topics Discussed in SAA Interviews with Flight Crews

Examples of quotes from debriefs with test site crews after a day of flying and the corresponding topic category.

SAA 1 SAA 6		
Information: Quality of alerts	9	There is, we didn't get to hear it yet though because the... at XXX they, they enabled it to before we had a chance to test it in that flight. Didn't get to hear it on the ground wherever we were seeing the alerts on the ground.
Information meets use: Transparency of tool	17	Can we design UTM to be almost completely transparent to the user such as just during the course of them flight planning, plotting their waypoints?
Operator experience: Situation Awareness	11	It's when you have it out there by itself and no one's got eyes on it and then you've got another object coming out at high speed somewhere near its path that you really need all that extra situational awareness.
Method: Procedures for flight/event	3	That kind of USB permission gain kind of jars that workflow and provides a disincentive to use this third party app when it's a lot of overhead just to get at the basic level of functionality working.
Automation: Functionality	17	If you can leverage that existing infrastructure. I'm just looking at the interstate highway system for one and if we have these existing nodes and the ability of VDOT to use the aircraft that can then connect, communicate with their DSRC network in a mobile manner I think opens up a lot of opportunities there.
Concept: Equipage requirements	21	I don't think we're there yet with the regulatory space. I don't know that we're going there at all. I think we are really what we're looking at is equipage requirements depending on the level of access and sophistication and risks that your missions require, so for BVLOS operations and opposite for people and things, maybe some of this would be, but we're definitely not headed down the path of imposing these equipage requirements on rc or just general user.
SAA 2		
Information: Reliability/ accuracy of information	17	We were seeing ADSB aircraft from XXX which is seems to be local and some of that is, seems to be there's a discrepancy and some of the ADSB timestamps. So like when I view a track list from the Ping station, I'll see like 15 aircraft and I'll look at them and they have like all these timestamps within like maybe a few hours. It was like four, maybe four hours or so, which doesn't really make sense. They should be like, if I log into that and they should all be like, I just received that timestamp. The seems like some of these ADSB out units from different aircraft are not programmed correctly on their timestamp.
Information meets user: Appropriateness of maneuver	10	He came straight at me so I couldn't do the RTL because it will cross its path….I saw the aircraft continue to move…. like that's unacceptable. So then the next movement is down and it so much easier for me to go down than it is for uh, for him to go down.
Operator experience: Situation Awareness	43	But this is also the rabbit hole we went down when we were talking by the tables that aren't for your, uh, the delay in this, this particular system. The delay to getting the information to pilot was such that you couldn't react on it as a sense and avoid use.
Method: Procedures for flight/event	10	What we're talking about is the response. Oh yeah. But it would be a TCAS like response of just the UAS. The reason the FAA doesn't want us to put TCAS on board UAS is because that would require manned aviation to

		avoid us. If there was a conflict, there would be both. Both aircraft are required to avoid.
Automation: Design of system	14	It's still that hierarchy of mobility, I guess where we have our mobile devices that we get out of the way.
SAA 3		
Information: Quality of alerting	21	… that's one thing that was missing on our display … I think we needed more audible alerting … I don't recall hearing any audibles. I mean, you know, we were... It's not a noisy environment but not a quiet environment either.
Information meets user: Confidence in information	15	So it's something that could add like just visual colors or visual indicators of, of the likes of the track either with trails or sizes of the, of the warning of some way, right? But visualizing the confidence of which we report actually in the radar packet. The confidence we have in the track that could be visually kind of identified on the screen in some way that helps the pilot kind of know that.
Operator experience: Workload	4	That's, that's really the big, um, I want to say not real world piece of this whole concept right now that the pilots are dealing with, is that they are dealing with two pieces of software to manage UTM functionality and then to manage is piloting and the work load involved there is really at unacceptable levels.
Method: Procedures for flight/event	3	Another thing that we had to kind of work around for this test with the current, uh, USS configuration was, um, that we only had the ability to define one radius and we went ahead and assume that that was our, um, well, I guess in different tests we actually made different assumptions, but, you know, … there's several layers of alerting, right?
Automation: Design of system	15	The other weakness we saw quite a bit today with the dependence on that server and its livelihood, and as you saw, we had a number of server fault then, you know, maybe that's the problem that can be solved, but the question remains is it a barrier that we want to tolerate? Um, I think there's a lot of functionality that can be gained with a cloud based systems …
SAA 4		
Information: Quality of alerts saliency of information	15	… a green, amber, red, a display. It was the icon of the aircraft. It has like a range warning system, but it doesn't throw up any popups. It doesn't waive any flags or anything. You just see the aircraft icons go from green to amber to red.
Information meets user: Information desired	6	If I was the cooperative bird, I would want to know basically what, uh, what any radar operator would want to know. I want to where the aircraft, or where the target is. Uh, is it approaching me? How fast is it going? Is it at the same altitude?
Operator experience: Situation Awareness	5	… it's the pilot's duty to give way. So I would start if I was just hand flying this thing and I was not prepared for this. Then the instant that I saw that track was going to crossover into my amber area. Then I would start, I would attempt to maneuver and get them to keep them outside the bubble.
Method: Procedures for flight/event	9	The way that I've written this to, uh, for the manual side in order to compensate for the lack of the timing that a computer would give us is a, the wording is that when an aircraft or target is inside the warning area, it's the pilot's duty to give way.
Automation: Functionality	13	Because you have to have that capability. When the aircraft loses link, you don't have the capability of the aircraft avoiding on its own. When you lose link, you have a rogue aircraft in the air, in the airspace, if it's a busy airspace and that's where we want to get to eventually that's a bad thing. So the aircraft has to be able to avoid the other aircraft.
Concept – Equipage requirements	1	… sense and avoid at all times, otherwise you don't get to play.

