Unmanned Aircraft Systems (UAS) Traffic Management (UTM) Project

UTM Technical Capability Level (TCL) Overview

Arwa Aweiss
NASA UTM Flight Test Director
Outline

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• TCL 1 National Campaign
• TCL 2 Flight Test
• TCL 2 National Campaign
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  • Objectives
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• TCL 3 Flight Demonstration
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  • Objectives
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• TCL 4 Flight Demonstration
  • Highlights and Objectives
  • Scenarios and Events
  • Measures of Performance (MOPs)
  • Summary and Ongoing Challenges
Technical Capability Level (TCL)

Risk-based development and test approach along four distinct TCLs

<table>
<thead>
<tr>
<th>TCL 1</th>
<th>TCL 2</th>
<th>TCL 3</th>
<th>TCL 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Traffic Density</td>
<td>Low-Mod Traffic Density</td>
<td>Moderate Traffic Density</td>
<td>High Traffic Density</td>
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<tr>
<td>Rural Applications</td>
<td>Rural / Industrial Applications</td>
<td>Suburban Applications</td>
<td>Urban Applications</td>
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<tr>
<td>Multiple VLOS Operations</td>
<td>Multiple BVLOS Operations</td>
<td>Mixed Operations</td>
<td>Dense BVLOS Operations</td>
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<tr>
<td>Notification-based Operations</td>
<td>Tracking and Operational Procedures</td>
<td>Vehicle to Vehicle Communication</td>
<td>Large Scale Contingency Management</td>
</tr>
</tbody>
</table>
Risk-based development and test approach along four distinct TCLs

TCL 1
- Remote Population
- Low Traffic Density
- Rural Applications
- Multiple VLOS Operations
- Notification-based Operations
TCL 1: Multiple Visual Line-of-Site Operations

- TCL 1 Flight Test
  - Crows Landing, CA
  - Remote unpopulated area (flat, agricultural, farmland)
  - August 2015 (8 days of flight)
  - 11 partner organizations, 10 Unmanned Aircraft System (UAS) platforms
  - 2 simultaneous Visual Line-of-Site (VLOS) operations

- Objectives
  - Demonstrate Unmanned Aircraft System Traffic Management (UTM) prototype features
  - Collect data on UAS navigation performance error
  - Collect data on aircraft tracking performance
  - Collect weather observations for forecasting models
  - Collect data on noise signature of UAS vehicles

- Summary
  - TCL 1 enabled multiple operations under constraints
  - First field test within visual line of sight
  - UAS and ground equipment should be rated for use based on the operational environment
  - All airspace users should have a common picture of the operating environment
TCL 1 National Campaign Highlights

4 Goals & Objectives

Participating Entities

20

6 FAA UAS Test Sites

April 19, 2016

7 Ranges

UAS Vehicles

17 Unique
TCL 1 National Campaign

• Goals and Objectives
  • Have 24 distinct vehicles (4 from each of the 6 FAA Test Sites) operational and flying while connected to UTM during the same hour; minimum success criterion (16 vehicles)
  • Expose the Test Sites to the UTM concept and research platform in order to obtain feedback from the Test Sites
  • Understand the potential applicability of UTM for further use at the Test Sites
  • Load the research platform with several distributed clients and test the Live, Virtual, Constructive capabilities for simulating operations in UTM together with live traffic

• UTM
  • Allowed for common situational awareness across all stakeholders
  • Kept traffic procedurally separated
  • Offered messages to inform the participants of activity relevant to their operations
Technical Capability Level (TCL 2)

Risk-based development and test approach along four distinct TCLs

- **TCL 1**
  - Remote Population
  - Low Traffic Density
  - Rural Applications
  - Multiple VLOS Operations
  - Notification-based Operations

- **TCL 2**
  - Sparse Population
  - Low-Mod Traffic Density
  - Rural / Industrial Applications
  - Multiple BVLOS Operations
  - Tracking and Operational Procedures
TCL 2: Multiple Beyond Visual Line-of-Sight (BVLOS) Operations

- **TCL 2 Flight Test**
  - Reno Stead Airport, Nevada
  - Desert terrain
  - October 2016 (5 days of flight)
  - 14 partner organizations, 11 UAS platforms
  - 2 simultaneous altitude-stratified operations
  - 4 scenarios (agriculture, lost hiker, ocean, earthquake)

