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

UTM Technical Capability Level (TCL) Overview

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Outline

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  - Measures of Performance (MOPs)
  - Summary and Ongoing Challenges

Technical Capability Level (TCL)

Risk-based development and test approach along four distinct TCLs

TCL 1	TCL 2	TCL 3	TCL 4
Remote Population	Sparse Population	Moderate Population	Dense Population
Low Traffic Density	Low-Mod Traffic Density	Moderate Traffic Density	High Traffic Density
Rural Applications	Rural / Industrial Applications	Suburban Applications	Urban Applications
Multiple VLOS Operations	Multiple BVLOS Operations	Mixed Operations	Dense BVLOS Operations
Notification-based Operations	Tracking and Operational Procedures	Vehicle to Vehicle Communication	Large Scale Contingency Management
		Public Safety Operations	

Technical Capability Level (TCL 1)

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

7 Ranges

April 19, 2016

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	TCL 2
Remote Population	Sparse Population
Low Traffic Density	Low-Mod Traffic Density
Rural Applications	Rural / Industrial Applications
Multiple VLOS Operations	Multiple BVLOS Operations
Notification-based 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

Test Range

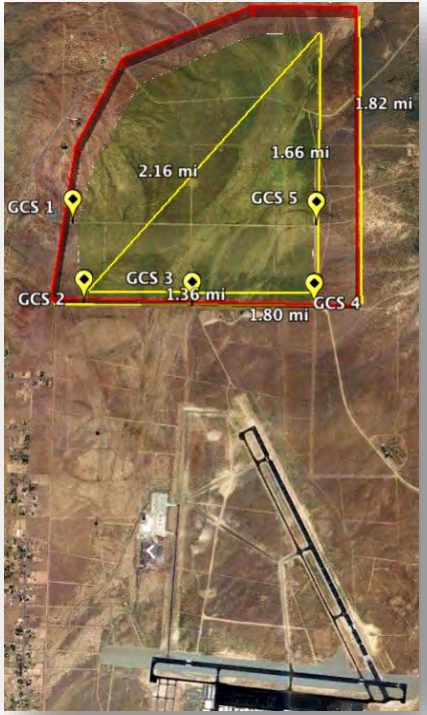


Image courtesy of Google Earth

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 Flight Operation Objectives

6 FAA UAS Test Sites

9 Ranges

May 15-June 9, 2017

Participating Entities

20

UAS Vehicles

32

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

Test Site	Altitude Stratified Operations	Beyond/ Extended Visual Line of Sight	Altitude Stratified BVLOS	Dynamic (enroute) Replanning	Response to Alerts From UTM System	Contingency Implementation
Alaska	X	X	X		X	X
Nevada	X	X	X	X	X	X
New York	X	X	X	X	X	X
North Dakota	X	X	X		X	X
Texas	X	X	X	X	X	X
Virginia	X	X	X	X	X	X

TCL 2 Vehicles, Operators and USS

Test Site	Vehicle Type	Operator	USS
Alaska	1 single rotor helicopter 3 quadcopter 2 octocopter	Alaska Center for UAS Integration (ACUASI)	Simulyze
Nevada	4 fixed wing 2 quadcopters 1 hexacopter 1 octocopter	Amazon, Carbon Autonomous, Drone America	AirMap, Amazon
New York	1 quadcopter 1 hexacopter 1 octocopter 1 fixed wing hybrid	Northeast UAS Airspace Integration Research Alliance (NUAIR)	NASA
North Dakota	1 hybrid delta-wing 4 fixed wing 2 hexacopter 1 simulated	Botlink, Isight RPV Services, SkySkopes, University of North Dakota, Unmanned Applications Institute International (UAI)	Simulyze
Texas	2 quadcopter 2 fixed wing	Lone Star UAS Center (LSUASC)	NASA
Virginia	1 fixed wing 2 quadcopter	Google (Project Wing), Intel, Virginia Tech	Google (Project Wing); ANRA

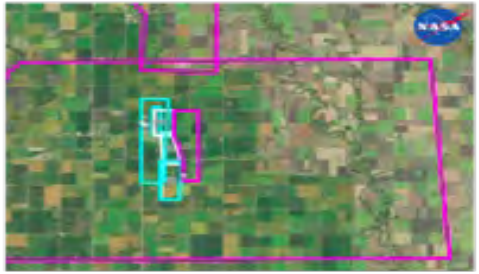
TCL 2 Flight Scenarios

- 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

4 simultaneous altitude stratified mapping missions

Multiple USS supporting operations in same geographic area

Dynamically re-plan operation for a search & rescue mission for lost hiker



4 live flights at various stages of being proposed (white), accepted (cyan), or activated (magenta)

