

Strategic Deconfliction Performance

Results and Analysis from the NASA UTM Technical Capability Level 4 Demonstration

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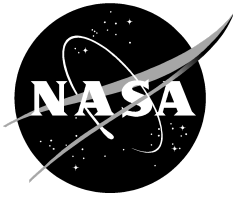
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Overview

Unmanned Aircraft System (UAS) Traffic Management (UTM) refers to the service-based, cooperative approach to the management of small UAS in the National Airspace System that is safe, scalable, and fair. UTM provides the means to manage the airspace in a complementary manner that does not burden the current air traffic control workforce or infrastructure but allows the Air Navigation Service Provider to maintain its regulatory and operational authority of the airspace.

A key feature of UTM is the ability to provide operators the means to strategically deconflict operations from others in the airspace through the digital exchange of information via supporting services. Through this approach, the four-dimensional operation volumes that encompass the intent of operators in a given area are discoverable and can be used for airspace awareness as well as planning conflict free operations that account for and avoid other operations. In certain cases, it is also possible to negotiate volume intersections for shared airspace use without the need to re-plan.

In the NASA UTM concept, strategic deconfliction is the first layer of three in the overall conflict management model. The three layers of the conflict management model, which follow the International Civil Aviation Organization's scheme [ICAO 2005] are: strategic conflict management, separate provision, and collision avoidance. In UTM, the strategic layer mostly occurs prior to departure, but is applicable to en route operations with sufficient planning horizon. The initial requirements for a strategic deconfliction capability within UTM are defined in a NASA publication [Rios 2018].

Within the concept and implementation of service-provided strategic deconfliction is the notion of priority. It is understood that there are instances in which an operation requires a priority designation within the UTM system and special handling accordingly to provide situation awareness and facilitate appropriate responses from other airspace users. Examples of situations requiring priority designation include: when an operator declares an emergency due to problems with the vehicle or its immediate surroundings; operations that are in support of certain organizations (e.g., public safety and first responders); or special missions that also require priority use of airspace (e.g., emergency medical deliveries).

The UTM concept also allows for dynamic constraints in the system. These also relate to the topic of priority in the sense that the airspace that the constraint encompasses may have different characteristics. These characteristics of a constraint may indicate operations that are allowed within the constraint in addition to those which must avoid it through strategic deconfliction with the volume. Operations that are specially permitted to access the UVR area are typically assigned priority status given the nature of their mission and their associated credentials.

The ability to perform strategic deconfliction, handle certain operations with a priority distinction, and establish constraints that are communicated throughout the UTM system, is predicated on an architecture that has been established through an evolutionary process in response to close collaboration with stakeholders from government and industry. Another important and influential aspect of these capabilities and architecture is the live, distributed flight tests that have been conducted across the Technical Capability Levels (TCLs) that culminated with a set of complex tests performed as part of TCL4 [Rios 2020]. The TCL4 flight test involved two FAA-designated UAS test sites building teams to collaborate with NASA's UTM Project on the execution of several detailed, small UAS scenarios in urban environments.

UTM Operational Architecture

The proposed system for managing small UAS at low altitude is much different than traditional air traffic management systems for commercial aircraft in the NAS. Within UTM, the operations are managed collaboratively by a collection of UAS Service Suppliers (USS). Each small UAS operation is managed by a USS to provide appropriate operational data to other USSs and to the operator. These data exchanges are in support of the Concept of Operations for UTM [Kopardekar 2016][FAA 2018][FAA 2020] and defined by a set of Application Programming Interfaces and UAS Service Supplier Specification [Rios 2019b]. The Air Navigation Service Provider (ANSP) still maintains authority over the airspace, but certain services are delegated to the USSs so that the ANSP does not directly manage this class of operations in nominal cases. These services include strategic deconfliction of operations. The high-level architecture is provided in [Figure 1](#).

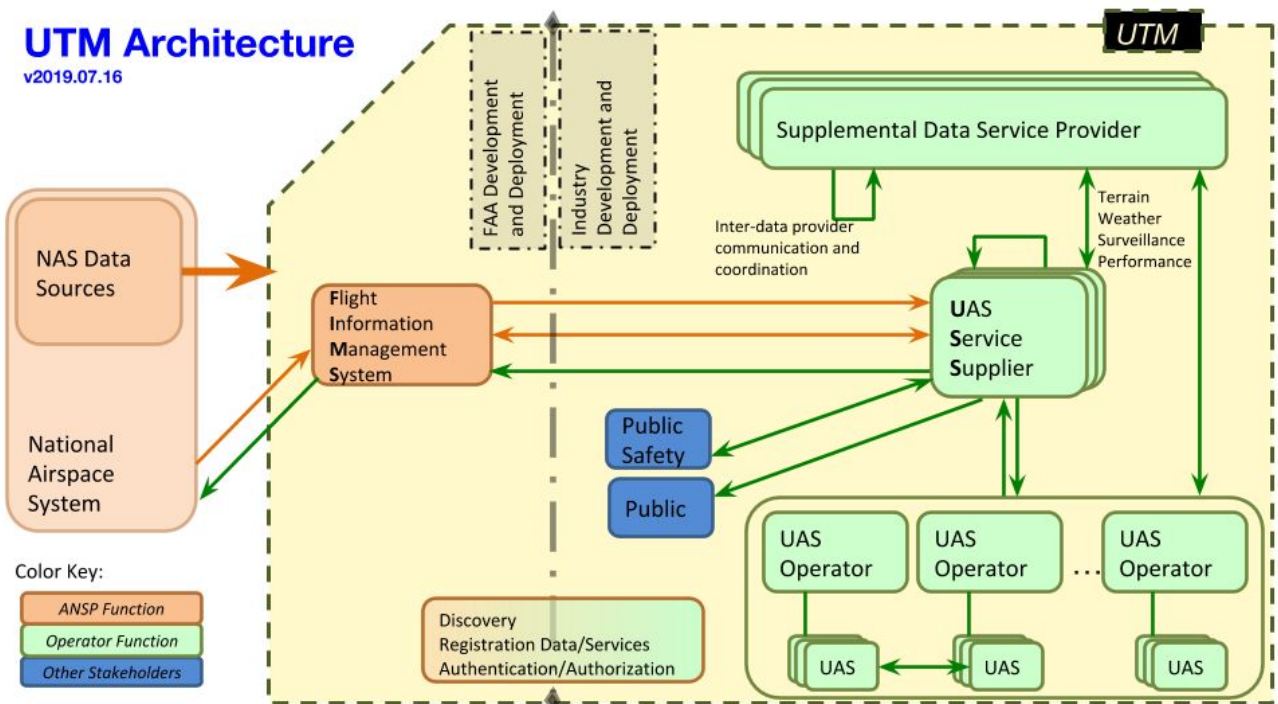


Figure 1: UTM high-level architecture.