- **Objective:** To test features relevant to the five core UTM Principles
  - UAS should avoid each other
  - UAS should avoid manned aircraft
  - UAS operators should have complete awareness of all constraints in the airspace
  - Public safety UAS have priority within the airspace
  - Flexibility where possible and structure where necessary
TCL 2: Multiple BVLOS Operations Summary

• TCL 2 focused on three areas
  • Feasibility
  • Functionality
  • Applicability and Integration

• TCL 2 enabled expanded multiple operations
  • Feasibility successfully demonstrated by safely conducting multiple BVLOS operations using an airspace traffic management system
  • Functionality successfully demonstrated the key functions that support multiple BVLOS operations
  • Applicability and Integration
    • Achieved by successful integration of numerous partner UAS systems into UTM and evaluation of the utility of the shared operation information
    • Operator feedback and human factors assessments aided in establishing information-sharing requirements in nominal and off-nominal conditions
TCL 2 National Campaign Highlights

- 6 Research Areas
- 6 FAA UAS Test Sites
- 9 Ranges
- May 15-June 9, 2017
- Participating Entities: 20
- UAS Vehicles: 32
- 20 UAS Vehicles
TCL 2 National Campaign Background

- Demonstrate, evaluate, and refine the functional designs, technology prototypes, and UTM Concept of Operations (ConOps)

- Flight test TCL 2 scenarios
  - Across a wide range of operating environments
  - Utilizing the Flight Information System-UAS Service Supplier (FIMS-USS) architecture for UTM
  - With a wide range of UAS platforms and UTM clients

- Accelerate UAS stakeholder development of UTM components

- Test objects pertinent to the NASA-FAA Research Transition Team (RTT) Data Exchange and Information Architecture Working Group
TCL 2 Flight Operations Objectives

- Demonstrate a BVLOS package delivery
- Test UAS Service Supplier and human operator reactions to Air Navigation Service Provider (ANSP) constraints and directives
- Conduct UTM Operations to test/determine information requirements between the components of the UTM system

<table>
<thead>
<tr>
<th>Test Site</th>
<th>Altitude Stratified Operations</th>
<th>Beyond/Extended Visual Line of Sight</th>
<th>Altitude Stratified BVLOS</th>
<th>Dynamic (enroute) Replanning</th>
<th>Response to Alerts From UTM System</th>
<th>Contingency Implementation</th>
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<tbody>
<tr>
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<td>X</td>
<td>X</td>
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</tr>
<tr>
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<td>X</td>
<td>X</td>
<td>X</td>
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<td>Test Site</td>
<td>Vehicle Type</td>
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<td>USS</td>
<td></td>
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<td>--------------------------------------------------------------------------</td>
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<tr>
<td>Alaska</td>
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<td>Simulyze</td>
<td></td>
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<tr>
<td></td>
<td>3 quadcopter</td>
<td></td>
<td></td>
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<tr>
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<td>2 octocopter</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Nevada</td>
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<td>Amazon,</td>
<td>AirMap, Amazon</td>
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<tr>
<td></td>
<td>2 quadcopters</td>
<td>Carbon Autonomous, Drone America</td>
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<tr>
<td></td>
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<tr>
<td></td>
<td>1 octocopter</td>
<td></td>
<td></td>
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<td>NASA</td>
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<td></td>
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<tr>
<td></td>
<td>1 octocopter</td>
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<td></td>
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<tr>
<td></td>
<td>1 fixed wing hybrid</td>
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<td>1 hybrid delta-wing</td>
<td>Botlink, Isight RPV Services, SkySkopes, University of North Dakota, Unmanned Applications Institute International (UAI)</td>
<td>Simulyze</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>4 fixed wing</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>2 hexacopter</td>
<td></td>
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<tr>
<td></td>
<td>1 simulated</td>
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<tr>
<td>Texas</td>
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<td>Lone Star UAS Center (LSUASC)</td>
<td>NASA</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>2 fixed wing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Virginia</td>
<td>1 fixed wing</td>
<td>Google (Project Wing), Intel, Virginia Tech</td>
<td>Google (Project Wing); ANRA</td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 quadcopter</td>
<td></td>
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</tr>
</tbody>
</table>

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TCL 2 Flight Scenarios

- Vehicles flew profiles that simulated real-world use cases
- Crafted to test different capabilities in the system, such as responses to alerts, lost link procedures, etc.
- Some scenarios included simultaneous interacting missions
TCL 2 National Campaign Summary

- Partners produced flight operation submissions to six unique UTM USS implementations over a total of nine geographically diverse test ranges.

