NASA/TM—2014–218299

Unmanned Aerial System (UAS) Traffic Management (UTM):

Enabling Low-Altitude Airspace and UAS Operations

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April 2014

DJI-1014
IPR2023-01227

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Acknowledgments

Note to Readers: The UTM ideas and this document were based on Parimal Kopardekar's NASA Aeronautics Research Institute seedling team proposal, NASA Ames Center Innovation Fund/Director's Innovation Fund proposal and award, and a filed provisional patent application ARC-17299-1.

Available from:

NASA Center for AeroSpace Information
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Document Purpose

The purpose of this document to describe initial ideas to generate discussions and multiple design options to enable low altitude airspace and UAS operations. The ideas expressed in this document offer one of the possibilities and are meant for discussion and should not be considered as the only option. The workshop is intended to generate discussions and explore a wide range of design options to enable low-altitude airspace operations. Readers are encouraged to provide feedback on every aspects of this document.

Background

Many civilian applications of Unmanned Aerial Systems (UAS) have been imagined ranging from remote to congested urban areas, including goods delivery, infrastructure surveillance, agricultural support, and medical services delivery. Further, these UAS will have different equipage and capabilities based on considerations such as affordability, and mission needs/applications. Such heterogeneous UAS mix, along with operations such as general aviation, helicopters, gliders must be safely accommodated at lower altitudes. However, key infrastructure to enable and safely manage widespread use of low-altitude airspace and UAS operations therein does not exist. Therefore, NASA is exploring functional design, concept and technology development, and a prototype UAS Traffic Management (UTM) system. UTM will support safe and efficient UAS operations for the delivery of goods and services.

Lesson from History

Today's Air Traffic Management (ATM) system was originated as a result of mid-air collision over the Grand Canyon in 1956. In order to safely enable widespread civilian UAS operations at the lower altitudes, an ATM-like system is needed. These low-altitude UAS operations will occur in the same airspace where today's gliders, general aviation, helicopter operations occur. Such a heterogeneous mix further justifies ATM like capability in the form of the UTM system.

Goal

The goal of UTM is to enable safe and efficient low-altitude airspace operations by providing services such as airspace design and dynamic configuration, dynamic geo-fencing, severe weather and wind avoidance, congestion management, terrain avoidance, route planning and re-routing, separation management, sequencing and spacing, and contingency management. Using lessons learned from today's ATM system, UTM functions and requirements would be developed. UTM is essential to enable the accelerated development and use of civilian UAS applications, and will support UAS ranging from those with minimal avionics capability, to those that are highly capable and/or autonomous.

The near-term goal (1-5 years) is to safely enable low-altitude airspace and UAS operations. The long-term goal (10-15 years) is to safely enable massively anticipated density of low-altitude airspace and UAS operations. The designs for short-term and long-term goals and density profiles may not be the same. By one account 70,000 operations by 2035 and some argue even this number is underestimated (Volpe report),

Functional Description of UTM

Figure 1 depicts the functional description of the UTM. The UTM will support a wide variety of UAS from those equipped with minimalistic avionics to autonomous UAS. The inputs to UTM will include: UAV mission/business flight plan or trajectory, real-time weather and wind, predicted wind and weather, airspace constraints (dynamically adjusted), community needs about sensitive areas (dynamically adjusted), three-dimensional maps that include man-made structures as well as natural terrain. The UTM will need persistent communication, navigation, and surveillance (CNS) coverage to ensure and monitoring conformance to the constraints. This could be provided by a combination of low-altitude radar, cell, satellite, and other means. The important aspect of this coverage is continuous robust, reliable, and redundant coverage to ensure monitoring and support needed for safe operations.

The UTM will provide authentication, airspace design, airspace corridors, and dynamic geo-fencing, weather integration, constraint management (congestion prediction), sequencing and spacing as needed, trajectory changes to ensure safety, contingency management, separation management, transition locations and locations with NAS, and geo-fencing design and dynamic adjustments. The contingency management services will include but are not limited to emergency landing site guidance for UAS and geo-fencing segments of airspace due to wind to ensure safe operations, which may be unable to continue the mission.