TCL4 Flight Test Summary

The overall planning and execution of TCL4 is described in a standalone publication [Rios 2020]. The following brief summary is intended to give context for the rest of the document.

The TCL4 Demonstration was the final in a series of demonstrations by the NASA UTM Project. Each demonstration from TCL1 to TCL4 increased in the number of capabilities and the complexity of the operational environment. Overall, the UTM Project sought to demonstrate, in concert with the FAA and industry, how UTM should work and to identify areas in need of further research. UTM is such a paradigm shift in how the airspace will be managed that often the anticipated challenges are not easily known. The TCL Demonstrations helped shape the

architecture and concept of UTM and aided in the identification of gaps and formulation of requirements.

TCL4 was executed at two of the FAA-designated UAS Test Sites: Nevada and Texas, managed by the Nevada Institute for Autonomous Systems and Lone Star UAS Center of Excellence & Innovation, respectively. Both sites were provided the same statement of work (SOW) and each developed a series of test plans to meet the SOW. These plans were finalized in coordination with the NASA UTM Project.

The test sites developed a team of partners to execute the flight testing. These included USS providers, UAS equipment manufacturers, weather service providers, cellular service providers, radar providers, operators, public safety agencies, and others. The SOW described five detailed scenarios with specific characteristics and test events that were considered the primary requirements of the flight test. The scenarios were run multiple times in TCL4 and each run involved live and simulated aircraft to safely create the desired interactions and generate the necessary density to test the system and concepts. The five scenarios are briefly presented in [Table 1](#).

Table 1. Summary of scenarios in TCL4.

Scenario	Description
1	Nominal high density UTM operations with multiple mission types. A sudden, simulated weather event is forecast to impact the area, which results in a UVR. Operators with current or planned operations within the UVR geometry respond by returning to the launch point, re-planning to utilize an identified safe landing location that is de-conflicted from other operations, or avoiding takeoff from within the UVR.
2	A pop-up concert takes place at a local venue that results in a number of UTM operations in the area. An public safety incident occurs at the concert resulting in a UVR being established to allow for a Public Safety UTM response and clearance of non-essential operations from the area. Those operations clearing the UVR must replan and de-conflict to ensure safe exit. UTM-enabled Remote ID is used to identify and contact operators that have not cleared the area. Special access to the UVR is granted for news coverage in addition to the public safety vehicles.
3	UTM operations are being conducted near an active airport with a medium density of sUAS operations. Reported events take place that require Remote ID of specific operations as well as security responses to monitor situations near the airport. Piloted general aviation aircraft are conducting flights in the area and one aircraft's path results in a conflict with a UTM operation's operation volume with a subsequent response from the UAS operator.
4	A simulated low battery situation forces a vehicle to land quickly, which requires nearby operations to re-plan and avoid the landing vehicle. Later, large-scale loss of communication and navigation events are experienced that require contingency management procedures in response. Remote ID is requested to identify vehicles that are reported to be congregating in a particular area during the events.
5	Multiple events are taking place in a suburban area, which draws a gradually increasing number of sUAS performing a variety of supporting missions. The increase in density is accommodated through strategic deconfliction that eventually requires UAS Service Supplier (USS) negotiations for re-planning or agreement to allow overlapping Operation Volumes. Operational density in one area increases with subsequent negotiations that result in shared airspace for multiple vehicles and a transition to cooperative separation. One USS supporting multiple operations experiences a critical failure, which results in contingency management procedures for affected flights and a switch to an alternate USS where able.

USS implementers were a key set of partners. This group represents key stakeholders in the future of the UTM System. Given the primacy of the USSs in UTM, NASA developed a series of collaborative simulations and checkout exercises that each USS needed to complete in order to be allowed to participate in the TCL4 flight testing. Some of this process is described in [Rios 2018] and [Rios 2018b]. This process also helped NASA inform potential future requirements related to USS Checkout procedures for a future operational UTM System [Smith 2019].

In the months leading up to the flight testing, the test sites worked with NASA to execute tabletop exercises, simulations, and shakeout flights to prepare for the actual field tests. At each of these stages, the data collection approach was solidified to support NASA's analysis requirements.

Measures of Performance

The NASA UTM Project defined twenty Measures of Performance (MOPs) to aid in quantifying the UTM System as designed and tested in TCL4. Each of these MOPs will be reported internally to NASA. Additionally, NASA will report out on most of these MOPs in various venues. Three of the MOPs will be detailed in this report.

The approach to defining MOPs is driven by NASA's "NASA Systems Engineering Processes and Requirements" [NASA 2013]. Requirements for a system are supported by Measures of Effectiveness (MOEs) which are qualitative in nature. These MOEs are supported by MOPs which are quantitative in nature. Formal definitions for requirements, MOEs, and MOPs are provided below. These relationships are illustrated in [Figure 2](#).

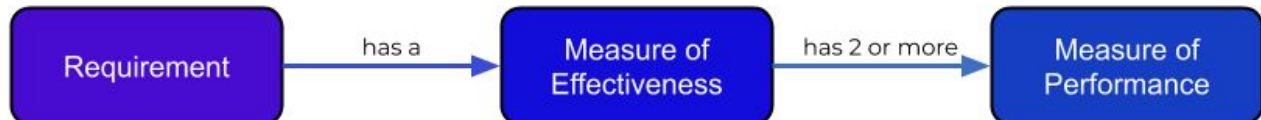


Figure 2. Relationships of requirements, MOEs, and MOPs.

The UTM System has several high-level requirements. The formal definition of a requirement used within the UTM Project is defined as:

The agreed upon need, capability, capacity, or demand for personnel, equipment, facilities, or other resources or services by specified quantities for specific periods of time or at a specified time expressed as a "shall" statement. Acceptable form for a requirement statement is individually clear, correct, feasible to obtain, unambiguous in meaning, and can be validated at the level of the system structure at which stated. In pairs of requirement statements or as a set, collectively, they are not redundant, are adequately related with respect to terms used, and are not in conflict with one another.

