Human-system interaction issues and proposed solutions to promote successful maturation of the UTM system

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***Abstract*— Over five years, NASA, together with partnering organizations, has been developing and successfully demonstrating the maturing capabilities of the Unmanned Aircraft Systems (UAS) Traffic Management (UTM) system and its ability to support communication and coordination among small UAS operations through a series of flight tests. During these flight tests, human-system interaction (HSI) elements were also explored in order to identify the barriers to implementation as human operators transitionally fulfill roles that will be ultimately tasked to future automation. Throughout the tests, similar issues were regularly documented and are expected to persist if not formally addressed by consistent procedures, intuitive design, or regulation. Documented here, along with suggested mitigations, are the most frequently noted HSI items, which include operator training, data standardization, and information quality.**

Keywords—small Unmanned Aircraft Systems (sUAS), UAS Traffic Management (UTM), future airspace management

I. Introduction

For the last five years (2015-2019), the Unmanned Aircraft Systems (UAS) Traffic Management (UTM) research project has been developing and testing concept ideas for enabling small UAS (sUAS) operations in low altitude airspace (i.e., ground to 400 feet) [1]. To do this, a series of incrementally complex flight test demonstrations, from rural farm-field flying to enacting contingency maneuvers in a downtown city area, were run at a total of eleven different test locations. The demonstrations resulted in over a thousand data collection flights using 89 live UAS (both multi-copter and fixed wing) with nearly seventy flight crews participating. During the later demonstrations, simulated vehicles were included in scenarios to test the system. By the end of the series, more than ten Unmanned Aircraft Systems (UAS) Service Suppliers (USSs) had taken part to manage flights' operational volumes and provide the ground control station (GCS) anchors for the UTM system. Each flight test successfully demonstrated a different layer of capabilities of the system with scenarios that had been scoped to set up sets of sUAS corner-case events to test new functionality.

The UTM system was developed in response to the need for an airspace system to manage the projected increasing usage of sUAS for aerial activities, especially in commercial applications [2]. It is a federated system that allows many operators to bring and link in their own USS which represents their own operations and facilitates participation in UTM. The system needs to facilitate automated communication and coordination between sUAS operations as the existing air traffic control systems, responsible for 5,000 daily airplane flights, could not feasibly monitor the millions of sUAS forecast to come into use in a near-term time-frame [3].

An aim of the UTM system is that it will ultimately operate in a largely automatic manner, relying less frequently on interaction from a human operator. Until that substantially-automated end state has been safely reached, thought needs to be given to how humans can best perform those tasks that need to be manually completed and interact with UTM (i.e., human-system interaction or HSI) in the interim. During this time, the efficiency and effectiveness of the system will depend on the level of workload, attention, and awareness required of the human operator.

The UTM research project advanced through a risk-based approach, where both the risks of the environment and the complexity of UAS operations encompassed four different technical capability levels (TCLs) (Fig. 1) [4]. The research and development was designed to advance through a series of five flight tests, from least through more complex and riskier environments, to explore the performance of the system. The first capability level, or TCL1, involved an environment that was assessed as low-risk due to the flying domain being characterized by open spaces with few structures and people. Operations during this time were straightforward and notification-based. As environmental complexity and risk increased in TCL2 through to TCL4, sUAS were operating over urban areas with closely-spaced structures of varying height,