- A portion of the flights were observed by ground and airborne surveillance systems that each provided these observations to USSs.

- TCL 2 National Campaign (NC) provided initial validation of the potential flexibility and scalability of the UTM concept and architecture.

- NC was very successful - NASA and partners made progress on the development and refinement of their software, hardware, and processes for operating UAS in accordance with the UTM ConOps.

- Measures of Performance (MOPs) were introduced as examples of potential metrics to routinely monitor in future operations UTM systems.
Risk-based development and test approach along four distinct TCLs

TCL 1
- Remote Population
- Low Traffic Density
- Rural Applications
- Multiple VLOS Operations
- Notification-based Operations

TCL 2
- Sparse Population
- Low-Mod Traffic Density
- Rural / Industrial Applications
- Multiple BVLOS Operations
- Tracking and Operational Procedures

TCL 3
- Moderate Population
- Moderate Traffic Density
- Suburban Applications
- Mixed Operations
- Vehicle to Vehicle Communication
- Public Safety Operations
TCL 3 Flight Demonstration Highlights

- **6 FAA UAS Test Sites**
- **7 Ranges**
- **Flight Window**
  - March 6 – May 30, 2018
- **Test Types**
  - 3 CNS
  - 6 SAA
  - 6 DAT
  - 5 CON
- **Participating Entities**
  - 30
- **UAS Vehicles**
  - 31
- **11 Unique Use Cases**
• Demonstrate, evaluate, and refine the functional designs, technology prototypes, and UTM ConOps for a wide range of vehicles in more complex environments
• UAS stakeholder development of UTM components
• Test objectives relevant to the NASA-FAA RTT Working Groups
  • Concept Use Cases (CON) - Explore operations to refine the UTM concept for a given technical capability level and its envisioned environment
  • Communication, Navigation, & Surveillance (CNS) - Evaluate solutions to ensure vehicles are under operational control and remain within a defined area
  • Sense & Avoid (SAA) - Evaluate effectiveness of different separation mitigation strategies
  • Data Exchange (DAT) - Identify gaps in the data model and evaluate procedures for off-nominal conditions
• All sites connected to the UTM system and testing was coordinated from the Airspace Operations Lab (AOL) at Ames Research Center
<table>
<thead>
<tr>
<th>Test Site</th>
<th>Number of Operators</th>
<th>Number of USS</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alaska</td>
<td>1</td>
<td>1</td>
<td>0</td>
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<tr>
<td></td>
<td>ACUASI</td>
<td>Simulyze</td>
<td></td>
</tr>
<tr>
<td>Nevada</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Amazon, DroneAmerica, ILOT, GE AirXos</td>
<td>Amazon, ANRA, AirMap, GE AirXos</td>
<td>CACI, Citadel, Switch, GC21T</td>
</tr>
<tr>
<td>New York</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Griffiss Airport</td>
<td>NASA</td>
<td>AXEnterprize, NUAIR</td>
</tr>
<tr>
<td>North Dakota</td>
<td>3</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Isight RPV, SkySkopes, Rockwell Collins/Iowa State University</td>
<td>Simulyze, Rockwell Collins</td>
<td>Altavian, Regulus, uAvionix</td>
</tr>
<tr>
<td>Texas</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Modern Technologies Solutions, Inc. (MTSI)</td>
<td>GE AirXos, Lone Star</td>
<td>AirRobot, Echodyne, Univ. North Texas</td>
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<tr>
<td>Virginia</td>
<td>4</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Google, Intel, Sense Fly, Virginia Tech Transportation Institute</td>
<td>Google, ANRA, AirMap</td>
<td>ASEC</td>
</tr>
</tbody>
</table>
# Examples of Test Questions for TCL 3

