Unmanned Aircraft Systems (UAS) Traffic Management (UTM) National Campaign II

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Presentation Overview

- Background
- UTM architecture
- Motivation
- Method
- Results
- Summary
- Next Steps

Background (Why UTM?)

- Millions of small Unmanned Aircraft Systems (sUAS) are predicted to fly in U.S. airspace within the next decade
  - Conduct a variety of public safety, commercial, & hobbyist operations
  - No established infrastructure exists to safely manage these

- NASA is collaborating with the FAA & UAS industry stakeholders to
  - Develop a research platform for a UAS Traffic Management (UTM) system
  - Determine how an operational UTM system can enable access for sUAS into low-altitude airspace in a safe, efficient, & fair manner

Background (UTM Services)

- UTM will provide for basic services such as flight planning, flight monitoring, hazardous weather & wind avoidance, UAS identification, & separation assurance as well as other potential services

- Most of these services will be provided by a number of commercial UAS Service Suppliers (USS) rather than by a single system

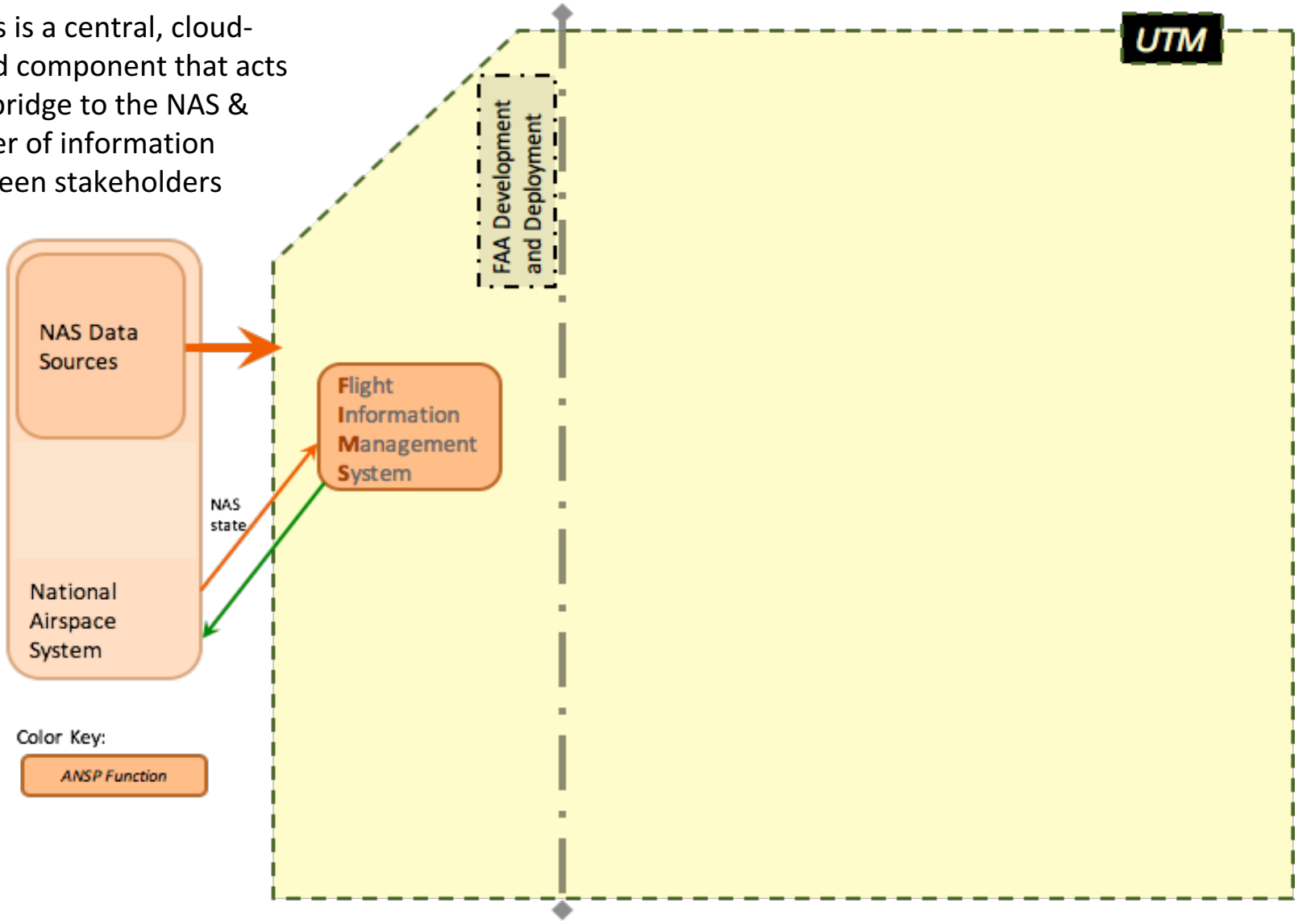
Background- Technical Capability Level (TCL)

- Support the entire range of sUAS (<=55 lbs)
- Account for risks associated with operations