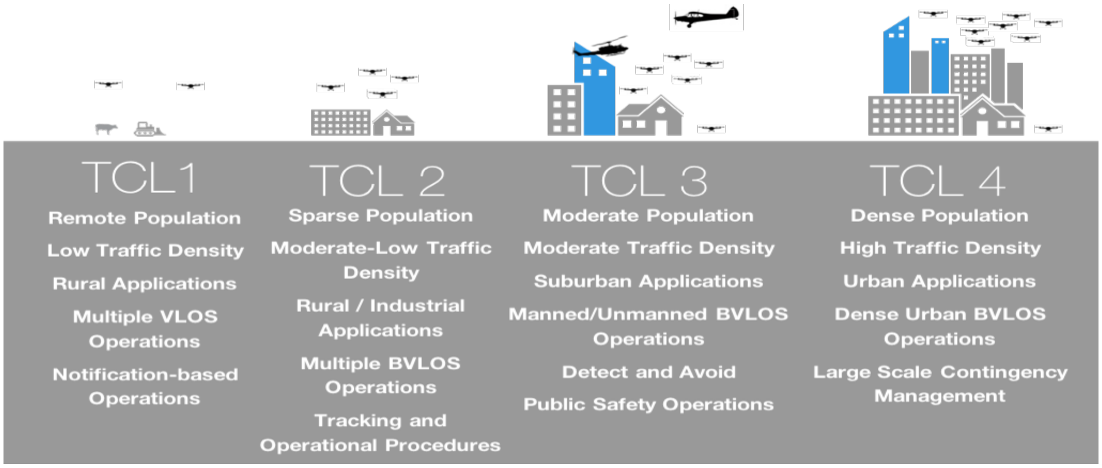

Fig. 1. NASA UTM planned technical capability level progression.

dense population, and many dynamic obstacles below (e.g., cars and people). For these operations, sUAS operators have to take airspace complexity into account in their flight planning and operations and prepare a series of contingency plans for a variety of different potential events, like loss of power or loss of communication with the vehicle.

During the five flight demonstrations of the prototype system, which were defined according to the level of the risk model that they were demonstrating, functions were frequently allocated to the human operator, while more functions transitioned from manual to automated as the system was developed. As the UTM system matures further, it is expected that the role of the human operator will change to being more supervisory, and therefore the nature of the HSI will also change.

For all of the flight tests, attention was paid to user information requirements, and the primary users were the ground control station crews including the UAS pilot-in-command (PIC), GCS operator, and UAS engineers. The subject of this paper is a metadata analysis that aims to examine the consistent themes that arose from the qualitative data collected from these teams across these five years of events.

II. Methods

During the four most recent sets of flight tests, data was specifically collected from the operators, including all members of the flight crews, about their experiences using UTM and their USS clients. Flight crews, the PIC in particular, often held manned aviation certifications, bringing their general or military aviation experience to meet the challenges at each test site. In addition, crews increasingly had UAS mission experience and many UAS flight hours. Qualitative data were collected through surveys, observations, and group interviews which were then compiled to describe the experience of operating within UTM.

The first flight test demonstration (Test 1), that was exploring TCL1 conditions (Fig. 1), was held over eight days, spread across a calendar year from August 2015 to September 2016. It tested three fundamental sUAS traffic management services: user authentication, flight planning, and information services in an open space area where environmental complexity was low (i.e., no structures and no population). Vehicles flew a series of box patterns with the UTM services in operation. In total, ten different aircraft flew more than 100 flights during the eight days. As the focus was the testing of UTM services, crews were not asked for their feedback as users in a structured way, only through informal discussions. While the flight test demonstrated the feasibility of the three focus services, it also drew attention to other important areas, such as the need for common situation awareness (SA) among all stakeholders. As a result, the following flight tests consistently included inquiry into the user experience and information requirements from a user-perspective, and it is only these data that are the focus of the summary analysis in this paper.

A. *Summary of data sources*

The second demonstration (Test 2) increased the level of complexity of the flight tests by inviting both new and existing partner organizations to operate together at a test site in Reno, Nevada (Fig. 2) under TCL2 conditions. The aim was to fly scenarios where there were multiple simultaneous sUAS in operation using the UTM system. The flight test took place during nine consecutive days in October 2016. Four scenarios were developed to script multi-vehicle, altitude stratified BVLOS (beyond visual line of sight) operations[1]. Across the range, five GCS locations were set up at different points around the test site. Eleven flight crews each brought their own vehicle to the flight demonstration. These eleven crews were divided into three separate groups of four or five crews (three crews participated twice to enable this). These three groups attended the flight demonstration for three days each: The first day consisted of an initial briefing and time for the crews to set up and test their equipment, while the second two days had the crews flying proficiency flights and a selection of test scenarios.