The UTM will be developed using autonomicity characteristics. These will include self-configuration, self-optimization, self-protection, and self-healing. Although the role of human operators needs to be carefully defined, it is anticipated that the humans will provide overall direction and goal-setting for the UTM system. The self-configuration aspect will determine whether the operations should continue given the current and/or predicted wind/weather conditions. The self-optimization aspect refers to given the traffic demand, how the airspace must be configured to make the operations most efficient in light of traffic demand. The self-protection aspect will ensure that all sensor data related to CNS and vehicle is accurate and operating at the desired integrity. Should the data integrity, sensor inputs, and precision reduce, the self-configuration aspect will identify the appropriate strategy such as increased separation buffer or gradually halting the operations. The self-healing aspect refers to safely returning to normalcy. The human may be the ultimate decision-maker regarding the continuation and return to normalcy of the operations.
The main aspect of UTM is that it will not require a human operator to monitor of every vehicle continuously. The UTM system will provide such monitoring, and coupled with autonomicity characteristics, it will provide human managers the right data to make strategic decisions related to initiation, continuation, and termination of airspace operations; as well as ensuring that only authenticated UAS operate in the airspace.

UTM Types

Two types of UTM system are envisioned. The first is the *Portable UTM System*, which will support operations such as agricultural needs. The system will be moved from one area to another easily. The second, the *Persistent UTM System*, will support low-altitude operations that are much more diverse and heterogeneous in nature based on multiple operators, missions, and range considerations. The Persistent UTM System will provide continuous coverage.