- TCL 1: *multiple* Visual Line of Sight (VLOS)
- TCL 2: *multiple* Beyond Visual Line of Sight (BVLOS), *rural*
- TCL 3: *multiple* BVLOS, *some manned aircraft, suburban*
- TCL 4: *complex urban* BVLOS

UTM Architecture

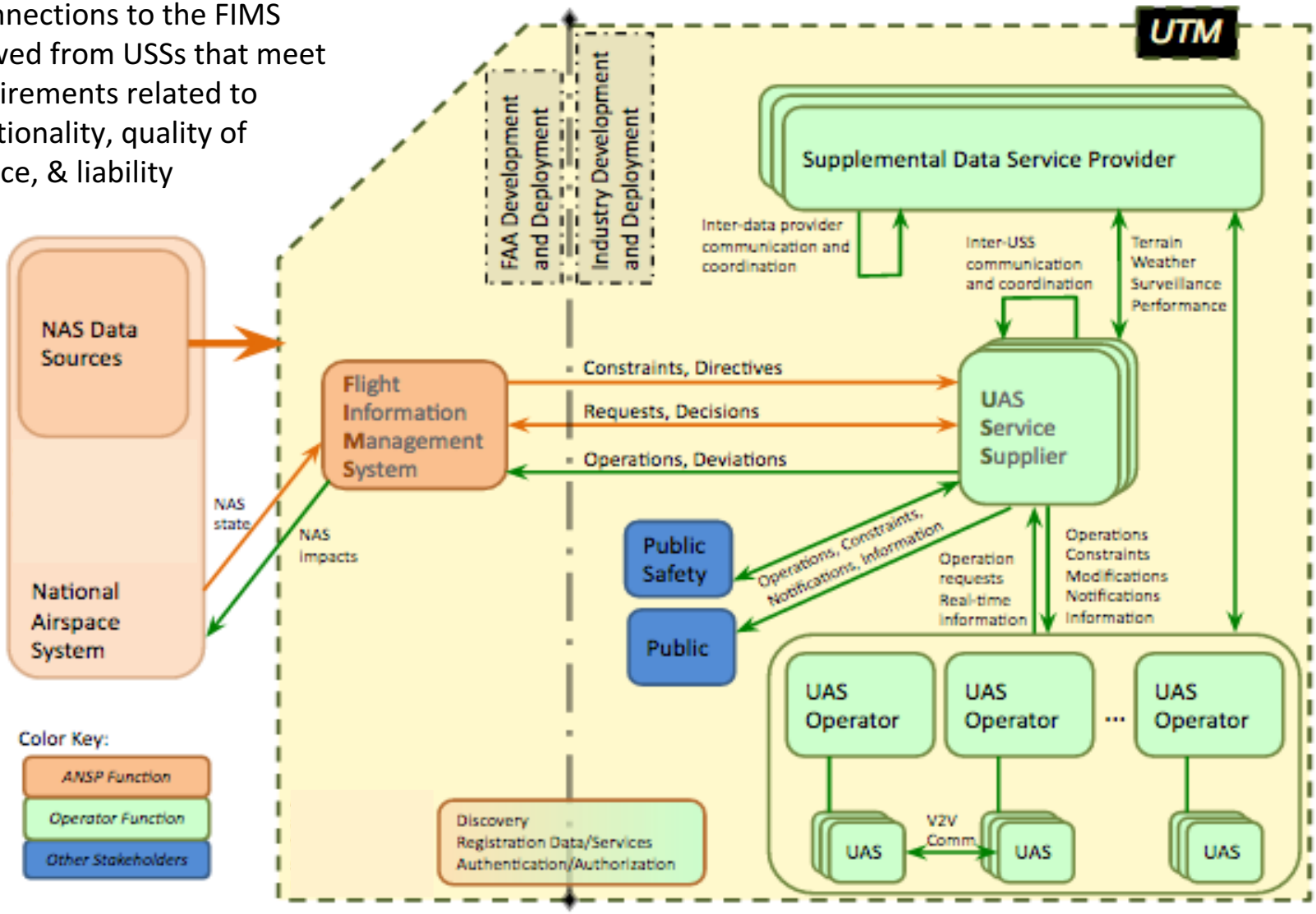
*FIMs is a central, cloud-based component that acts as a bridge to the NAS & broker of information between stakeholders



*FIMs provides truth data about constraints in the airspace, messages related to UTM operations, & other relevant data

UTM Architecture

*Connections to the FIMS allowed from USSs that meet requirements related to functionality, quality of service, & liability



*Connections & communications are internet-based & built on industry standards & protocols

Technical Capability Level (TCL 2) National Campaign

- Flight testing from May 15th through June 9th, 2017 at six FAA UAS Test Sites
- Demonstrate, evaluate, & refine the functional designs, technology prototypes, & UTM ConOps
  - Test TCL 2 scenarios
    - across a wide range of operating environments
    - utilizing the FIMS-USS architecture for UTM
    - with a wide range of UAS platforms & UTM Clients
  - Accelerate UAS stakeholder development of UTM components

Flight Operation Objectives

- Conduct UTM Operations to test/determine information requirements between the components of the UTM system
- Conduct UTM Operations with an industry-developed TCL 2-compatible USS
- Test & evaluate scheduling & planning capabilities