Each MOP is connected to a defined Measure of Effectiveness (MOE). An MOE is defined by NASA as:

A measure by which a stakeholder's expectations will be judged in assessing satisfaction with products or systems produced and delivered in accordance with the associated technical effort. An MOE is deemed to be critical to not only the acceptability of the product by the stakeholder but also critical to operational/mission usage. An MOE

is typically qualitative in nature or not able to be used directly as a "design-to" requirement.

A MOP is defined by NASA [NASA 2013] as:

A quantitative measure that, when met by the design solution, will help ensure that an MOE for a product or system will be satisfied. MOPs are given special attention during design to ensure that the MOEs with which they are associated are met. There are generally two or more measures of performance for each MOE.

The requirements supported by the MOPs in this document are listed in [Table 2](#).

Table 2. Summary of requirements supported by MOPs in this document.

REQ ID	Title	Description	Source
UTM-REQ-1	The UTM System SHALL aid in sUAS staying clear of each other.	A fundamental feature of an air traffic management system is to aid in keeping aircraft safe, including from each other.	[NASA 2016]
UTM-REQ-2	The UTM System SHALL aid in sUAS staying clear of traditional aviation.	Traditional aviation encompasses many forms of air vehicles and operation types. UTM needs to aid sUAS operators in staying clear of these operations.	[NASA 2016]
UTM-REQ-5	The UTM System SHALL allow for priority of Public Safety operations over other nominal operations.	Public safety operations need to perform their essential tasks safely, without interference from nominal operations. UTM protocols allow for this need.	[NASA 2016]

Summary of Measures of Performance

[Table 3](#) provides a summary of the three MOPs reported in this document. Further details are provided in the subsequent subsections.

Table 3. Summary of MOPs reported in this document.

MOP ID	Title	Description	Minimum Success	Target Success
UTM-MOP-01	Strategic deconfliction rate	Percentage of nominal (i.e. non-emergency, non-priority) ACTIVE UTM Operations that have 4D disjoint Operation Plans OR have a Negotiation Agreement to allow intersection with each other Operation that intersects with it.	> 90%	100%
UTM-MOP-18	Replan rate in response to priority operation	Calculate the percentage of operations affected by a pop-up priority operation that are able to replan to deconflict with that priority operation prior to departure of the pop-up priority operation.	> 90%	100%
UTM-MOP-20	Deconfliction rate for priority operations	Percentage of public safety operations with a given lead time that have strategically deconflicted plans, i.e, public safety operations that have no conflicts (prior to departure) with existing operations.	95% @ 5 min lead	100% @ 5 min lead

NASA UTM Data Collection Architecture

The UTM data collection architecture is the result of lessons learned from previous TCLs as well as industry best-practices as applied to UTM testing. A key requirement for partner participation with NASA in UTM flight testing was the delivery of data for further analysis. There are two primary flows of data into NASA from the stakeholders involved in testing. First, there is the data exchanged as part of the operational concept. These would include data such as operation plans, positions, and other UTM messages. All of these data were collected live with a designated USS Data Collector (UDC) that interacts with the other USSs as if it were a USS. The other flow of data was specified as part of NASA's Data Management Plan for TCL4. These include data that are used for research purposes and are not necessarily part of the UTM operational concept. These data would include elements such as latency measurements, vehicle logs, and weather data. These data were submitted to a Data Management Plan (DMP) system during or after testing.

Both flows of data end up in a Universal Data Store (UDS). The UDS within this architecture provides a single source of truth for all TCL4 data, implementing a key architectural pattern in data collection and analysis. UDS is used for all visualization and analysis of TCL4 testing data. [Figure 3](#) summarizes this data collection architecture.

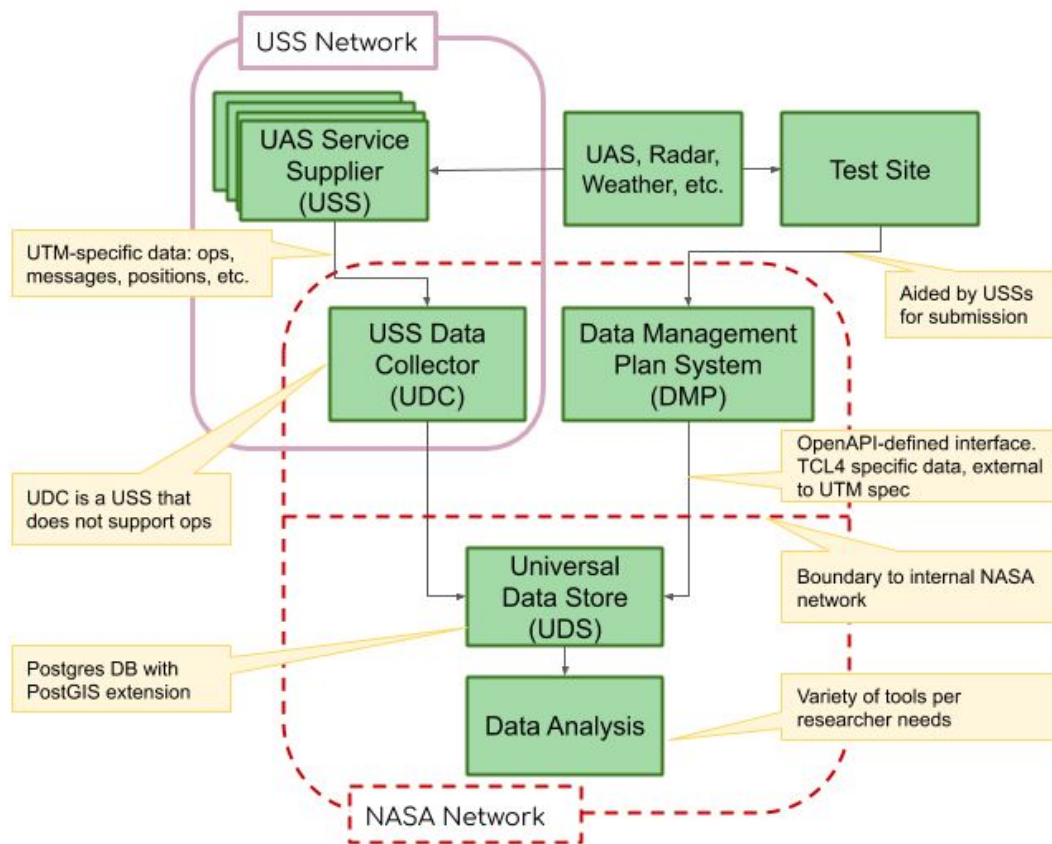


Figure 3. TCL4 data management architecture.