[1] Due to test and vehicle constraints most flights were visual line of sight operations.

Generally, crews flew two proficiency flights and two scenarios per flying day, generating 36 sUAS data collection flights, although the third group had one flight day cancelled due to high winds. Over the five data collection flying days, 72 participant survey responses were collected, five end of day group debriefs were held, and researcher observations were conducted during the operations of all eleven crews.

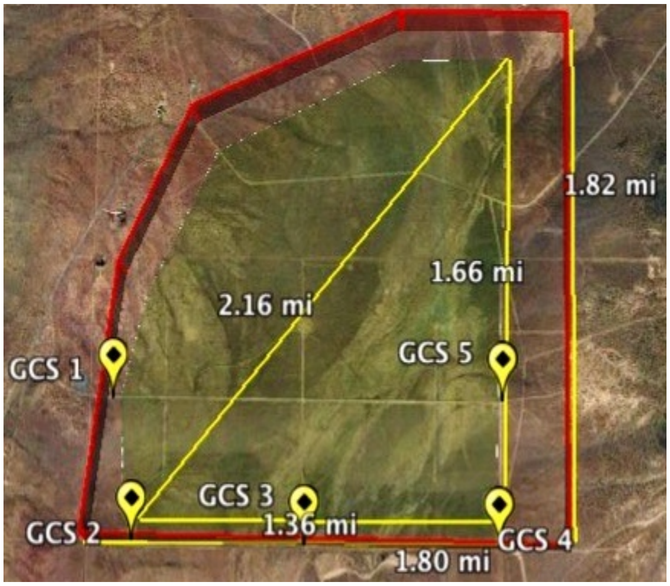

Fig. 2. Location of the second UTM flight test demonstration (Test 2) under TCL2 with ground control stations GCSs marked.

In 2017, the third demonstration (Test 3) invited six test-partners to host flight tests at their local testing sites, involving other partners of their own choosing, and they were given the ability to tailor the test scenarios to the features and environments of their respective sites. All sites had few structures, were sparsely populated and were considered TCL2. Each site organized a shakedown followed by approximately a week of flying for data collection – yielding a total of 17 flying days[2] over eleven calendar days. The demonstration resulted in over 270 data collection flights flown by 18 flight crews using 27 live rotorcraft, and seven USSs. Test sites were asked to incorporate six advanced flying challenges, such as BVLOS and stratified operations, with a selection of five complexity-increasing events, such as contingency maneuvers. These challenges were incorporated by partner sites into scenarios that they created, which took advantage of the unique features of the terrain and conditions at their of their respective test sites. Sites created a total of 17 test scenarios. Over the 17 days when flights were conducted, 141 participant survey responses were collected, 18 end-of-day group debriefs were held and the research team made 34 sets of observations of flight crews.

During 2018, the fourth demonstration (Test 4) was conducted by the same six organizations as Test 3, flying out of four new locations and three of the same locations as the 2017 tests. They completed 33 days of flying in a March to May flight window across the six sites. The demonstration generated over 800 data collection flights using 28 live rotorcraft, piloted by 17 flight crews, linked into the UTM system by nine USSs. All sites flew a subset of 20 scenario outlines that had been scoped by the UTM project. These short vignettes, or performance tests, addressed one of the four themes of key concern for the third level of UTM operations: exploring Communication, Navigation and Surveillance (CNS) issues, Sense and Avoid (SAA) tools, data and information exchange routines, and tests that exercised procedural aspects of the UTM concept. For example, the "CNS1" test involved using redundant command and control (C2) and explored whether control could be maintained of the sUAS when one communications link was lost. By contrast, tests like "Concept 2," required sites to create an event that included contingency maneuvers [5]. Over the 50 flight-days, 274 participant survey responses were collected, 22 end of day group debriefs were held, and the research team observed multiple crews during over 50 flight sessions.