Research Areas of Interest

- Related to technologies that enable TCL 2 UTM capabilities
- Test & evaluate geofencing & conformance monitoring capabilities
- Evaluate human factors requirements related to data creation & display

Test Site	USS Technology	Geofence Technology	Ground-based Sense & Avoid (SAA)	Airborne Sense & Avoid (SAA)	Communication Navigation Surveillance (CNS)	Human Factors
Alaska		X			X	
Nevada	X	X	X	X	X	X
New York	X	X			X	
North Dakota	X	X	X		X	X
Texas				X		
Virginia	X			X		

Flight Operation Features

- ✈ Demonstrate a Beyond Visual Line of Sight (BVLOS) package delivery
- ✈ Test USS & human operator reactions to ANSP constraints & directives

Test Site	Altitude Stratified Operations	Beyond/ Extended Visual Line of Sight (BVLOS)	Altitude Stratified BVLOS	Dynamic (en-route) 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

Vehicles, Operators, and USS

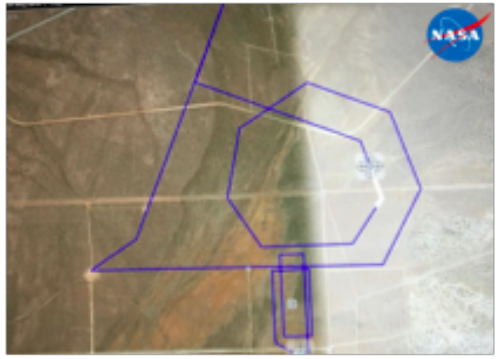
Test Site	Vehicle Type	Operator	USS
Alaska	1 single rotor helicopter 3 quadcopter 2 octocopter	Alaska Center for UAS Integration (ACUASI)	Simulyze
Nevada	4 fixed wing 2 quadcopters 1 hexacopter 1 octocopter	Amazon Carbon Autonomous Drone America	AirMap Amazon
New York	1 quadcopter 1 hexacopter 1 octocopter 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

Flight Scenarios

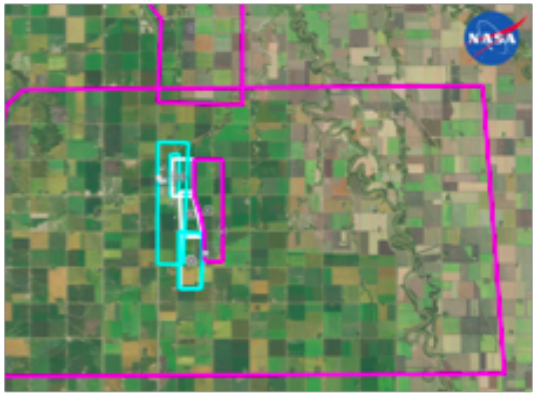
- Vehicles flew profiles that simulated real-world use cases
- Crafted to test different capabilities in the system, such as responses to alerts, lost link procedures, etc.
- Some scenarios included simultaneous interacting missions

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

Data Collection

- Data flows between UAS operators & a USS are a key element of the overall UTM ConOps
- 1,488 flight operation submissions to six USSs across six test sites
- During operations
  - UAS operators using the NASA USS submitted digital flight data directly via the NASA USS prototype & those using a non-NASA USS submitted to a NASA database
  - Data was gathered from the Ground Control Stations by the test sites, formatted, & sent to NASA
  - Human factors researchers at the test sites observed operations, recorded actions, administered questionnaires, & conducted debrief discussions
  - Human factors team situated at NASA Ames observed operations, recorded data, & supported the deployed team
  - UAS operators self-reported off-nominal situations

Results

- Data collection & analysis focused on producing measures of performance (MOP) that could ultimately characterize the overall UTM system behavior as implemented in the overall test environment

- For TCL 2 National Campaign, these MOPs
  - are an initial benchmark, not a full indication of UTM characteristics; more data needed to draw generalizable conclusions
  - were introduced as potential metrics that can be monitored in future operational UTM system
  - provide examples of potential MOPs that could be useful for investigations of UTM trends, USS & UAS design, policy decisions, & market research