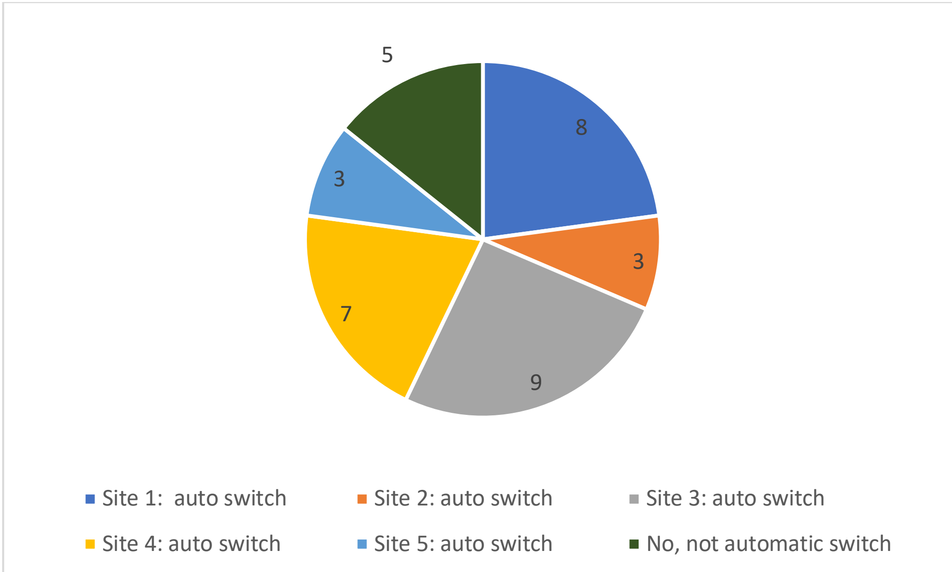
Appendix 13: Examples of Notes from SAA Observations

A selection of excerpts from NASA representatives' field observation notes and the corresponding topic category.

SAA 1	
Information: Reliability, accuracy	Can't always see the second vehicle on the screen – some flights you can see both vehicles in others you can't. On a couple of occasions NASA reports that they can't see [vehicle 1] but we wonder whether it's actually [vehicle 2] they can't see.
Information: Quality of alerts, Transparency of tool	The ability to submit multiple operations under one volume. [Site 6] are not trying to do this but after a flight where there were lots of odd rogue messages but no alerting when the vehicles intruded on each other, ANRA said that [Site 6] had submitted both vehicles to the same operation that caused those effects because the vehicles were "cooperating". XX couldn't see why you would ever want to have the alerting completely off.
Other: Operator buy-in	Not enough information on the USS for pilots to be able to fly by it, so although they are looking at it during this week of testing they say they would not use it in the field.
Method: Procedures for flight/event	Crew was unclear what constituted a resolution maneuver in the SAA flight tests and what defined that they had successfully completed the test.
SAA 2	
Information: Quality of alerts, usefulness	Auditory alerts were turned off • Brought up two excellent discussions: 1. Reason why they muted alerts (would continually warn about its own ADSB tracks as an intruder) and the concept of selectively muting alerts. 2. Refresh rate of displays vs actual computational time of data needed to DAA.
Information: Accuracy	The UAV popped up immediately for the manned AC and he was able to locate and fly in the direction of the UAV.
SAA 4	
Method: Procedures for flight/event, automation functions	Somewhere along their path, they would come within 50m of each other and trigger an intruder alert. In an automated DAA, this intruder alert would trigger an automated response from the vehicle. Today however, it was a manual response to the intruder alert.
Information: Usability/usefulness, intuitiveness	The radar can see both aircraft and sends that data to mission planner, but mission planner cannot discriminate between radar tracks belonging to the intruder from those belonging to ownship, putting the pilot (when BVLOS) or automation in a situation where they might try to "avoid themselves."
Information: Usefulness	Successfully got radar displayed on GCS. This involved getting radar tracks, converting them into "ADS-B like" tracks to get them into mission planner (GCS).
SAA 6	
Information: Quality of alerts	First pass at 20mph, we did get an alert on the [USS] display but no audio alert only the red volume a message appears.
Information: Quality of alerts, reliability	Car makes a couple more passes, we can see alerting. Some of it is spurious as the car is nowhere near the UAV.
General SAA	