In 2019, the fifth demonstration (Test 5) comprised two flight tests that lasted ten days each; these occurred in the states of Texas and Nevada. These flight tests were focused on the most complex environments thus far in which sUAS are likely to fly (i.e., densely populated urban settings) as shown in Fig. 3, and events that may be critical in urban city locations, such as avoiding dynamic obstacles, landing in close proximity to buildings, and dealing with system failures. This demonstration resulted in over 700 data collection flights using 14 live rotorcraft and 30 simulated vehicles which were operated by 17 flight crews and seven USSs. The approach was designed for a

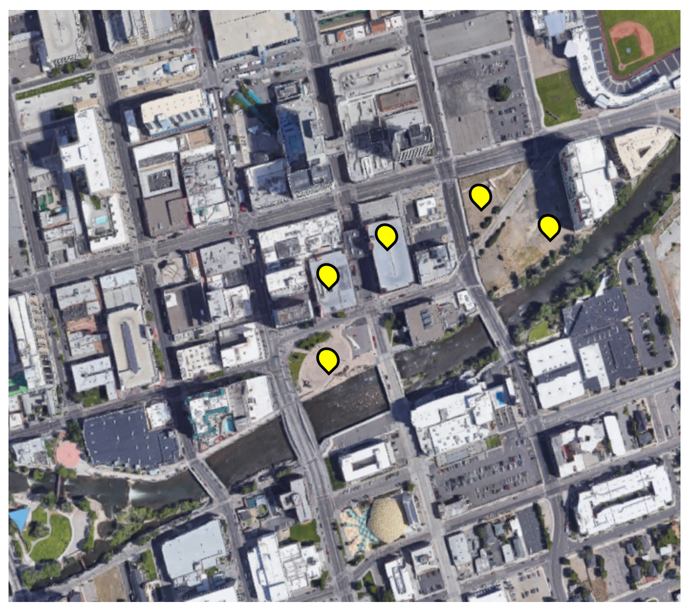

Fig. 3. One location for the fifth UTM flight test demonstration (Test 5, 2019) under TCL4 with GCS marked.

2 Each day of flying for each site was counted as a separate "flying day" even though one site may have flown on the same calendar day as another site.

TCL4 level of risk, demonstrating events that may be critical in city locations, such as avoiding dynamic obstacles, landing in close proximity to buildings, and dealing with system failures. This demonstration resulted in over 700 data collection flights using 14 live rotorcraft and 30 simulated vehicles flown by 17 flight crews and seven USSs.

The approach was designed with five scenarios that set up diverse sets of UAS events and activities. These scenarios focused on a variety of potential events and issues, some of which were an incoming weather front, sharing airspace, a USS failure, and multiple vehicles experiencing CNS issues. The test site was required to complete three executions of each scenario. Over the 19 days when flights were conducted, 149 participant survey responses were collected, 19 end of day group debriefs were held and the research team observed over 75 flight sessions.

This document presents a summary of the qualitative data collected over the four demonstrations from October 2016 to August 2019, i.e., Test 2 to Test 5. The common types of data were participant surveys, group debriefs, and researcher observations (Table 1). These were developed by considering common human-system interaction themes, including user information requirements, user decision making, user situation awareness, and communication. Although the methods of data collection and themes were the same, the focus questions for each demonstration differed. The survey questions, discussions in group debriefs, and researcher observations were tailored to the scenario events that were being exercised and hence are not specifically comparable. The summary below explores common threads between the main findings across the most recent four years of data collection (excluding the first year, which explored the Test 1 study with TCL1 characteristics) .

TABLE I. QUALITATIVE DATA COLLECTION SUMMARY ACROSS FIVE UTM FLIGHT DEMONSTRATIONS.