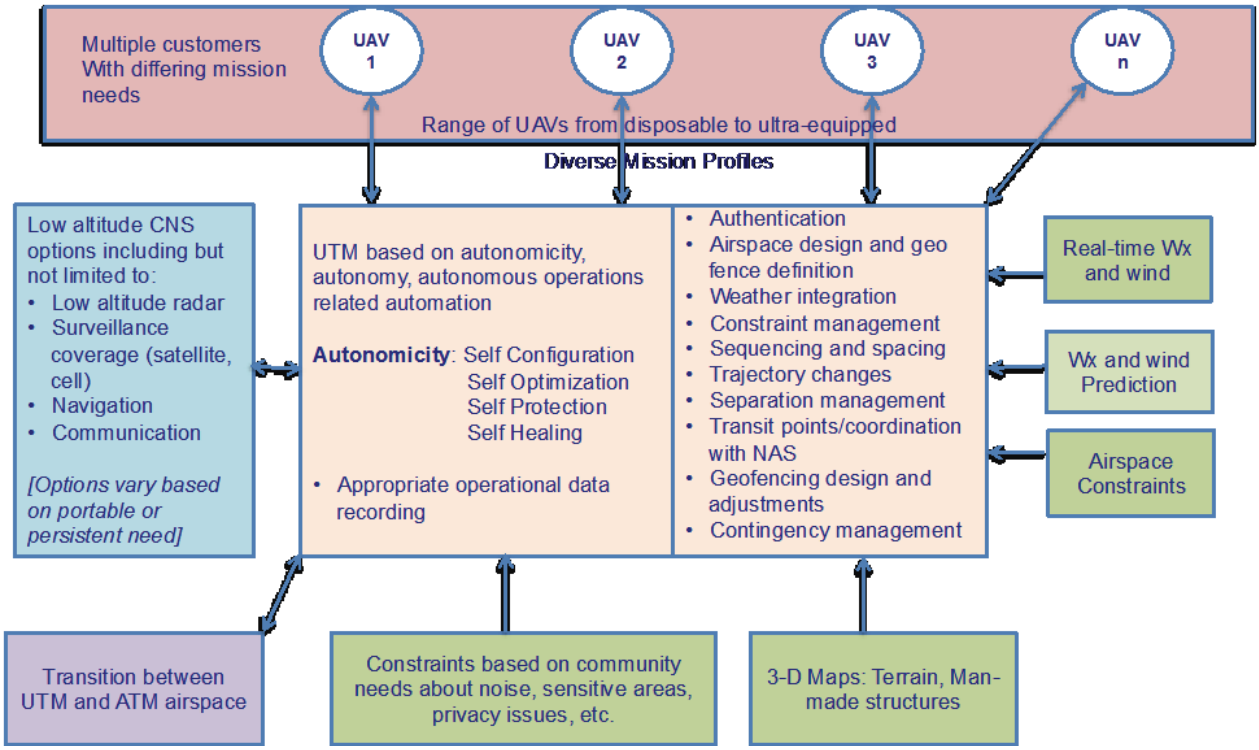

Figure 1: Example Functional Description of UTM

UTM Operational Business Models

The current ATM system is based on a single service provider in the United States. The UTM System may open up several possibilities for service provider options. These include:

1. Single service provider for the entire nation such as a government entity
2. Single service provider for the entire nation provided by a non-government entity (for profit or not for profit entity)
3. Multiple service providers by regional areas where UTM service provided by state/local government entities (these will be connected and compatible)
4. Multiple service providers by regional areas where UTM service provided by non-government entities (these will be connected and compatible)

Under all possibilities, a fee-for-service and/or route charge based model could be considered to support the operations, upgrade, and maintenance of UTM system. If a non-government is allowed to operate the low-altitude airspace operations with the UTM system, it is anticipated that the FAA will still need to certify the UTM system prior to its implementation and use.

UTM Scope

In the initial phases, UTM system is expected to support low-altitude airspace and UAS operations in remote areas and related applications such as wildlife monitoring and agricultural applications. Over period of time, the UTM system would support increasingly denser areas with goods and services delivery operations. Ultimately, the UTM system would support low altitude operations in urban areas for deliveries of goods and services.

Partnerships

A number of partners have expressed an interested in working with the NASA in exploring the research, development, prototyping, testing, and possibly implementation (if proven feasible) of the UTM System. These include public organizations, universities, and private organizations including but not limited to industry representing retailers, cargo/goods delivery operators, system integrators, UAS manufacturers, avionics industry, insurance industries, venture capitalists interested in funding UAS developers/operators, and personal vehicle manufacturers. Therefore, public-private-academia partnerships are expected to define and develop the UTM System.

Stages of UTM Research, Development, Testing, and Implementation

Table 1 shows the key activities by the fiscal year from conceptual design to the prototype testing and technology transfer of the UTM system for the near-term accelerated initiation of low-altitude airspace and UAS operations. Many aspects are very similar to the ATM system, however the UTM system will be unique given the challenges associated with low altitude CNS, different performance characteristics of UAS vehicles, mission needs, and suitability to wind and weather conditions. Furthermore, key capabilities such as newer and more representative trajectory models for UAS will have to be developed. Foundational research such as determination of separation minima in the vertical and horizontal directions, acceptable and hazardous wind and weather conditions, airspace stratification, rules of the road, and procedures will have to be developed. The activities listed in Table 1 can be accelerated based on the availability of resources, stakeholder needs, and other priorities.

NASA expects to coordinate closely with the FAA and NOAA throughout the development stages of UTM system. UTM testing will also be conducted in restricted area in the beginning and later on in the FAA approved test sites prior to its prototype demonstration and implementation.