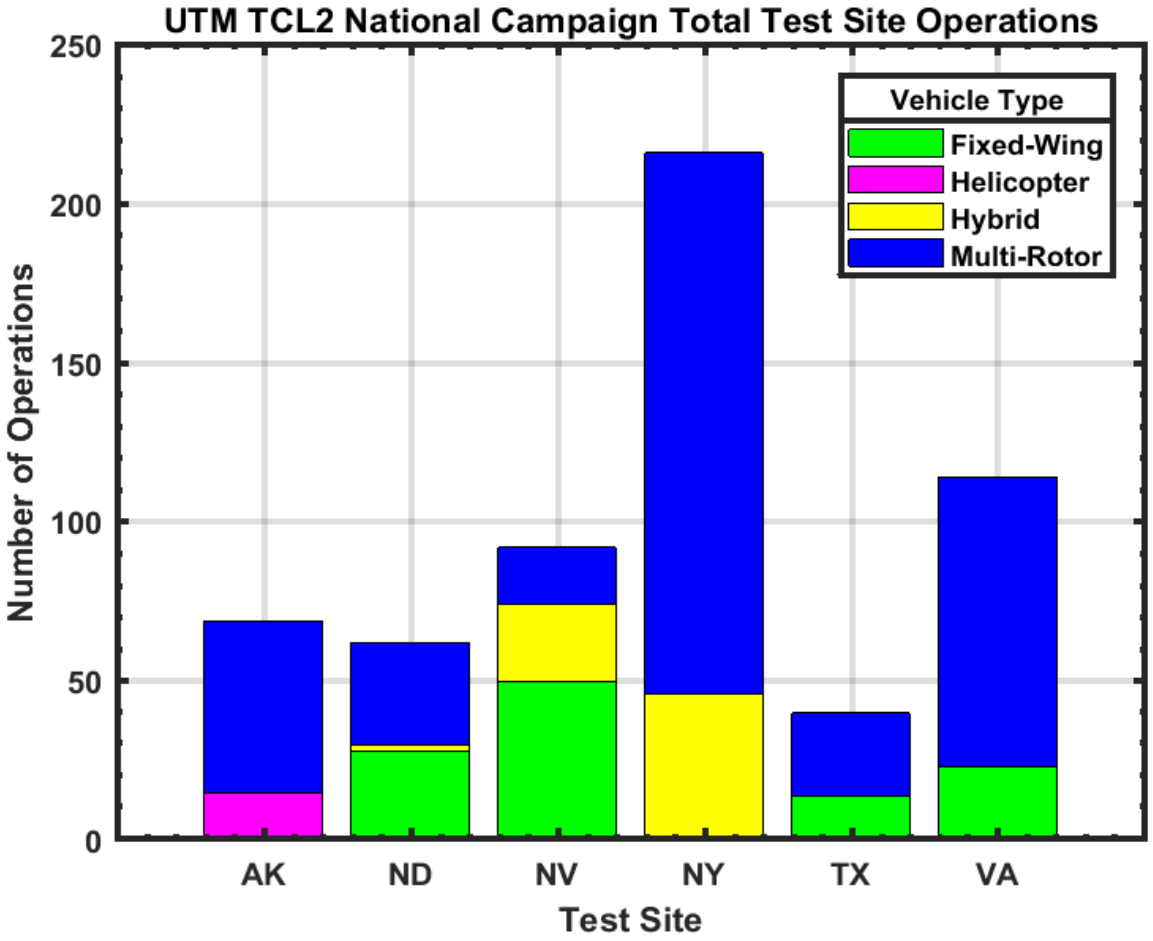
Results

MOPs will provide a basis for comparison with future tests, including

- number of submitted, accepted, & rejected operation plans
- number of nonconformance & rogue operations
- time & distance flown with UTM System
- time spent in active, nonconforming, & rogue states

Number of Submitted and Accepted Operation Plans

- number of submitted plans -> provides a partial indication of the scale of testing in terms of number of operations planned & executed

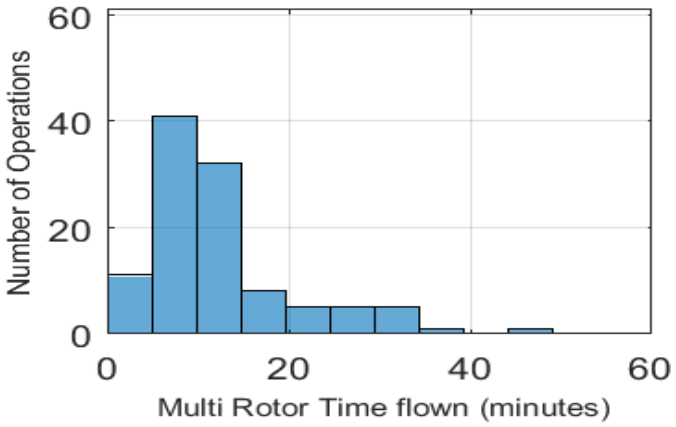


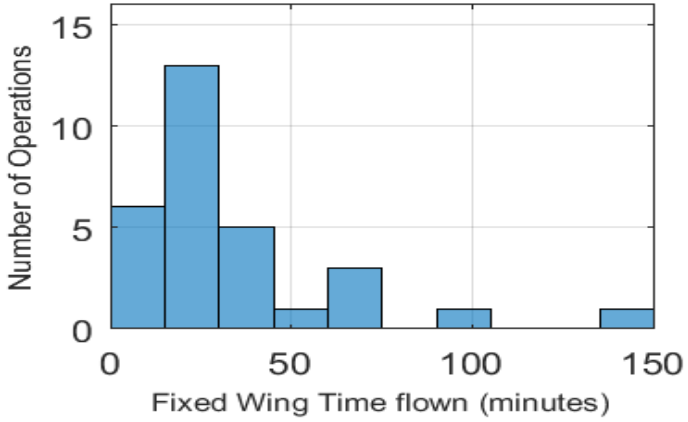
- Diversity of operations & vehicle types used for missions
- Numbers don't express loading of system, but are based on the number of vehicles & of the repetitions scenario was flown