Data collection test name	**Flight demonstration level and year**				
	Test 1	***Test 2***	***Test 3***	***Test 4***	***Test 5***
Technical Capability Level	TCL1	TCL2	TCL2	TCL3	TCL4
Date	2015-16	2016	2017	2018	2019
	Data collected				
Participant surveys	N/A	72 asked at the end of flights	141 online	274 online	149 online
Interviews/ debriefs	N/A	5	18	22	19
Hours of debrief	N/A	Approx. 5 hours	Approx. 9 hours	Approx. 8.5 hours	Approx. 9 hours
Flight sessions observed[a]	N/A	24	34	50	75

[a.] Flight sessions were observed by a team specifically focused on user interaction and experience of the operations.

III. DISCUSSION

The flight test demonstrations were intentionally designed to test the UTM system – specifically the architecture and the software components within it. However, assisted by real-world settings, the demonstrations also highlighted issues in the wider UTM environment that may need to be addressed.

The flight tests successfully demonstrated that the UTM system is rapidly developing into a viable mechanism for allowing communication and coordination between increasingly numerous sUAS operations. The UTM system correctly collected an increasing amount of incoming information about operations, and USSs were able to retrieve the necessary information in order to inform their users about negotiations, their own and others' operational states, potential conflicts, airspace restrictions, and other actionable items. However, the success of the system architecture demonstrated the need for further inquiry into ensuring that the human operator, interacting with UTM through a USS, is able to effectively utilize all of the maturing capabilities of the system. The development of USSs progressed through the years, and the USSs that each operator used to interface with UTM varied within each series of flight tests. This allowed trends to emerge within the observations, particularly in regards to the amount of operator familiarity with UTM, the amount of information that was displayed, and the standardizations and procedures.

A. System Level Issues – Operator Training

For the first four flight tests (Test 1 to Test 4, see Table 1), the PIC role was filled by individuals who held a pilot rating (e.g., manned flight certificate such as for an instructor or a private pilot license [PPL]) in addition to the remote pilot certificate with sUAS rating (i.e., Part 107) [6]. These pilots drew on their manned flying experience to communicate on the test range, scan for traffic, and plan flights with respect to weather. In Test 1 through Test 4, crews were able to understand the UTM procedures and usability complications with their USS, such as too little information, by drawing on their aviation background and because fewer factors needed to be considered for solution options due to the less complex environments.

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However, for the fifth demonstration (Test 5), the consequences of actions became more severe, as the environment was more complex. For example, there were many more structures to be aware of, which resulted in fewer breakout options and generally an increased time pressure. One of the test sites in Test 5 took a different approach to their crews and trained a group of non-pilots to operate a fleet of sUAS. This approach provided a good opportunity to observe whether novice users of the UTM system had different needs or methods for using UTM information. Novice users required more explanation or detail around information presented by the UTM system. Notifications that were only two or three words or used UTM-system jargon were not always understood and there was insufficient time to look up information during operations. In addition, novice users did not always know the action-options that were intended in response to events, could not revert to common aviation procedures (unlike those with a PPL), and did not understand the safety implications of some of the action-options in response to scenario events. This would suggest that additional elements of pilot training should include (accepted) procedures for reacting to a range of possible events.

B. *Information Quantity*

1) *Too much information*

Throughout the flight tests, researchers noted instances of an over-abundance of information. This was less apparent when the flight tests had fewer aircraft that were flying more nominal scenarios in rural environments, but became more so when the airspace was more densely occupied by other UASs and obstacles. Display clutter was first noted during the third flight test (Test 3) and became more common from there as the amount of incoming information increased. Users could receive messages about the state of their own operation, other operations, conflicts, negotiations, airspace restrictions and emergency alerts, and were oftentimes over-saturated with information. For example, one participant in Test 5 said: “There were over 80 negotiations. I didn’t get a lot of info on each but if I did it would have been too much anyway. "Consequences of insufficient information filtering were that similar messages were sometimes ignored by crews if they seemed to be duplicates, non-persistent messages were sometimes missed if they were obscured by more recent messages, and the mental effort to maintain information currency was sometimes difficult.