General Data Reduction

All data were collected during each run of each scenario. However, not all data in the TCL4 datastore were intended or appropriate for calculation of each MOP. Thus, several layers of filtering are required to ensure that the appropriate data are used as starting points for the analysis. In general, live and simulated flights were treated the same in terms of data collection. Each specific operation had data requirements levied upon it depending on several variables, including for example whether it was live vs. simulation, whether it was part of a particular scenario, or if it was a particular vehicle type. Some data collection was limited to live vehicles with, for example, certain equipment installed that would not have been reasonable to collect from a simulated aircraft. Some analysis was applicable only to live aircraft, and is noted as such.

To determine valid operations for analysis, the metadata of each model is filtered as follows:

1. Only models identified by the submitter as valid via a metadata flag
2. Only operations that changed altitude by 75ft, which is based on the standard gps error model of ~ 2 sigma.
3. Only valid demonstration scenarios, with corresponding valid run numbers. Some scenarios are for testing or shakeout of the operations or various subsystems and are not intended for data analysis.

After flight testing was complete, the NASA team determined that 23 total runs were of sufficient quality (had sufficient duration, with appropriate threshold of active operations, and all core systems functioning normally) for analysis of strategic deconfliction MOPs (i.e. those presented in this paper). The result of the general data reduction is illustrated in [Figure 4](#). Further filtering per the needs of each MOP in this paper will be described in those sections.

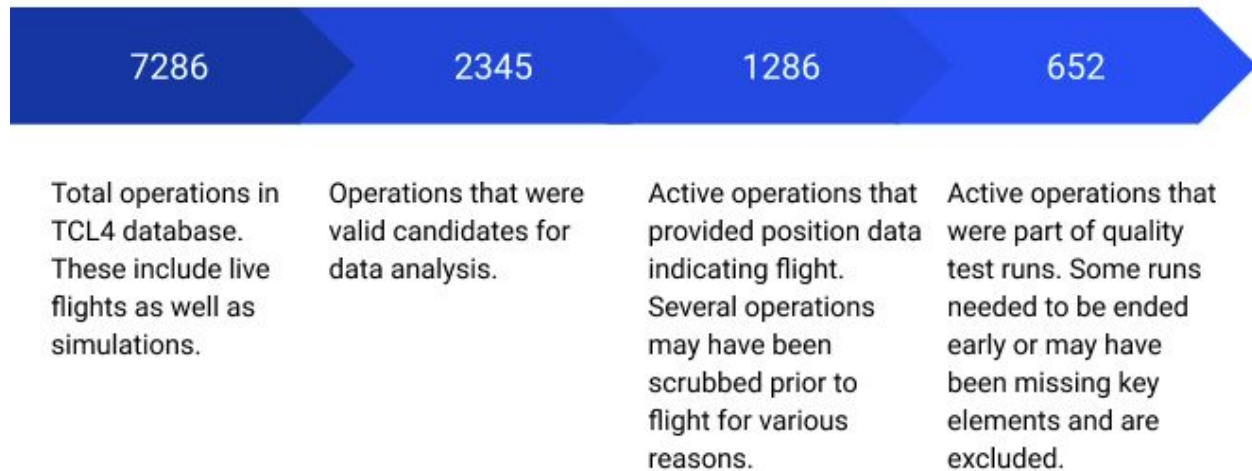


Figure 4. Filtering of operations with appropriate characteristics for analysis.

Measure of Performance 01: Strategic Deconfliction Rate

UTM-MOP-01 is titled “Strategic deconfliction rate.” The high-level description is “Percentage of nominal (i.e. non-emergency, non-priority) ACTIVE UTM Operations that have 4D-disjoint Operation Plans OR have a Negotiation Agreement to allow intersection with each other Operation that intersects with it.” An “intersection” occurs when at least one 4D volume of one operations intersects with at least one 4D volume of another operation. Given previous experience in flight testing the UTM System, the success criterion was set at 95% with a target success of 100%.

This MOP is fundamental to the UTM concept. UTM is designed to provide a mechanism for small UAS operators to share information about their operations with other stakeholders, including other operators. The MOP supports UTM-MOE-1 by ensuring that operations endeavor to stay clear of each other on a strategic time horizon (typically prior to flight, but sometimes due to changes while in flight), via the use of their respective USSs.

Data Reduction

For this analysis, the valid operations identified in the ‘General Data Reduction’ section were used as the preliminary filter. Coordinating a flight test of multiple live vehicles and multiple simulated vehicles in an urban environment is a fragile endeavor. Weather, networking, subsystems, crew readiness, and many other issues can delay or halt the run of a given scenario. After flight testing was complete, the NASA team determined that 23 total runs were of sufficient quality for analysis of strategic deconfliction MOPs. Thus, all operations from other runs were excluded from analysis.

Since UTM-MOP-01 is for “nominal” operations, all operations that indicated an off-nominal state either via its operation plans or UTM messages were also excluded. Those operations are explored in other MOPs. In addition, some operations were submitted to the UTM System, but

never flew. So, if there were no position reports indicating a change in altitude of at least 75 feet, an operation was excluded from analysis.

Ultimately, this filtering process left 327 operations from the 23 quality runs (as defined above) across both test sites (Texas and Nevada) as shown in [Figure 5](#), with good representation of live and simulated operations.

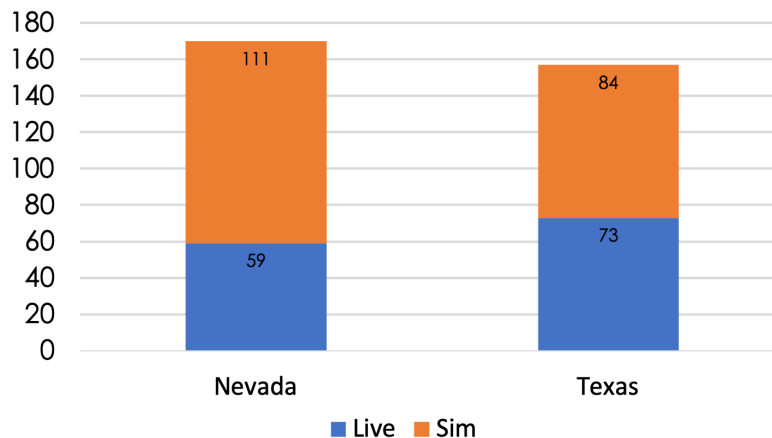


Figure 5. Breakdown of the 327 operations used for UTM-MOPS-01 analysis.