Information: Usability, quality of alerts	Think an audio component would be useful – having to look at the screen to see alerts makes it not useful, for 2 reasons: 1) you won't know when alerts will arrive when you're flying real world missions, so you won't be looking at the screen waiting for them; 2) having to look at the alerts means you take your eye off your vehicle.
Information: Quality of alerts	For one test with the [Vehicle 1] intruding on the [Vehicle 2] we did not get any alerting.

Appendix 14: CNS Capability on UAV



Count of responses indicating aircraft that automatically switched to their back up C2 link on failure of the primary link.

Appendix 15: Examples of Topics Discussed in CNS Interviews with Flight Crews

Examples of quotes from debriefs with test site crews after a day of flying CNS tests and the corresponding topic category.

CNS 1		
Information: Availability	18	I was watching on one USS, we had multiple USSs today executing different lost-link things. I couldn't tell when that happened at all, and I was kind of isolated, looking at when XXX's stuff would go lost link, I'd have to listen on the radio to figure out when that even happened. So, there's no information provided right now across USSs and, if we were operating in adjacent air spaces, it would be very valuable I think to share in some information.
Information meets user: Information desired or wanted	16	It should also broadcast the last known heading, altitude, and airspeed so you can take a guess that it is going in that direction and that is a place to avoid.
Operator experience: Situation Awareness	12	You really only have to know – even if someone else is even having trouble, you shouldn't have to know about it unless it's putting them in danger or affecting your airspace or where you're operating.
Method: Procedures for flight/event	5	If you still have one link and are in control of your vehicle, and you're going to stay in your own space, I don't care, really. Someone cares, but it's not me if I'm trying to operation my own mission and you're not coming into my space.
Automation: Design of system	20	We were able to have a flight window open, execute the flight, and be midway through the flight before the XX USS figured out that is what we are doing. And then the XX USS closed ours and we had no indication for why it closed. (This was during the first flight of CNS3 three minutes into the flight).
Concept: Privacy/ sharing	8	I'm comfortable with the notion of, if you lose one link, and your secondary link doesn't impair your mission at all, doesn't put any other aircraft in harm's way, and you're confident in the robust, that it's not going to impact anybody, I don't know if you have to share that.
CNS 2		
Information: Reliability/ accuracy of information	11	… but the fact that the degraded GPS is difficult to get, should give him some, uh, mean doesn't provide certainty, but it should certainly give [NASA] some additional comfort in [the] CNS work that it's...not that you can't jam or anything, but GPS is a highly available and, and uh, is very reliable, you know, so much so that even putting a shroud around the antenna was not creating difficulty.
Information meets user: Accuracy of information	2	It's also important for a troubleshooting perspective to see if the number of satellites and the reported HDOP are incongruent. Like if I have high HDOP but I have 16 satellites, there may be something else going on.
Operator experience: Situation Awareness	2	So in the event that I lose GPS, I have a general idea of where the aircraft is. Even though I may, it may take me a second to figure out what orientation I'm in, uh, and I can take over the flight by a manual control and return it back to my position or if I feel that I am not comfortable with that, then I can actually have it lands where it is.
Method: Procedures for flight/event	4	… procedures that, that sometimes it's not clear why things are working and why things aren't and we just have to, you know, reset them a number of times and, and everything... And eventually, eventually got it. Um, but you know, we're, we're learning …