2) *Too little information*

Researchers also observed users lacking information that they wanted or needed. In early tests when the USS client interfaces were less developed, some details were absent that users required in order to react quickly to messages, but this was a less critical issue as the operating environment allowed them time to obtain those details. As the tests advanced into more dense and urban environments, increasing the amount of information for each user to process, the USS interfaces also greatly matured to be more user-friendly, which is reflected in a general increase in situation awareness over time. This is illustrated in Fig. 4, which shows the mean of participants’ responses to a question about their perceived SA across four flight tests, from 2016 (Test 2) to 2019 (Test 5). The general trend in terms of participants consistently rating their SA as

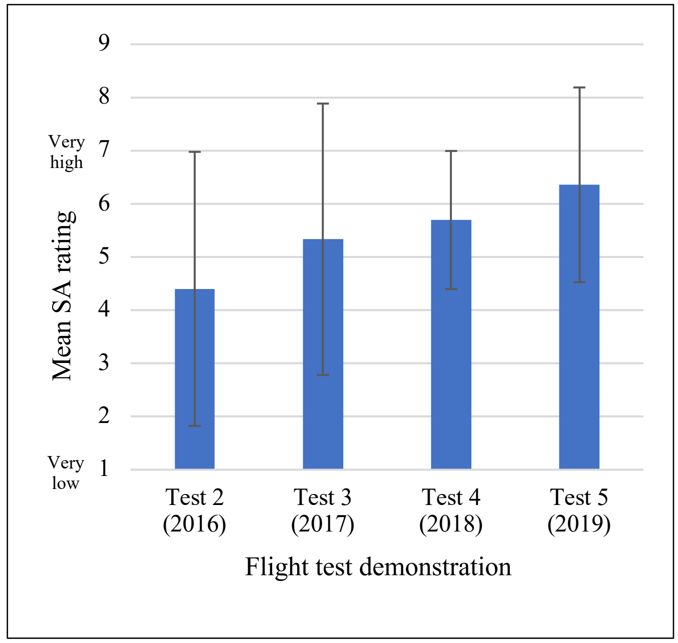

Fig. 4. Mean situation awareness responses from flight demonstrations held in 2016 and 2018. Response scale was 1-7, extended in chart to show deviations, n-Test 2 = 30, n-Test 3 = 27, n-Test 4 = 41, n-Test 5 = 14. Note: Survey questions were not identical across all flight tests. Only data from comparable questions have been included here.

slightly higher every year to the later years, after the UTM system had been developed and improved for an additional period. However, users in these later tests had less time to act, and so the need for each message to contain more necessary information grew. Acting quickly on sub-optimal information seemed to lower users’ confidence in their decisions (Fig. 5) as they were often observed to seek out second opinions. Figure 5 shows the mean of participants’ responses to a question about their confidence in the accuracy of information they received from UTM across two different flight tests, one in 2017 (Test 3) and one in 2019 (Test 5). During Test 5, participants gave, on average, lower (i.e., less confident) responses to these questions. Users’ awareness for how their own operation interplays with the surrounding environment could be improved by streamlining the incoming messages and alerts and by tailoring the included text to facilitate easy and quick comprehension.

C. *Standardization*

1) *Uncommon terminology*

The language and commonly used phrases for messaging were observed as a source of confusion that manifested more as the user groups became diversified. Throughout the tests, users who had a hand in developing their USS clients did not struggle with interpreting the information it displayed, and Test 2 to Test 4 showed that these were the most common types of users. Later, as users with different backgrounds emerged, flight crews were sometimes confused about the information they were receiving. Equipping operators with shared terminology to use while flying in the UTM airspace could increase the efficiency with which they conduct those operations.