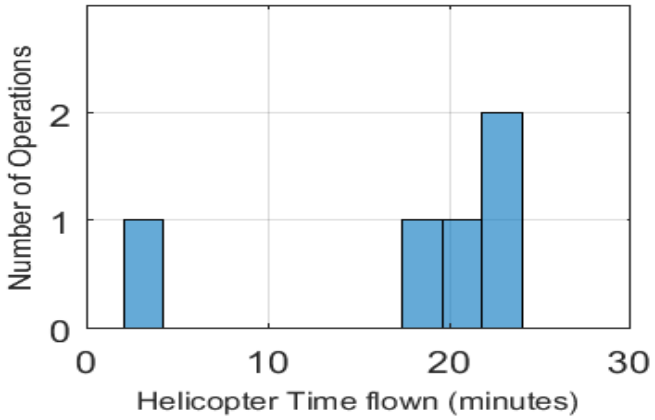
- number of accepted plans -> provides a partial indication of the effectiveness of operation planning: Over 90% were accepted

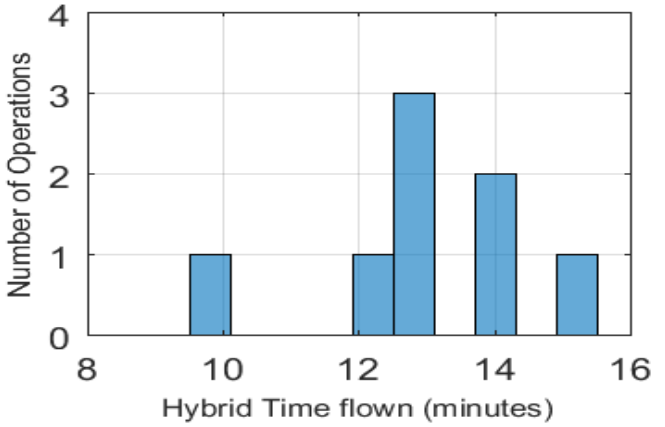
Time and Distance Flown in UTM System

- Provide a partial indication of the overall scale of testing conducted & the UAS operator preferred mission time & distance for each vehicle type
- Could be applied to operating fleets, aircraft models, operating environments, & individual operators to characterize distribution of time & distance of their preferred UTM applications



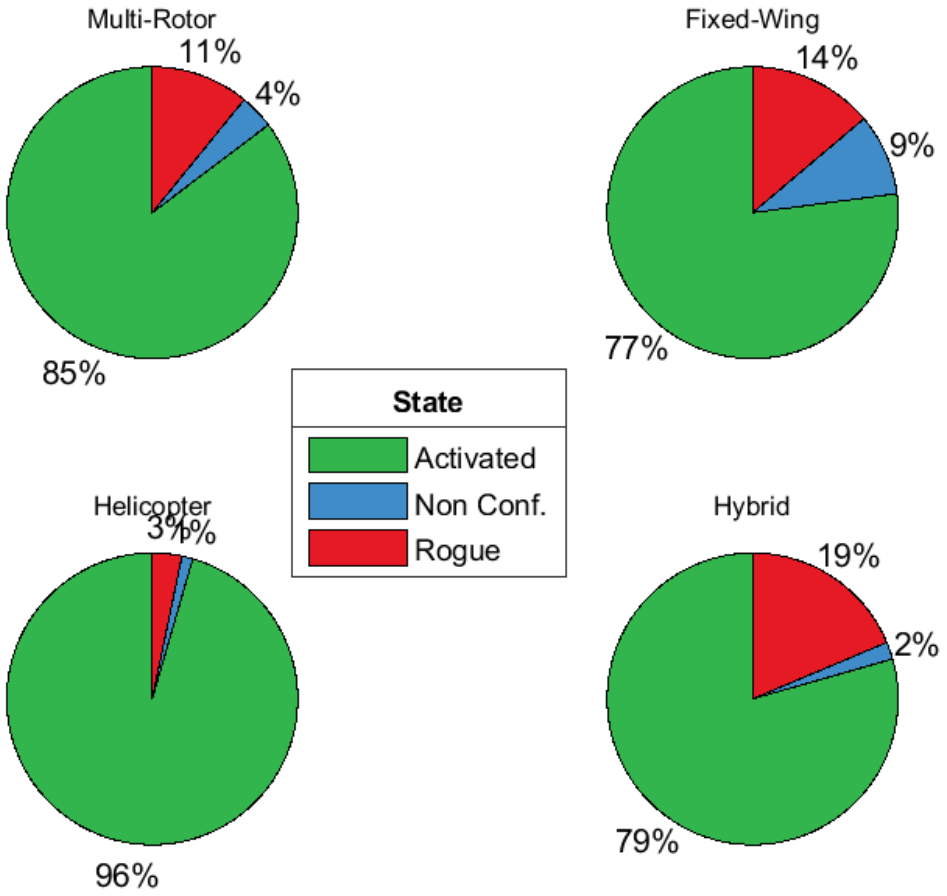






Time Spent in Activated, Nonconforming, & Rogue States

Provides partial indications of: 1) the ability of UTM users to effectively plan UTM operations & 2) the vehicle's ability to conform to those plans