Results

From the 327 operations under analysis for UTM-MOP-01, there were several intersecting operations. However, every intersection is not inherently “bad.” The UTM concept allows for intersecting operations if the operators have an agreement to do so. This “negotiation agreement” is the outcome of a series of message exchanges. When operators agree to let their operation plans intersect, they are indicating that separation during the time of intersecting operation volumes is assured via some other means, likely involving technologies on-board the vehicle. Operations that have a negotiation agreement codify that agreement by updating their operation plans indicating to each other and other stakeholders that the intersection is agreed upon. Such operations are considered to be strategically deconflicted.

There were 208 pairs of operations with intersections AND corresponding negotiation agreements. There were 185 distinct operations involved with those 208 operation pairs.

There were 8 operation pairs, across 16 distinct operations, that were in conflict, because they were not strategically deconflicted. All of these conflicting operations were simulations; no live operations were in conflict with any other operation. With 16 out of the 327 operations in conflict, the success criterion of 95% for UTM-MOP-01 was met.

The most interesting aspect of the failure to deconflict is that nearly all of them involved pairs of operations that were managed by the same USS. Only 1 of the 8 conflict pairs involved operations managed by different USSs. This is illustrated in [Figure 6](#). Further discussion of this finding is provided in the [Discussion section](#) below.

USS INVOLVEMENT IN NOMINAL STRATEGIC CONFLICTS

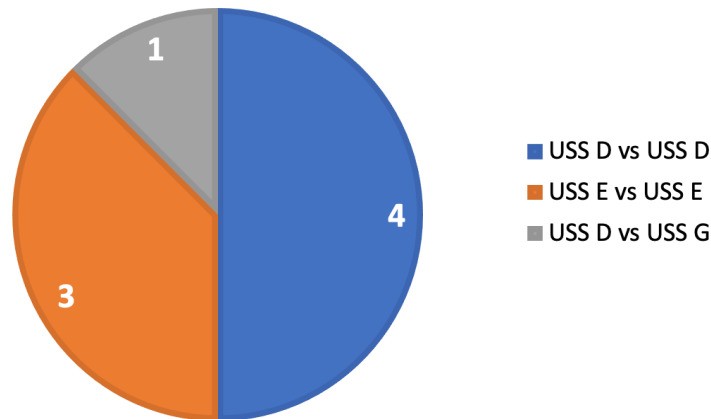


Figure 6. Most unresolved conflicts occurred between two operations managed by the same USS.

Discussion

There are three key findings from the data collection and analysis related to UTM-MOP-01. This section will list and provide discussion on each.

Strategic Deconfliction is Effective

USSs and their operators effectively used the strategic deconfliction concept and its implementation within TCL4. Over time within the UTM concept developed at NASA, strategic deconfliction evolved to allow negotiations and those negotiations allowed for operators to agree to intersect under certain conditions. Generally, operations were successfully deconflicted prior to departure, even in relatively dense scenarios.

Intra-USS Negotiations

The majority of the conflicts that were not captured in TCL4 involved operations managed by the same USS. This implies an issue with the approach to managing conflicts internal to a given USS. Without access to the algorithms implemented by the independent USS developers, it is difficult to know why operations within a given USS might not be deconflicted. In the NASA USS implementation, a simple approach was taken. The NASA USS would reject an operator's plan if it intersected with an existing plan managed by the NASA USS, thus ensuring that the NASA USS would not support two operations that overlapped. This would trigger that rejected operator to replan to avoid the existing operation. If an operator submitted a plan that did not intersect an existing plan managed by the NASA USS, but did intersect a plan managed by an external USS, the negotiation process would be initiated automatically by the NASA USS with that external USS.

It appeared that some USSs accepted all operations from the operators they supported, with the intention of deconflicting them via negotiation with external USSs. Without pilot debriefs of every one of the 100's of operations correlated against the data, it is unclear why a USS would allow intersections within operations it is managing. As a hypothesis based on working on USS designs and the partner systems, some partner USS processes apparently simply neglected checking against operations they were already managing. This indicates the need for explicit requirements on future operational USSs that they indeed deconflict their own operations with the same due diligence they use with external USSs. This can be as simple as the USS

ensuring that intersecting operations that it manages establish a negotiation agreement to intersect. This agreement would be visible to other stakeholders to indicate that the intersection is known and is being managed by the respective operators and the USS.

Protocol Adherence

Negotiations are a potentially complex activity with several edge cases. Due to the needs of the flight test, lack of fully developed protocols, and relatively short development time, many USSs implemented “shortcuts” in negotiation. These might take the form of internal rules that stated things like “accept all intersection requests from simulated aircraft” or “reject all negotiations for live operations.” These are valid approaches in terms of the negotiation protocols for TCL4 in that they did not break any established rules. The logic required to more robustly implement negotiation would take significant effort and a well-defined specification. This is an important consideration for future standards development and future checkout processes for USSs.

Measures of Performance 18 and 20: Pop-up Priority Operations

UTM-MOP-18 is entitled “Replan rate in response to priority operation.” The high-level description is documented as “Calculate the percentage of operations affected by a pop-up priority operation that are able to replan to deconflict with that priority operation prior to departure of the pop-up priority operation.” The minimum success criteria for MOP-18 was documented at greater than 90% with a target success of 100%. UTM-MOP-20 is titled “Deconfliction rate for priority operations.” The high-level description is documented as “Calculate the percentage of public safety operations with a given lead time that have strategically deconflicted plans, i.e, public safety operations that have no conflicts (prior to departure) with existing operations.” The minimum success criteria for MOP-20 was documented using a 5-minute lookahead time at 95% with a target success of 100%.

Due to the tempo of operations and the need to keep the orchestration of flights progressing, the priority operations did not typically depart later than 5 minutes after the operation was announced via the USS Network. Thus, the lookahead requirement was dropped for analysis. In addition, operators deconflicted from the pop-up priority operation in various ways that were not considered in the drafting of the MOP. This may have been in response to the fact that there was insufficient time from announcement of the priority operation to that operation entering the airspace, or a lack of understanding of the scenario or concept by stakeholders, or other reasons. Given the execution anomalies, these MOPs as originally documented are officially cataloged as “inconclusive” for TCL4. However, there are many insights to be gained through examination of the collected data. This section examines the conflicts that the priority operations and nominal operations faced, regardless of lookahead time as well as the varied approaches that operators took to minimize those conflicts.

Data

Operations within the UTM concept as tested in TCL4 would announce their priority status as part of their operation plan using specific data elements. Though, in certain scenarios, an operation may be perceived as having some “priority” due to its access to otherwise closed resources.