<table>
<thead>
<tr>
<th>Test</th>
<th>Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>DAT: USS failure</td>
<td>How should the USS safely manage the planned/inflight operations?</td>
</tr>
<tr>
<td>DAT: Negotiation</td>
<td>How do the USS like to negotiate? What adjustments need to be existing data model?</td>
</tr>
<tr>
<td>CON: Public view of data</td>
<td>What information can the public see?</td>
</tr>
<tr>
<td>CON: Breach of controlled airspace</td>
<td>Who should be notified of approach and/or breach of unauthorized airspace?</td>
</tr>
<tr>
<td>CNS: Radio Frequency (RF) interference that the UA measurement</td>
<td>How will the operator characterize RF environment operates in and evaluate its impact on UA’s Command and Control (C2) link?</td>
</tr>
<tr>
<td>CNS: C2 loss</td>
<td>What is the method to detect C2 loss and the subsequent process to switch between redundant C2 Link?</td>
</tr>
<tr>
<td>SAA: Air-to-air conflict mitigation</td>
<td>What is expected response times of the resolution? How effective was the conflict resolution?</td>
</tr>
<tr>
<td>SAA: System level conflict mitigation and off-nominal conditions</td>
<td>Where do the timelines between USS mitigations and onboard overlap? What procedures should be in place to ensure conditions separation in off-nominal conditions?</td>
</tr>
</tbody>
</table>
TCL 3 Flight Demonstration Summary

- Focused testing to address the joint FAA-NASA RTT’s target research areas
  - Development and testing of systems that enable improved navigation, long-range communications, and sense and avoid capabilities
  - Testing of existing technologies to determine potential improvements
  - Development and testing of tools that provide increased situational awareness of the flight environment and air traffic
- Accelerated partner development of their USSs (8 including NASA prototype) to NASA specifications
- Developed UAS Identification capability and demonstrated its ability to identify whether a UAS is part of the UTM system
- TCL 3 Demonstration
  - Assisted in identifying gaps in the data model and interface between components of the UTM System
  - Assisted in refining the UTM concept for specific technical capability levels and envisioned operational environment
  - Assisted in development of performance requirements and guidelines for SAA and CNS technologies and procedures
Risk-based development and test approach along four distinct TCLs
TCL 4 Flight Demonstration Highlights

- 2 FAA UAS Test Sites
- 6 Ranges
- Flight Window:
  - Nevada: May-June
  - Corpus Christi: July-August, 2019
- Participating Entities: 35
- UAS Vehicles: 9 Unique
- Scenario Breakdown:
  - Required Missions
  - Defining Characteristics
  - Triggering Events

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TCL 4 Flight Demonstration Objectives

- Test UTM in true urban environment
- Industry to provide all USS
- Test several UAS on-board technologies for separation, collision avoidance, communication, identification, navigation, and safe landing
- Investigate system response to real world events
  - UAS to UAS encounters
  - UAS to manned aircraft encounters
  - Static and dynamic obstacle avoidance
  - Loss of comm links and navigation source
  - Weather events
  - Dynamic airspace constraints
  - Emergency priority operations
TCL 4 Required Test Scenarios

- Five scenarios designed to represent a “day in the life of UAS operations” in a geographic region

- Each scenario had multiple required missions (e.g., package delivery), defining characteristics (e.g., high density), and a set of triggering events (e.g., collision avoidance encounter) that exercised different technologies and procedures
  - Scenario 1: *Normal High-Density Operations Interrupted by a Weather Event*
  - Scenario 2: *Pop-up Concert in a Park, Emergency Operations, Temporary Airspace Restriction*
  - Scenario 3: *UAS Near Airport, Mixed Operation with Manned Aircraft, Rogue UAS*
  - Scenario 4: *Flight Over People, Safe Landing, UAS Obstacle Collision and Response*
  - Scenario 5: *High Density Operations, USS Negotiation, USS Failure*
TCL 4 Characteristics and Triggering Events

• Sample Scenario Characteristics (39 total)
  • High density, high tempo
  • Operations near structures
  • Remote launch/land
  • Rooftop to rooftop operations
  • Remote Identification, broadcast
  • Remote Identification, network
  • USS negotiations
  • In-flight emergency operations
  • Public safety operations
  • UAS in controlled airspace