Operation volume (cyan) priority operation for police vehicle to search for lost child. Other vehicle (magenta) needed to replan mission

2 operations supported by different USS; one conducting package delivery & the other a surveillance mission

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

Technical Capability Level (TCL 3) Flight Demonstration

Risk-based development and test approach along four distinct TCLs

TCL 3 Flight Demonstration Highlights

6 FAA UAS Test Sites

7 Ranges

Flight Window

March 6 – May 30, 2018

Participating Entities

30

UAS Vehicles

31

4

Test Types

3 CNS

6 SAA

6 DAT

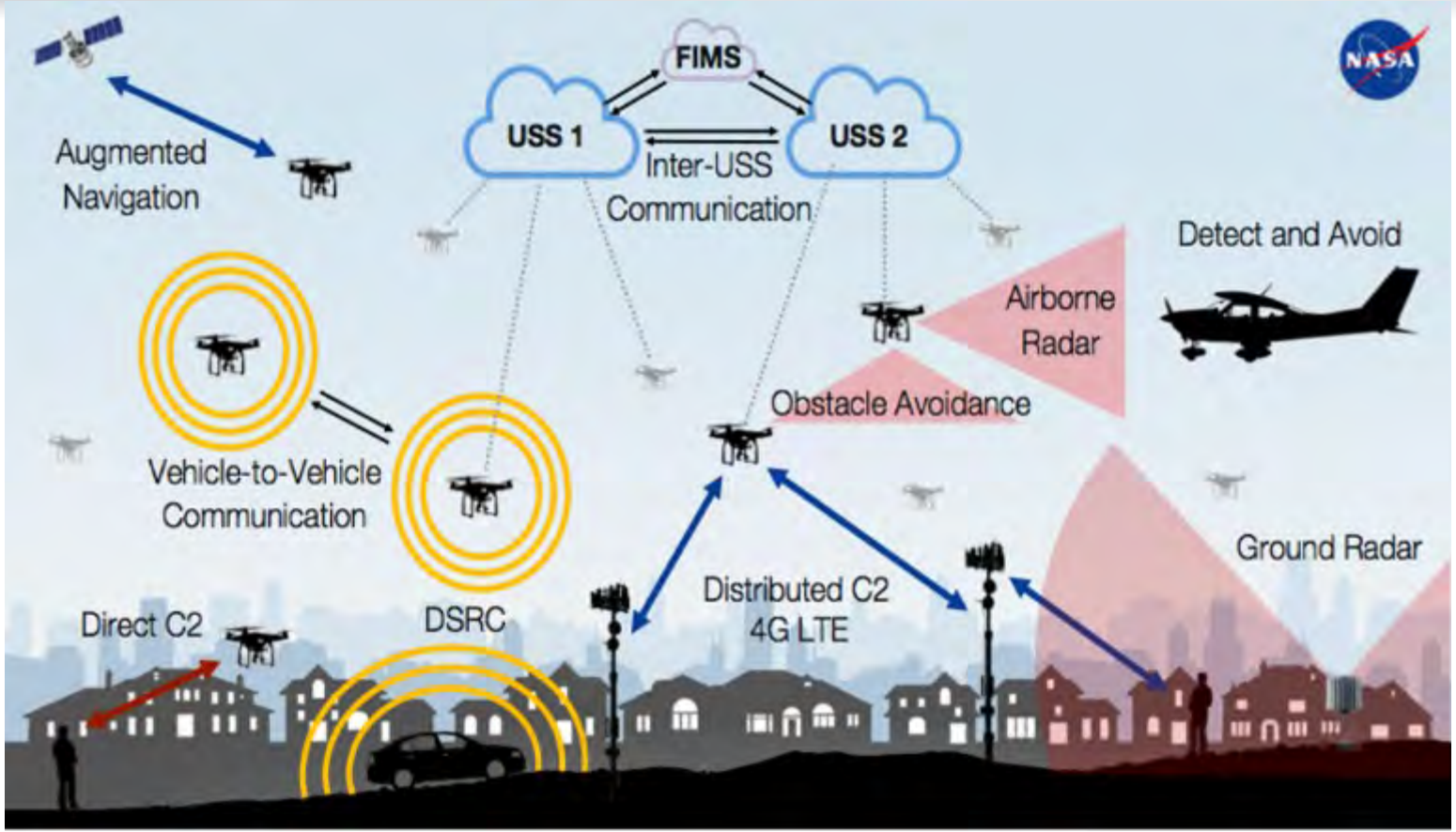
5 CON

11 Unique Use Cases

TCL 3 Flight Demonstration Objectives

- 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

TCL 3 Flight Tests



TCL 3 Operators, USS and Other Participants

Test Site	Number of Operators	Number of USS	Other
Alaska	1 ACUASI	1 Simulyze	0
Nevada	4 Amazon, Drone America, ILOT, GE AirXos	4 Amazon, ANRA, AirMap, GE AirXos	4 CACI, Citadel, Switch, GC21T
New York	1 Griffiss Airport	1 NASA	2 AXEnterprize, NUAIR
North Dakota	3 Isight RPV, SkySkopes, Rockwell Collins/Iowa State University	2 Simulyze, Rockwell Collins	3 Altavian, Regulus, uAvionix
Texas	1 Modern Technologies Solutions, Inc. (MTSI)	2 GE AirXos, Lone Star	3 AirRobot, Echodyne, Univ. North Texas
Virginia	4 Google, Intel, Sense Fly, Virginia Tech Transportation Institute	3 Google, ANRA, AirMap	1 ASEC

Examples of Test Questions for TCL 3

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

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

Technical Capability Level (TCL 4)

Risk-based development and test approach along four distinct TCLs

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		Public Safety Operations	

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

5

Scenarios

Required Missions

Defining Characteristics

Triggering Events

UAS

8 Unique Vehicles

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

USS	UAS Operators	Onboard Technologies		Ground Systems	
		Provider	Purpose	Provider	
Uber Elevate	Uber Elevate	FLARM / ICAROUS	Detect & Avoid	Fortem	Radar
AirXos (GE Venture)	AviSight	Vehicle – Vehicle Comm. U of N. TX	Detect & Avoid	Echodyne	Radar
Air Map	Drone America	RTK	Navigation Truth Source	ACAMP	Weather Stations
ANRA	Switch	Relma Tech	Remote Identification	Applied Tech.	Weather Stations
Avision Robotics	Utah State University	Near Earth Autonomy/LIDAR	Safe Landing Site		
Collins Aerospace	Lone Star	Fruity Chutes	Parachute		
One Sky (AGi)	Near Earth Autonomy				
	Corpus Christi Fire Dept.				