Percentage of time in each state

Off-nominal reports and Human Factors Results

- Number of Off-Nominal Operational-Situation Reports
  - Can be used to track changes in the frequency of reportable off-nominal events & awareness of such events
  - 15 reports were correctly submitted to NASA from test participants

- Human Factors results
  - Information participants felt they needed about other operations did not always match the information they were willing to share about their own
  - Flight crew participants' awareness & understanding of UTM limited because they were often not involved in USS development or the test-plan/scenario design -> flight crew interaction with UTM
  - Display design & usability influenced what information operators looked at or listened to -> understanding of operational situation
  - Response time to a UTM notification depended heavily on a team's structure, communication efficiency, & procedures

Test Site & Partner Suggestions

- Allow multiple UAS to launch/operate/recover in the same airspace
- USS - to- USS communications is necessary to deconflict flight plans
- There is a need for a USS Discovery service that allows operators to discover USSs & USSs to discover each other & subscribe to each other's operations

Test Site & Partner Suggestions

- The expectation that a pilot would message during an emergency procedure is not feasible because pilot workload would be too high

- Displaying neighboring UTM operations would be very useful in planning phases

- A UTM client should allow queries & visualization of any associated operation volumes, constraints, or other UTM aircraft in the event of alerts or negative UTM responses

Summary

- TCL 2 National Campaign provided initial validation of the potential flexibility & scalability of the UTM concept & architecture
- Partners produced 1,488 flight operation submissions to a total of six unique UTM USSs across six geographically diverse test sites
- NC was very successful -> NASA & partners made progress on the development & refinement of their software, hardware, & processes for operating UAS in accordance with the UTM ConOps
- Lessons learned shaping flight tests for TCL 3 & beyond & factoring into continued discussions between NASA & UAS stakeholders about technologies & concepts
- MOPs were introduced as examples of potential metrics to routinely monitor in future operations UTM systems

Next Steps

- TCL 3 National Campaign will
  - take place February through May 2018
  - be at same six test sites
  - test the TCL 3 UTM system
  - have flight tests related to SAA, CNS, data exchange, and use cases

- TCL4 expected to begin in the end of 2018

- sUAS Low Altitude Authorization and Notification Capability (LAANC) provides the initial data framework for some UTM features

Backup

BACKUP

Nonconforming and Rogue Operations

- Nonconforming Operation - an operation participating in UTM can be designated by the NASA USS as nonconforming for the any of the following reasons:
  - A UA travels outside of its conformance geography (or volume)
    - The conformance geography is the activated segment of the 4D volume that the operation plans to operate within
  - A UA sends insufficient position reports
- Rogue Operation - a permanently nonconforming operation. An operation participating in UTM will be designated by the NASA USS as rogue for any of the following reasons:
  - A UA travels outside of its protected geography (or volume)
    - The protected geography contains the conformance geography plus a buffer
  - A UA remains nonconforming for 60 seconds or longer
- A rogue operation is treated by the USS as if it has no intent or capability for returning to conformance with its operation plan
- A nonconforming operation is temporarily allowed by the USS to return to conformance with its operation plan