Automation: Degradation	10	The biggest problem/fear is RF interferences that changes the flight pattern of the aircraft, could be GPS signal interference, C2 band interference, backup RC band interference, or overload on the onboard RF circuits.
CNS 3		
Information: Usefulness of information	7	But the thing is that the interface doesn't tell us why. It actually grays that button out with the alert icon in it. If it closes and tells us specifically why it closed you because of time conflict or altitude conflict, otherwise we are taking another shot in the dark.
Information meets user: Confidence in information	1	That's probably my biggest concern of stuff we could be flying around – power lines or large metal structures (inaudible) interference and you start kind of seeing it dance around up there. That makes me more nervous than if my video goes out or something like that.
Operator experience: Lack of awareness	1	But for us we didn't have any explanation in the USS interface for why it got closed. They had to go on the back end and figure out why.
Method: Procedures for flight/event	4	So I was piloting the aircraft and basically just looking, watching the aircraft, I wasn't paying a lot of attention to the ground control station. I had XX watching that for me and just kinda trusted him to tell me if anything was out of the ordinary or if everything was working like it was supposed to. I mean, it works fine for us because I can just keep my eyes on the aircraft and do it that way.
Automation: Functions	12	So, from the moment we send time and receive acknowledgment that loop should be less than 3 seconds. If it exceeds that then there is something wrong there.
Concept: Design of system	2	Another USS was on our LUN, …. Multiple USS's can be on that, but, we just saw another USS that came onto our LUN that was pushing our band data, and it turned out it was rejecting your plan.

Appendix 16: Examples of Notes from CNS Observations

A selection of excerpts from NASA representatives' field observation notes and the corresponding topic category.

CNS 1	
Information: Quality of alerts	There was a visual indicator located on the bottom of the GCS screen, which remained clear when all was good but turned red in case of a loss of communication link, notifying the operator about the loss.
Automation: Design of system and functions	The link/signal status is monitored with a dedicated application, developed basically for the specific architecture of the UAS they are using. They are logging and monitoring the network and links status over time with a very basic terminal application. At the moment the interface is used to check the status only of LTE and Wi-Fi signals since the SATCOM is still not integrated. The application is test-oriented and color-coded areas are used to check if the signal is drop under a specific threshold. For the Wi-Fi link they are also using a dedicated commercial application to monitor the status and strength of the signal.
Information required/desired	The UTM/USS information are monitored as feedback to check if the positions of the UAV are updated correctly during the signal drop, during the switchover of the communication links. The big concern regards the possibility to go non-conforming/rogue if the communication switchover takes too long.
Automation: Design of system and functions	The RF datasets have been collected but at the moment such information will be mainly used to characterize the environment around the test site. Currently there are no plans on how to integrate such information directly within UTM environment (or if and how real time evaluations of RF interference can be shared for operations).
Automation: Design of system	The time to complete the switchover is very short. The adopted solution, which is architecture-dependent, allows to automate the process of switchover and there is no drop of information on user/pilot side since the communication links are monitored over time and kept in a sort of "hot redundancy" to make the transition as seamless as possible. For this reason, the position updates are checked as normal to be sure that there is no information loss because of the process (through the UTM client tool). The tool used for link status monitoring is instead checked only to be sure that the automatic switchover behaves as expected.
Information required/desired	NASA Rep question: If it was your vehicle with the C2 link issue, would you be OK with sharing that information to other users of your USS? What about neighboring USSs? TSO Response: Yes. Major issues with communication links can be shared without problems, also if a level of priority/criticality must be defined/formalized to avoid possible communication of false alarms. The communication of C2 link issues can be shared with other neighboring USSs once it is communicated to the associated USS. From this point of view, it is more a matter of data sharing across USSs and not an issue regarding the UAS operator, once the C2 problems has been notified.
Other: Operator buy-in	Once it has been decided to share a subset of the information of a UAS mission (relevant to the purposes of traffic control) with other organizations that use UAS for their business there are no particular constraints for the public. In that scenario the only limit comes from the type of data that can be exploited/useful to public (to avoid overflow of information). The key point is to decide what subset of information is shared outside your own organization. These rules apply for any data consumer outside an organization, regardless if they are vehicle operators or not. Inside the same organization there should be no constraints on the amount and type of the information shared among the vehicle operators.
Automation: Design of system	LTE was lost because the signal got stuck in a rare feedback loop.
CNS 3	
Other: Confounds	The GNSS (Global Navigation Satellite System) interference can degrade the position quality and when it occurs the tracking and positioning signal can be lost completely. Devices like chirp jammers can for example disrupt the GPS/GNSS signals quite easily (if not properly

	mitigated) and UAV navigation capabilities could be strongly affected by such technologies/equipment. Other sources of interference that can result in a reduction or loss of UAV's ability to navigate as planned could be represented by some form of self-interference due to payload or UAV electronics equipment.
Information meets user: Effectiveness of data	There was confusion from the team due to non-conforming. Position updates had a delay for more than 2 seconds.