Specifically, an operation may be added to a whitelist of operations that are allowed into a newly announced UAS Volume Reservation (UVR). A UVR is a constraint in the UTM airspace that is typically short-lived and dynamically announced. UVRs support use cases such as pop-up events on the ground, extreme weather events, public safety events (airborne or ground-based), etc. By default all operations are excluded from a UVR. However, if an operation has its identifier added to the UVR as a permitted operation, it would be permitted to have plans that intersect the UVR and could therefore enter it. This analysis includes such operations as “priority” operations to gain insight into how they interacted with other operations.

From the complete list of operations available for this MOPs analysis (652, as outlined in the [General Data Reduction](#) section), there were 21 operations that qualified as priority operations, either by announcing their status in the operation plan or by inclusion within a UVR announcement.

These priority operations in TCL4 would often (by design) intersect existing nominal operations (both simulated and live). The operation plan models and their respective operation volumes provided the 4D information to calculate any intersections in plans, allowing insight into whether active, nominal operations could remove intersections between their active plans and the newly announced priority operation. It is important to note in this testing that the exact moment of a priority operation being announced was not always known by participants, but they

did know (via scenario design) that such a pop-up operation would occur. As always, range safety protocols kept operations safely separated regardless of the state of the UTM systems under test.

There were 64 nominal operations that intersected with the 21 priority operations, upon announcement of the priority operation (either via UVR or the operation itself), resulting in 85 total operations for analysis. Of those 64 nominal operations intersecting with the priority operations upon announcement, 15 remained in conflict upon the priority operation activating its plan. Those 15 operations intersected with 5 distinct priority operations, thus some priority operations were intersecting with multiple nominal operations upon take off. Of the 5 distinct priority operations. The actions of the 15 nominal and 5 priority intersecting operations are analyzed in the next section along with overall analysis for these MOPs.

Including the operations that were whitelisted in a UVR as a “priority” operation greatly expands the documented definitions of priority operations within UTM. The operators flying these missions may have had an implicit notion that they were flying a “priority” operation due to exemption from an announced UVR. However, to require existing operations to deconflict from a newly announced operation, that newly announced operation would need to include the appropriate priority data elements in its operation plan. In the UTM concept, if these elements are not included in the operation plan, the operation is still considered nominal, and it has an added ability to fly into a UVR. However, by including these implicitly priority operations, additional data are available that may provide insights into the use of the UTM system in TCL4.

Analysis

As mentioned above, there were 15 nominal operations still in conflict with priority operations upon takeoff time of the priority operation. These 15 conflicting nominal operations fell into one of four distinct categories:

1. The nominal operation keeps its aircraft clear (i.e. the position of the operation is not inside) of the priority operation’s volume, even though its volumes intersect with priority operation’s volumes
2. The nominal operation becomes an emergency operation itself
3. The nominal operation transits through the active priority operation’s volumes with a negotiation agreement
4. The nominal operation transits through the active priority operation’s volumes without a negotiation agreement

These categories and the overall counts are summarized in [Figure 7](#).

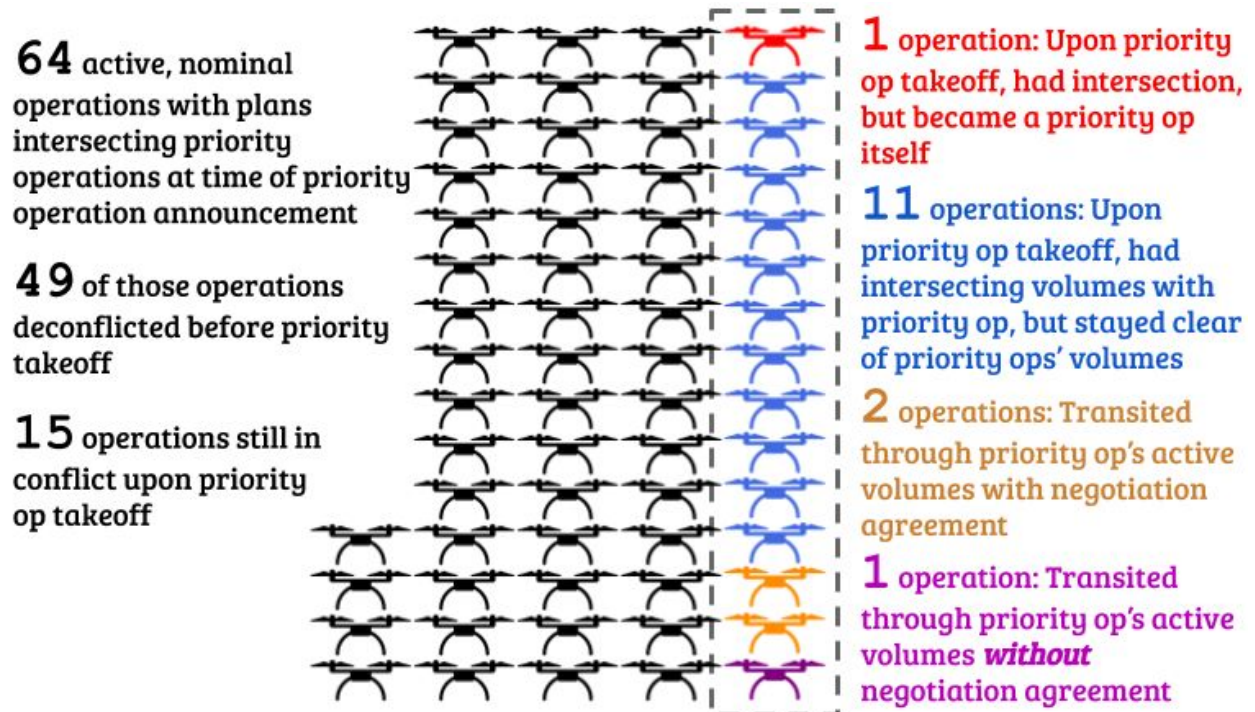


Figure 7. Summary of the conflicting operations for MOPs 18 and 20.

To further understand how and why operations were not able to maintain strategic deconfliction, it is illustrative to examine the outlier cases. In the following sections, a closer look at two of those cases is provided.

Case 1: Misbehaved Priority Operation

In Figure 11, there is a nominal operation that failed to deconflict with a pop-up priority operation and transits the priority operation's volumes without a negotiation agreement. Upon first reading of such a statement, it would be natural to assume that the affected nominal operation failed in its UTM duties to deconflict from a priority operation and further endangered the airspace and surrounding areas by transiting that priority operation's volumes. However, a closer look at the timeline of events sheds light on the actual culprit in this interaction. The timeline is depicted in [Figure 8](#).