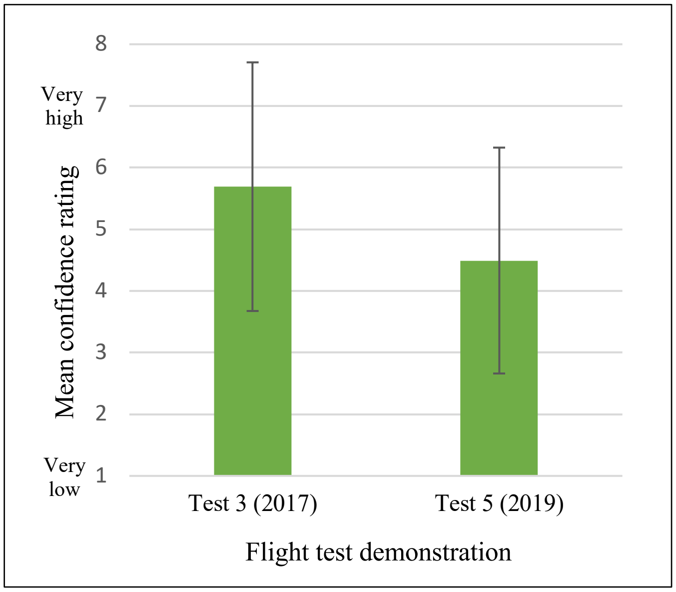

Fig. 5. Mean confidence in accuracy of information responses from flight demonstrations held in 2017 and 2019. Response scale was 1-7, extended in chart to show deviations, n-Test 3 = 42, n-Test 5 = 65. Note: Survey questions were not identical across all flight tests. Only data from comparable questions have been included here.

2) Measurement consistency

Across trials, systems or operators varied in terms of methods used to calculate altitudes or used different units of measurement entirely (see [7]). Some systems were using AGL (height above ground level), while others were using MSL (mean sea level) or WGS84 (World Geodetic System 84) as their standard. This was especially problematic and slowed the pace of operations when two or more sUAS were attempting to fly stratified, with one above another. When an operation was unexpectedly rejected by the UTM system due to an altitude-conflict, time had to be taken to resolve the issue. This occurred usually via voice communication, which is not intended as a common interaction in the UTM concept. An accepted standard for common measurements must be established to further increase the efficiency of UAS operations in the UTM working airspace.

3) Undefined procedures

Similar to the issue with uncommon terminology, users were not generally observed to have a full understanding of how to respond to specific UTM events. The live flight demonstrations were designed so that the earliest tests looked at the robustness of the UTM system under nominal conditions (i.e., one or two vehicles flying within line of sight of their operators), and later tests introduced more off-nominal conditions (i.e., large-scale contingencies and emergency management). While these tests successfully demonstrated the UTM concept and the capabilities of the system under these stressors, it also exposed gaps in procedures for the human operator when interacting with UTM through their USS client during these events. The absence of standard or established procedures was less concerning during the first three tests considered in this paper due to the nature of the scenarios where operators had fewer planned events to react to and more time to strategize their actions.

The later demonstration scenarios were designed to include many overlapping events occurring in densely populated urban areas, adding both urgency and complexity to the decision making process. As an example, there were multiple ways to respond to a vehicle emergency including: land immediately, directly and immediately return to launch, or retracing the original route to the launch point, either with or without creating a new UTM volume to remain within. In simple scenarios, operators had more time to make these decisions, and there were fewer nearby UASs or static obstacles to consider. Later, the need to proceduralize responses became more apparent as operators were faced with complex decisions. For example, one participant in Test 5 said: "We have arrangements … to always decline re-plan negotiation requests and always accept intersection requests." Not only would procedures help users make quick decisions and be confident about their own actions, they would also assist a user's ability to predict the actions of other operations.