TCL 4 Summary Video

TCL 4 Reno Test Area

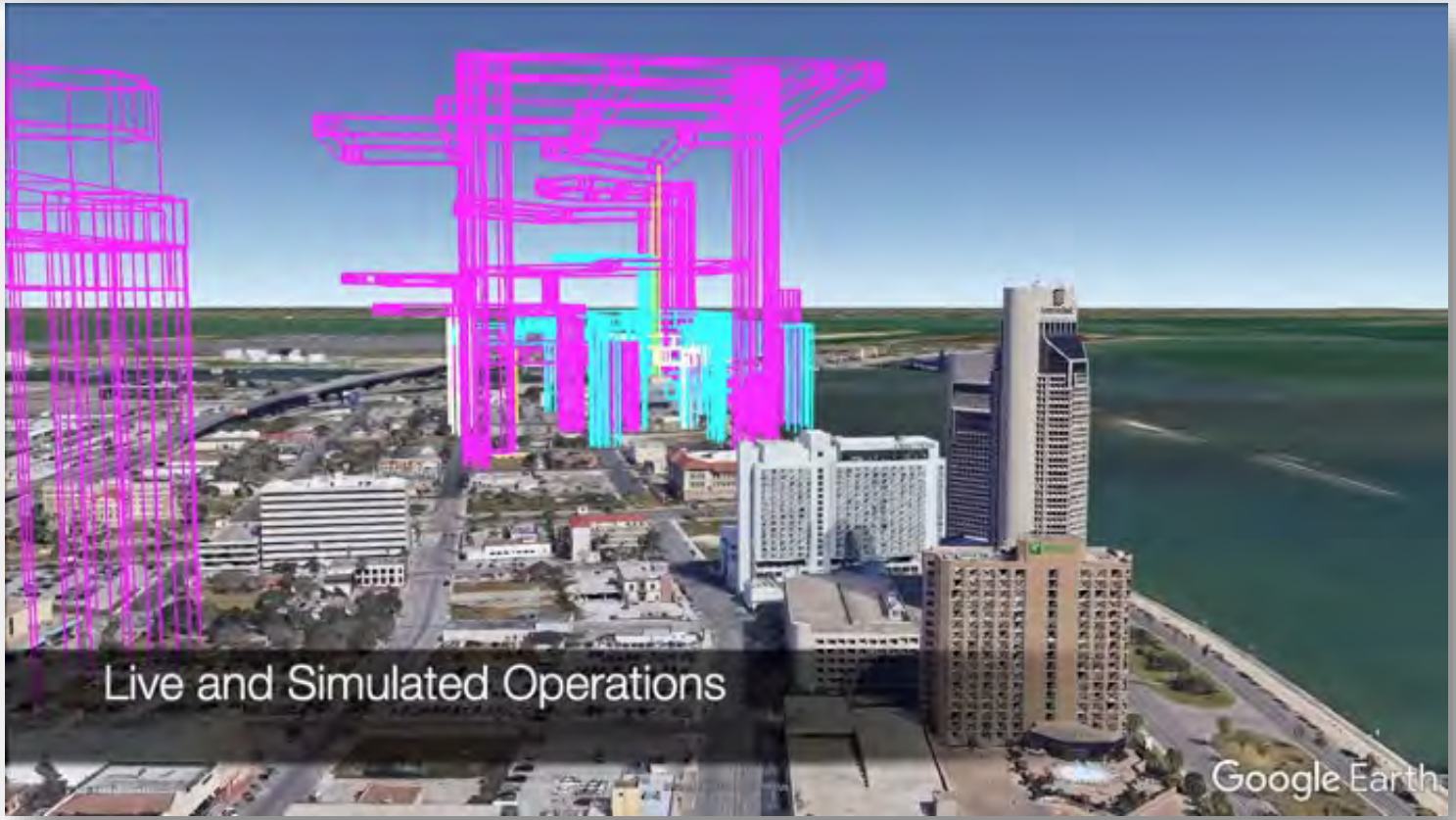
TCL 4 Downtown Reno Flight Range
UTM Generated Flight Volumes for Each UAS

TCL 4 Downtown Reno

Four UAS Flying in Downtown Reno, NV June 18, 2019

TCL 4 Corpus Christi Test Areas

TCL 4 Downtown Corpus Christi Flight Range UTM Generated Flight Volumes for Each UAS



TCL 4 Downtown Corpus Christi

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

CONCEPT

DATA+ ARCH

SAA

COMM+ NAV

TCL 4 Flight Demonstration Summary

- 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

- **TCL 1 National Campaign**: Rios, J., Mulfinger, D., Homola, J., and Venkatesan, P., "NASA UAS Traffic Management National Campaign," 35th Digital Avionics Systems Conference (DASC), Sacramento, CA, 25-29 Sep. 2016.
  - 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.

- **TCL 2 National Campaign:** Aweiss, A., Owens, B., Rios, J., Homola, J., and Mohlenbrink, C., "Unmanned Aircraft Systems (UAS) Traffic Management (UTM) National Campaign II," AIAA-2018-1727, 2018 AIAA Science and Technology Forum (SciTech), Kissimmee, FL, 8-12 Jan. 2018.
  - 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.

- **TCL 3 Flight Demonstration:** Aweiss, A., Homola, J., Rios, J., Jung, J., Johnson, M., Mercer, J., Modi, H., Torres, E., and Ishihara, A., "Flight Demonstration of Unmanned Aircraft System (UAS) Traffic Management (UTM) at Technical Capability Level 3," 38th Digital Avionics Systems Conference (DASC), San Diego, CA, 8-12 Sep. 2019.
  - 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.

- **TCL 4 Flight Demonstration:** Rios, J., Aweiss, A., Jung, J., Homola, J., Johnson, M., and Johnson, R., "Flight Demonstration of Unmanned Aircraft System (UAS) Traffic Management (UTM) at Technical Capability Level 4," 2020 AIAA Aviation Forum, Virtual Event, 15-19 June 2020.
  - 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.