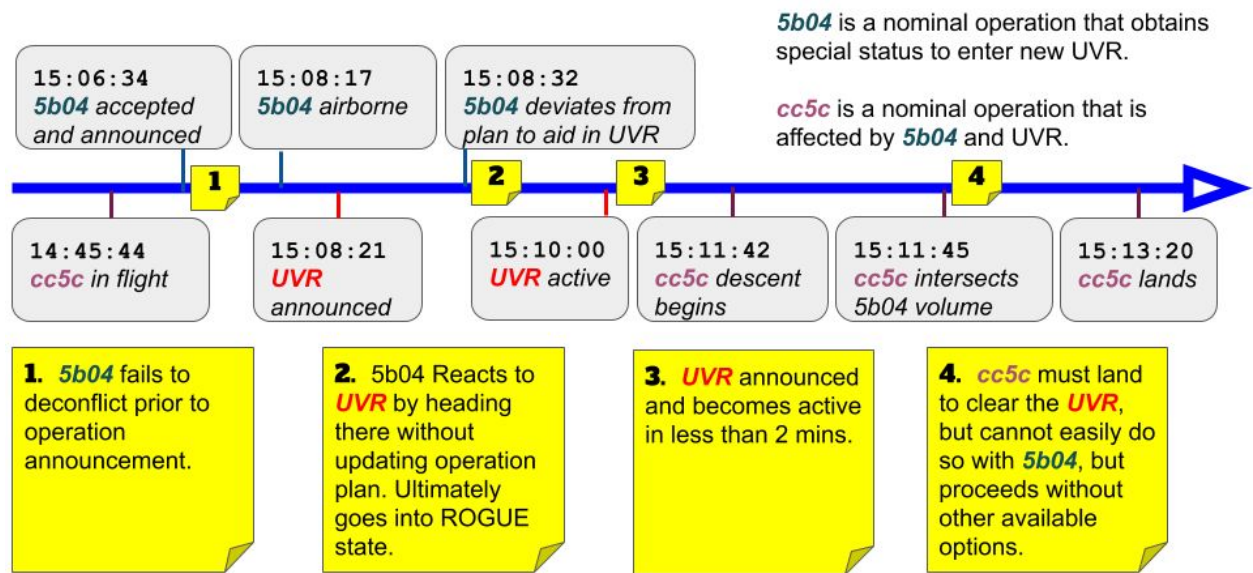


Figure 8. Timeline of events for simulated operation cc5c interacting with operation 5b04.

As noted above, the planned activity in this scenario was for a UVR to be announced with at least a five-minute lead time from announcement to activation. In that announcement, certain operations would be “whitelisted” via their flight identifiers and allowed to continue operation within the UVR or change their plans to enter the impending UVR. The whitelisted operation is not a priority operation in the technical definitions within UTM, but is allowed to enter the UVR.

Operation 5b04 is the whitelisted operation, with operation cc5c being an airborne nominal operation that is not whitelisted. In this scenario, cc5c is simulated and 5b04 is a real operation, but their interactions via their USSs occur as if they are both real operations. Operation 5b04 submitted its original operation plan to the TCL4 data collection system with volumes intersecting the existing cc5c operation. This is not allowed per UTM protocols, as each operation needs to be deconflicted from every other existing operation or have a negotiation agreement in place to allow operations to intersect. Operation 5b04 did have a negotiation agreement with two other operations, but not with cc5c. This is most likely due to the USS for cc5c rejecting a negotiation request, which is a valid response to such a request. It appears that 5b04 used the conflicting plan anyway and began its mission.

After commencing flight, 5b04 and the other operations received information of a UVR via their USSs. That UVR had a scheduled start time just a couple minutes into the future. Operation 5b04 was on the whitelist for this UVR. In the scenario, the plan was for operation 5b04 to head to the UVR to assist in a mock public safety activity. 5b04 did go to the UVR as designed in the scenario, but did not update its plan, thus leaving its planned volumes and becoming ROGUE per UTM specifications. The supporting USS tracked that status appropriately and applied the state per the UTM specification. The disconnect in procedures was between the USS and the operator for 5b04. [Figure 9](#) depicts the two interacting flights shortly after the announcement of the UVR (denoted by yellow boundary) prior to the descent initiation of 5b04.

Operation cc5c had no escape from conflict. Much like a shopper in a grocery store happily shopping and then having the manager turn the lights out, lock the door, and then accuse the shopper of trespassing: Operation cc5c was caught in a situation where it could not get out of the airspace without further breaking boundaries. This is why it had to descend through 5b04’s

operation volumes to land (see [Figure 10](#)). Thus, the against-protocol actions of 5b04, had a cascading effect on another operation, forcing it to break protocols to safely exit the airspace.



Figure 9. 5b04 (blue) and priority cc5c (green) inside UVR (yellow boundary).



Figure 10. 5b04 forced to descend through cc5c's active volume below to clear UVR.

Case 2: UVR begets Emergency

In another example of how operations dealt with the pop up of the UVR, Operation 8b95 was another live operation in flight when 5b04 was announced and took flight. A depiction of the timeline of events between these two operations is shown in Figure 15.