D. UTM Beyond TCL4

Given the successful progression, development, and demonstration of the UTM system, new generations of UAS operators, who are using UTM and flying their sUAS in public areas to serve local populations, will need to be able to interact efficiently and effectively with the system to fully utilize its capabilities. These operators will need to be aware not only of the functioning of their vehicles but also how to manage their flight volumes through UTM and how to monitor for and interpret the activity of surrounding sUAS operations. Operators will need to be able to understand and respond to UTM alerts and warnings.

The UTM system has a planned end state that is more automated than the prototype system tested during Tests 1 to 5. As tools are developed and the system is utilized, many functions will gradually transition from manual to automated. Until functions are safely automated, human operators will continue to complete these tasks. This leads to two broad challenges for human-system integration within UTM. Consideration needs to be given to the interaction required between the operator and UTM (HSI) to enable the operator to complete all the tasks they are required to fulfil as the system moves through every stage of its development. As stated earlier, in the early fielding of the system, the level of operator workload, and attention needed to successfully operate while flying an sUAS will determine its efficiency and effectiveness. Tasks will naturally be coherent because operators are involved in every aspect of the system. As the UTM system matures, the nature of the HSI is predicted to transition to a state where the system completes many more of the operational functions and the operator moves into a more supervisory role [9]. As this process occurs, a second broad challenge arises, which is to consider what users need to know about the integration between automated tools so that they can find the information they need should they need to become a manual part of (intervene in) the system (e.g., for corner-case events where there is not yet an automated solution) [10].

To support different stages of HSI, information presented in interfaces will need to be tailored. During initial operation of UTM, information about events and alerts needs to be clear and timely as operators have to comprehend information in real-time to make decisions and take actions. As levels of automation increase and operators step into a more supervisory role, information presented to operators will need to provide a higher-level view of operations – but one where the user can drill down into specific topics if the need arises. For all stages of automation, displays should be well-organized.

IV. Summary

The series of UTM flight tests hosted by NASA across five years and 17 locations were successful demonstrations of the UTM system. The tests resulted in over 2000 data collection sUAS flights and involved 72 flight crews. The viability of the concept of a UTM network for sUAS traffic was successfully demonstrated.

A thrust in the flight test research was to explore methods for the exchange of information. Although UTM itself was shown to support the communication and coordination between sUAS operations, through the years of data collection many HSI challenges and obstacles to successful operation were observed. Three of these categories were highlighted above: standardization, information quality, and considering the complete system during transition to automation. The specific challenges within these categories were present from the beginning of the research, and most became more apparent as both the operations and the operating environment increased in complexity. An operator's ability to maintain a successful, efficient, and safe flight was sometimes challenged by a lack of universal standardization of measurement units and calculations, non-specific procedures, and by non-standard(ized) terminology. A set of standard metrics will help operators ensure that they are maintaining safe distances and buffers. An over-abundance of information that was not always pertinent to current tasks also posed challenges, as it could clutter the displays and potentially overwhelm the user, leaving them unable to locate the information they desired or to potentially miss important notices that were relevant to their own operation. Conversely, having too little information was also a cause for concern, like when pertinent messages did not contain enough context to be immediately usable, and this necessitated that the operator spend time looking for the missing information elsewhere. These issues were compounded by differences in training and/or experience using the UTM system in a real-world environment, often leaving the operator feeling uncertain of the appropriateness of their own actions. As the UTM system is developed and its elements achieve more automated functions, consideration needs to be given to the way the operator's role will transition while ensuring that user SA is maintained.

All of the challenges outlined in the meta-analysis were sustained throughout the maturing of the UTM system and should be expected to remain and advance into comparable systems if not formally addressed. Looking to future airspace operations, with the development of urban air mobility (UAM) concepts, that are founded on some of the principles of UTM, these findings could be used to inform this future airspace exploration and guide further human-system interaction research. The obstacles discussed, and their potential negative impacts on a human operator's ability to attain ideal performance in these environments, could be alleviated by following commonly agreed upon conventions and directions, possibly established by a regulating authority.

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