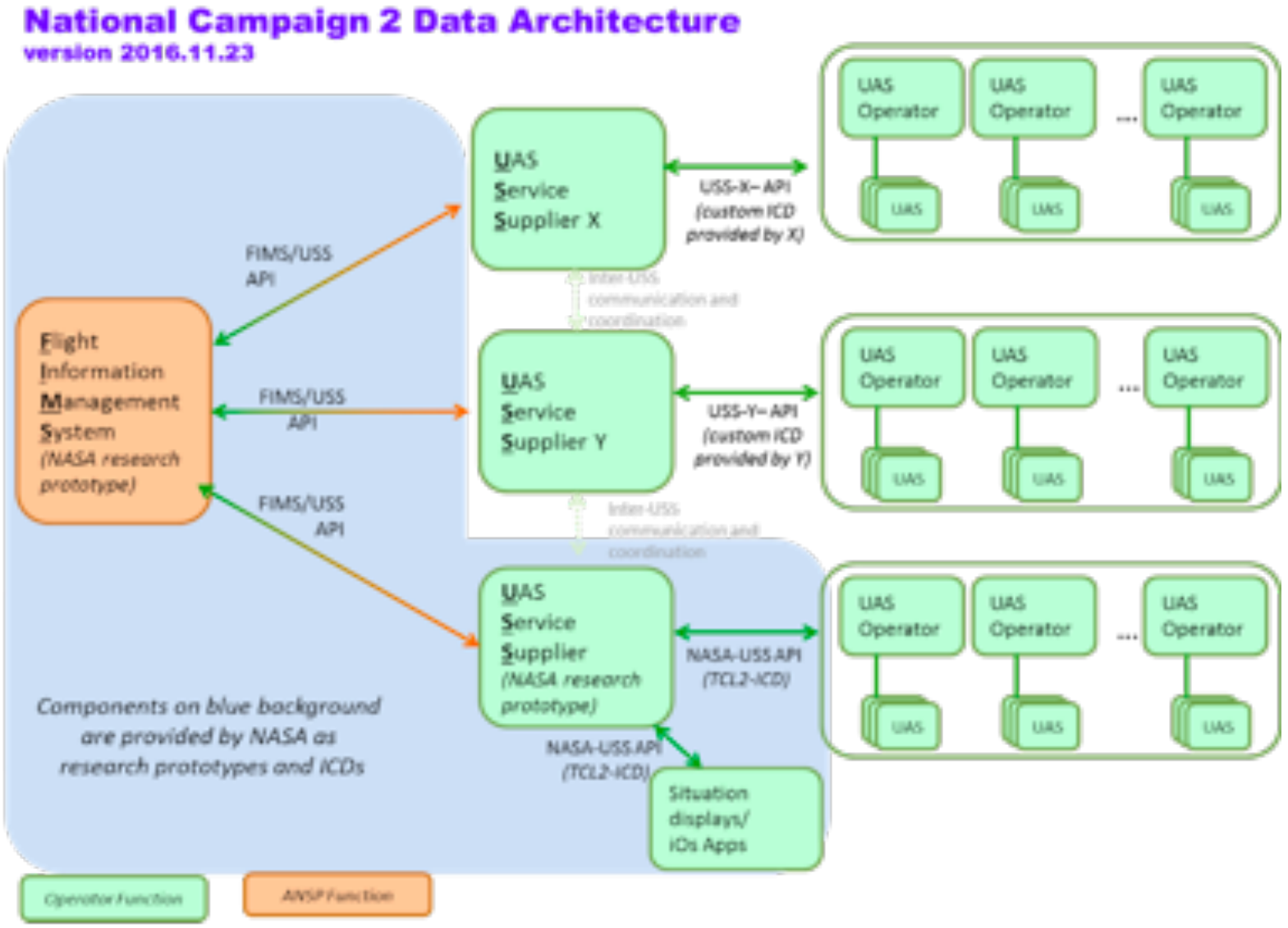
Human Factors Results Details

- **participants' limited UTM understanding:** -For many test sites, different organizations were responsible for the USS component, the scenario design, and the vehicle's conduct, and often did not coordinate with each other leading up to the event. Since most of our participants were the flight crews (who commonly had little/no knowledge of the USS or test scenarios), when we asked them about UTM (ex: how would you rate the timeliness of the notifications provided to you by your USS?), they often answered n/a, since they didn't know/understand if/how they were interacting with UTM.
- **display design/usability:** Work-in-progress-interfaces manifested in many ways, ranging from USSs that submitted flight geographies unrelated to the actual operation, to USS clients that had aural annunciations for notifications of rogue-states. Consequently, the former flight crews had a lower understanding of the UTM situation, whereas the latter flight crews had a better understanding of the UTM situation.
- **information about others vs. self:** When asked what information they would like to know about a neighboring flight, participants had a long list of items that they thought would give them good situation awareness. However, when asked in a separate question what information they would be happy to broadcast about their own vehicle, the list was much more limited and some participants discussed security concerns in sharing any information. Sharing their own contact information (in both nominal and off-nominal situations), and sharing position reports and battery health under nominal situations did not garner unanimous support, even though the participants acknowledged that such information from a neighboring aircraft would be helpful.
- **response time:** Teams either had a dedicated UTM operator co-located with the flight crew, or had a remote UTM operator who was serving multiple flight crews simultaneously. Both arrangements have advantages and disadvantages, but in terms of response time, the advantage goes to team with the in-crew UTM operator. That UTM operator is with the rest of the flight crew, so when a UTM event happens, they are able to easily describe to (or show) the flight crew what's going on and can directly take the team's input for any needed response/decision. When the UTM operator is separate from the flight crew, they have to describe the situation over the radio, then the flight crew has to describe their decision back to the UTM operator, who can then input it. This added a layer of communication in each direction that slowed down response time.

Media Coverage

- Media events were hosted at NASA Ames & the FAA designated UAS Test Sites
- Over 25 distinct accounts of the UTM TCL 2 National Campaign appeared on regional news broadcasts, business & technology news websites, Facebook, & YouTube
  - Facebook Live Event (produced by NASA PAO): https://www.facebook.com/nasaames/videos/10154368128626394/?fref=mentions
  - NASA produced YouTube video: https://www.youtube.com/watch?v=VdUKwZNM42g
- A live, streamed Q&A session was conducted between NASA ARC Airspace Operations Laboratory (AOL) & the AIAA Aviation Conference in Denver, CO

TCL 2 National Campaign Architecture



Datasets

- *The Full Dataset*

The Full Dataset includes all 1762 operation plans submitted to the USSs connected to the FIMs over the timeframe of the TCL 2 National Campaign plus six non-cooperative or intruder flights (i.e., flights intentionally flown without UTM submitted operations plans) included in the data the test sites provided to NASA per the data management plan.