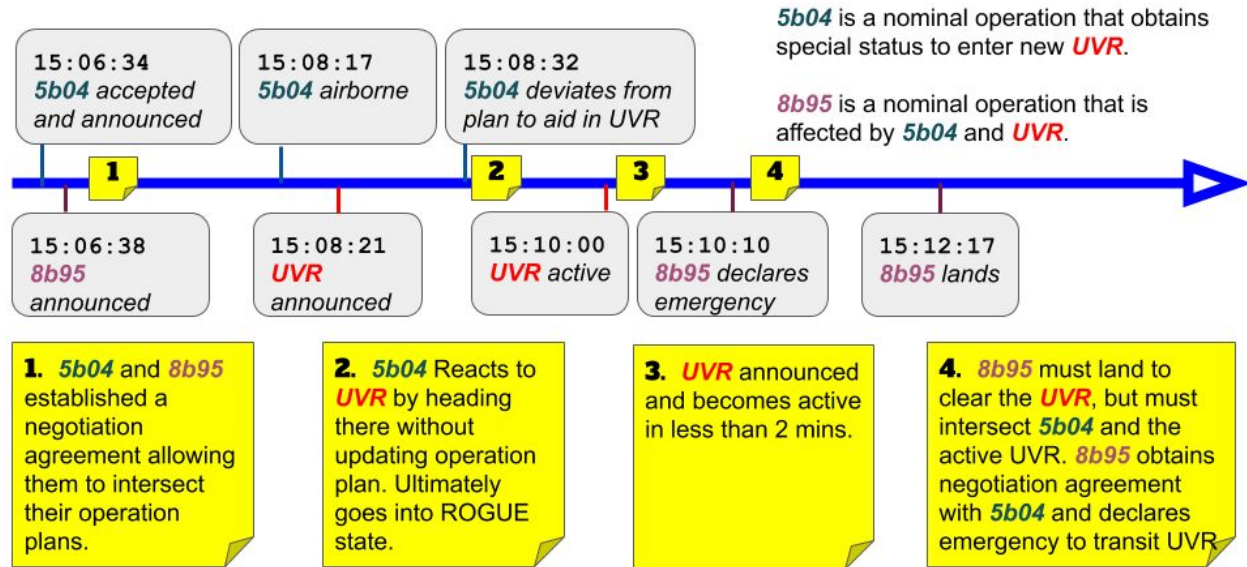


Figure 11. Timeline of events for simulated operation 8b95 interacting with operation 5b04.

In this case 8b95 and 5b04 had an initial negotiation agreement to intersect and rely on other means of separation (Figure 16). When the UVR occurred, 8b95 did not have time to land without intersecting the UVR. So, 10 seconds after the UVR was activated, 8b95 declared itself in an emergency state (within the context of the flight test, not in practical operational terms) and proceeded to head for a safe landing. The updated plan to reach this landing included another intersection with 5b04, which they codified with a new negotiation agreement (Figure 17).

This would be considered a special case of how deconfliction should work in UTM, but it was within protocol. It illustrates the effective use of the protocols in a time-constrained scenario, with some decisions likely made in real-time. The system also clearly supported the ability of the flight crews and the USSs to handle these negotiations.



Figure 12. 8b95 (blue) and 5b04 (green) with negotiated intersect prior to UVR.



Figure 13. In response to UVR, 8b95 declared emergency and updated operation to return and land safely with negotiated intersection with 5b04.

Discussion

There are several key takeaway messages from the data collection and analysis related to UTM-MOP-18 and UTM-MOP-20. This section will list and provide discussion on each.

UVR Warning Time

Without appropriate time between the announcement and activation of a UVR, a compliant operation may be forced into non-compliance to safely stay clear of the UVR. This was understood prior to TCL4 [Homola, 2019], but due to the acceleration of certain testing conditions, the practical effects of a limited warning time were observed.

Operator Understanding

The actions of certain operations in the context of priority announcements and UVR implementations indicate a lack of understanding of the UTM protocols. This has been an understood deficiency for some time in the context of all TCL activities over the years. Operators were better informed in TCL4 than in prior tests, but the protocols and actions were more complex than before. These priority and UVR scenarios highlighted this gap. Overall this can be seen as a shortcoming in NASA's training for the TCL4 test partners. With more time and resources, operator education would be a valuable addition to future tests. In addition, this finding highlights the need to ensure all operators and pilots within the future operational UTM environment receive appropriate training and education on UTM concepts and protocols. There is more to operating in this collaborative environment than flying an individual mission under current day rules and procedures. For further discussion on operator feedback on the UTM TCL4 effort, see [Martin 2020a] for Texas operation feedback and [Martin 2020b] for Nevada operator feedback.

Restriction breeds Creativity

Even with the acceleration of TCL4 flight schedules and the difficulty in finding appropriate deconfliction solutions, there is evidence that many operators and USSs were able to find viable approaches to constrained situations and stay within the UTM protocols. This is an important highlight, especially in light of the limited training provided to stakeholders on UTM concepts as noted above. It is encouraging to note that the concept as tested in TCL4 can support data exchanges that lead to safer operations in unanticipated scenarios.

Overall Discussion

The analysis of the three MOPs presented in this document each revealed a selection of insights. Those are summarized in Table 4.

Table 4. Summary of lessons and insights from strategic negotiation testing.

MOP	Lesson/Insight	Summary
UTM-MOP-01	Strategic Deconfliction Effective	Overall, USSs were able to share data about each others' operations under management and use that information to keep them separated. When separation was not possible or perhaps inefficient, USSs were able to negotiate intersections where appropriate.
UTM-MOP-01	Intra-USS Deconfliction	USSs are typically checked-out on their ability to deconflict operations with other USSs. It is also important to ensure that a USS deconflicts the operations it is managing via targeted checkout tests for those use cases. Otherwise, there is a distinct possibility that operations may be in conflict due to USS errors.
UTM-MOP-01	Protocol Adherence	Negotiation protocols may be quite complex to handle all use cases. If overly complex, there is an implementation cost that may encourage the use of simplified responses to negotiation procedures.
UTM-MOP-18 UTM-MOP-20	UVR Warning Time	As hypothesized prior to TCL4, a UVR that does not offer enough time for operations to react safely and efficiently, will introduce complexity and difficulty onto operators and USSs. Appropriate lead time from UVR announcement to UVR activation is critical.
UTM-MOP-18 UTM-MOP-20	Operator Understanding	Some actions during the scenarios indicate a lack of understanding of the protocols and concepts of UTM on the part of the operators. In TCL4 this was not the direct fault of the operators, but it does indicate the need to properly train all stakeholders for their role in an future operational version of UTM. In a future operational system, operators are ultimately responsible for the safety of their operations and knowledge of the involved systems.
UTM-MOP-18 UTM-MOP-20	Restriction breeds Creativity	Even when faced with a difficult situation in terms of a sudden UVR and dense airspace, operators and USSs could find legitimate, in-specification approaches to handling the situation.

The MOPs for strategic deconfliction provide insight into how a future operational UTM System may aid in the safe separation of beyond visual-line-of-sight operations of sUAS. With further efforts on protocol development and standardization, the USS-USS communications related to strategic deconfliction will be vital to enabling safe access to orders of magnitude more operations than are possible in today's environment.

The work of the NASA UTM Project is being transferred to the FAA via a Research Transition Team. Some aspects are also being transferred to industry via standards bodies and publications such as this one. NASA plans to continue research on the UTM concept. This includes graduating concepts and architectures to other aviation domains such as Urban Air

Mobility (UAM), high altitude operations (over 60,000 ft), and space traffic management. Thus, the results from UTM testing will likely have broad impact on future aerospace applications.

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