• Sample Triggering Events (16 total)
  • Volume reservation (UVR)
  • UAS conflict with UAS
  • UAS conflict with obstacle
  • UAS conflict with manned aircraft
  • Safe landing
  • Large Scale loss link, Global Positioning System
  • UAS accident and response
  • USS negotiations
  • Loss of UAS
### Key TCL 4 Partners

<table>
<thead>
<tr>
<th>USS</th>
<th>UAS Operators</th>
<th>Onboard Technologies</th>
<th>Ground Systems</th>
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<tbody>
<tr>
<td></td>
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<td>PROVIDER</td>
<td>PURPOSE</td>
</tr>
<tr>
<td>AirXos (GE Venture)</td>
<td>AviSight</td>
<td>Detect &amp; Avoid</td>
<td>Echodyne Radar</td>
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<tr>
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<td>Drone America</td>
<td>RTK</td>
<td>Navigation Truth Source</td>
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<td>ANRA</td>
<td>Switch</td>
<td>Relma Tech</td>
<td>Remote Identification</td>
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<td>Utah State University</td>
<td>Near Earth Autonomy</td>
<td>Safe Landing Site</td>
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<td>Lone Star</td>
<td>Near Earth Autonomy/LIDAR</td>
<td>Parachute</td>
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<td>One Sky (AGi)</td>
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<td>Fruity Chutes</td>
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TCL 4 Downtown Reno Flight Range
UTM Generated Flight Volumes for Each UAS
Four UAS Flying in Downtown Reno, NV
June 18, 2019
TCL 4 Downtown Corpus Christi Flight Range
UTM Generated Flight Volumes for Each UAS
2 of 3 UAS Over Urban Canyon, Downtown Corpus Christi August 16, 2019
TCL 4 Measures of Performance

01: Strategic Deconflict Rate
02: Flight Containment
03: V2V Reception
04: Operator Alerting
05: Safe Landing Rate
06: Nav Loss During Conflict
07: Dynamic Restriction Replan
08: Duration of Conflict
09: C2 Loss During Conflict
10: Loss of Well Clear
11: USS Endpoint Security
12: Remote ID Lookup
13: USS Latency
14: Contingency Plan Response
15: Pilot Assessment
16: High Density Ops
17: BVLOS Ops
18: Dynamic Priority Op Replan
19: Rate of C2 Loss
20: Public Safety Deconflict

MOPs are organized by RTT Work Groups
A network of up to seven USS’s provided by industry successfully coordinated UAS operations under nominal and contingency operations.

UTM safely managed large numbers of UAS in crowded airspace – up to 5 live and 15 simulated flights simultaneously in area <1 sq. mile.

Cloud-based UTM provided a secure and efficient platform for all users.

Remote identification of UAS using UTM network found feasible.

Integration of multiple onboard technologies to address hazards of dense urban operations is challenging.

Extensive coordination and resources are required for local municipalities to be comfortable with flights in their urban environments.
Ongoing Challenges from TCL 4

- Performance, reliability, and integration of on-board capabilities of small UAS are challenges in future complex operations such as BVLOS operations over a populated area.

- Environmental factors (e.g., electromagnetic interference, micro-climates) remain a concern for the safety of operations.

- Large variation in platform maturity across UAS manufacturers.

- Ongoing input from local municipalities is needed to support safety and security.
Publications of Research Findings

  - Exposed the six FAA UAS designated Test Sites to the UTM concept in a hands-on manner and opened the possibility for future tests organized in a similar manner as the UTM concept matured.

  - Provided initial validation of different aspects of the UTM concept including: UAS Service Supplier technologies and procedures; geofencing technologies/conformance monitoring; and ground-based and airborne surveillance/sense & avoid.

  - Focused on four research areas and eleven use cases. It demonstrated the UTM technologies and procedures of safe small UAS operations given the assumptions and conditions of TCL 3.

  - Indicated the viability of the UTM concept to manage large scale operations and contingencies in an urban environment. The FAA and other regulators will be able to leverage results to inform future rule-making and identify additional gaps that require further analysis.