- *The User-Filtered Dataset*

The User-Filtered Dataset excludes operation plans submitted from USS users that were not directly involved in flight test activities. The total number of operations plans in this data subset is 1488.

- *The Manually Processed Dataset*

The Manually Processed Dataset excludes operation plans that submitted invalid aircraft data, operations plans that did not submit position reports, & operations that submitted position reports at locations other than the test sites in addition to the operation plans excluded from the User Filtered Dataset. Operations excluded from the Manually Processed Dataset set due to a lack of position reports include operations that were rejected & aborted before activation as well as operations where an aircraft flew but failed to submit a position report due to navigation or communication issues.

Each operation from this subset was manually validated & categorized (by data quality & operation type) by examining submission inputs from the USS user, visualizations of the position data, information in the final test reports submitted to NASA by the test sites, & notes from the human factors researchers deployed to the test sites. The total number of operation plans in this data subset is 611.

Datasets

- *The Data Management Plan (DMP) Dataset*

This dataset includes operations with detailed operation data that the test sites pre-processed & submitted to NASA in the form of data files that met the DMP specification. The DMP Dataset includes 135 operations (including the six intruder flights) & was run through automated validation checks & ingested into a common database with the data submitted directly to the FIMS & Dapper.

- *The Filtered DMP Dataset*

The Filtered DMP Dataset includes the intersection of operations from the Manually Processed Dataset & the DMP Dataset. The total number of operations in this data subset is 133 including the six intruder flights. Because the test sites provided detailed data for these operations & they were manually processed, the operations in this data subset are currently considered to be the best suited for further study. Of these 133 operations, 127 were classified as actual aircraft flights with acceptable data quality.

More details

- Test objects pertinent to the NASA-FAA RTT Working Groups (Sense & Avoid, Data exchange, concept use cases, & Communication, Navigation, Surveillance)
- Lower level measures that potentially speak to key aspects of specific technologies and processes - Examples for Sense and Avoid RTT group to test effectiveness of the following:
  - Airspace constraints
  - Ground surveillance
  - Non-cooperative deconfliction
  - Pilot report
  - Conflict alert
  - Time duration between conflict alert and aircraft exiting protected geography
  - Scheduling and planning
    - Number of rogue operations due to flying beyond operation stop time
  - Flight planning
    - Number of lateral flight geography violations per geofencing mechanism and vehicle type
  - Conformance monitoring
    - Number of lateral flight geography violations per flight

More details

- Partial indication for example, because accepted Operations doesn't really indicate effectiveness of their flight planning, to properly guage effectiveness you would also need to have measures that demonstrate a balance of airspace efficiency, safety, and mission success. So for instance if they were able conduct a successful mission (without any off-nominal deviations), they were able to stay in their operational volumes, and they planned missions without conflicts (with respect to a specific airspace density), then they were effective at planning their operation.

Background (Technical Capability Levels)

- Technical Capability Level (TCL 2) is the second of four increasingly complex TCLs
  - Support the entire range of sUAS (<=55 lbs)
  - Account for risks associated with operations

- TCL 2 supports operations that are
  - Low density & beyond-visual-line of sight (BVLOS)
  - Over sparsely populated areas & where there are few manned aircraft with close proximity to the area of operation

FAA designated UAS Test Sites

- Nevada Institute for Autonomous Systems (NIAS)
- Griffiss International Airport
- Virginia Tech Mid-Atlantic Aviation Partnership (MAAP)
- University of Alaska Fairbanks
- Lone Star UAS Center (LSUASC)
- Northern Plains Unmanned Aircraft Systems Test Site (NPUASTS)

Results

- Data collection & analysis focused on producing measures of performance (MOP) that characterize the overall UTM system behavior as implemented in the overall test environment
- For TCL 2 National Campaign, these MOPs
  - are an initial benchmark, not a full indication of UTM characteristics; more data needed to draw generalizable conclusions
  - were introduced as potential metrics that can be monitored in future operational UTM system
  - and other potential MOPs (SAA & CNS) when more data is collected will be useful for investigations of UTM trends, USS & UAS design, policy decisions, and market research
- MOPs will provide bases for comparison with future tests, including
  - number of submitted, accepted, & rejected operation plans
  - number of nonconformance & rogue operations
  - time & distance flown with UTM System
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Background- Technical Capability Level (TCL)

- **TCL 1: *multiple* VLOS**
  - Info sharing
- **TCL 2: *multiple* BVLOS, *rural***
  - Intent sharing
- **TCL 3: *multiple* BVLOS, *near airports, suburban***
  - Airborne DAA, V2V
- **TCL 4: *complex urban* BVLOS**
  - BVLOS to doorstep
  - Track & locate

Background- Technical Capability Level (TCL)

TCL1: ***multiple VLOS***

API-based networked ops

Info sharing

TCL2: ***multiple BVLOS, rural***

Initial BVLOS

Intent sharing

Geo-fenced ops

TCL3: ***multiple BVLOS, near airports, suburban***

Routine BVLOS

Airborne DAA, V2V

Avoid static obstacles

TCL4: ***complex urban BVLOS***

BVLOS to doorstep

Track and locate

Avoid dynamic obstacles

Large scale contingencies