Table A-1: Tentative Key Activities Associated with UTM System

FY	Tentative Key Activities (1-5 year accelerated near-term option)
2014	• Partnership building, workshop to discuss functions, issues, and paths to move forward • Identify UTM functional design options and conduct architectural trade studies • Initial analysis of the functional design vetted in autonomicity principles
2015	• Develop Build #1 of UTM functionality (e.g., airspace design, geo-fencing, develop trajectory models) • Conduct safety case analysis and cost/benefit analysis of UTM system alternatives/architectures • Conduct trade studies for communication, surveillance, navigation, and networked needs and alternatives (e.g., radar, cell, satellite communications, many others) • Identify roles/responsibilities of human supervisor to manage UTM
2016	• Conduct initial Live, Virtual, and Constructive (LVC) simulation study to test initial requirements • Continue to develop and mature UTM technology, Build # 2 (e.g., weather/wind integration, trajectory routing/rerouting, terrain/man-made object avoidance, congestion management, contingency management) • Conduct initial part-task simulation studies and analysis of UTM functions • Initial demonstrations/tests to enable low-altitude airspace operations with UTM system design(s)
2017	• Continue to develop and mature UTM system functionality Build # 3 (e.g., separation standards, separation management alternatives) • Conduct fast time and/or part-task simulations to demonstrate feasibility and benefits of UTM • Conduct interim demonstration/tests of UTM system design(s)
2018	• Continue maturity of UTM Build # 3 functionality towards prototype • Conduct trades and analysis of surveillance, communication, navigation needs and finalize an architecture • UTM fast time analysis of degraded and off-nominal conditions • Conduct simulation studies to demonstrate UTM feasibility and maturity in LVC environment • Conduct interim demonstrations/tests of UTM system design(s)

FY	Tentative Key Activities (1-5 year accelerated near-term option)
2019	• Develop mature UTM Build # 4 prototype system (add machine learning component for Wx and trajectory management) • Conduct UTM simulations in LVC with many flights • Conduct UTM system demonstration in real life (portable as well as persistent systems) • Technology transfer of mature UTM system and/or its sub-components
2020 and beyond	• Further research based on UAS and UTM autonomy, autonomicity, and advanced operations and vehicles will continue to enable expected massive growth and demand, diverse applications, reach into congested urban areas, and change in city/urban design to accommodate UAS operations

Workshop Breakout Goals

1. **Low-altitude missions, scenarios, use cases, and applications**: Identify/compile various missions, use cases, vehicle types, and weight classes, altitudes at which these vehicles will operate.
2. **Near-term UTM Design Options**: Identify alternative UTM system designs, and supporting research and development activities, to accelerate low-altitude airspace and UAS operations in 1-5 years
3. **Long-term UTM Design Options**: Identify alternative UTM system designs, and supporting research and development activities, to accommodate massive future demand for low-altitude airspace and UAS operations in 10-15 years
4. **Demonstration Ideas and Stages**: Identify near-term demonstration ideas that include heterogeneous vehicle/operations mix, missions/scenarios, alternate UTM design(s), and relevant metrics to safely enable low-altitude airspace and UAS operations.
5. **Business Models and other Considerations**: Identify alternative business models to manage UTM system, and management strategy for issues such as privacy, insurability, security, and public perceptions.

Summary

Many civilian applications of low-altitude airspace and UAS have been imagined. Learning from the history of ATM, to safely enable diverse operations, a management system is needed. NASA is exploring the research and development of a UTM system to enable low-altitude airspace and UAS operations. The UTM system will be based on autonomicity characteristics with self-configuration, self-optimization, self-protection, and self-healing properties. The UTM system will consider input related to real-time and predicted winds and weather, 3-D mapping, low-altitude CNS, community needs related to airspace, and other constraints. The human manager is supposed to set the goals of UTM system based on the inputs from various sensors. The UTM system could function in two modes: portable and persistent mode. The UTM system operations may offer opportunities to examine different service provide options and fee-for-service and/or route charge options. Many committed partners are willing to work with NASA to research, develop, test, and implement the UTM system. Public-private-academia partnerships are expected throughout the development phase of UTM system with a tight collaboration with FAA. A prototype UTM system technology transfer is expected by 2019, which can be accelerated based on the resources and stakeholder needs. Further, long-term UTM system design options must be identified to accommodate the expected massive number of operations in this airspace. The initial near-term UTM design options targeted for 1-5 year implementation and long-term UTM design options targeted for 10-15 year implementation would provide continued research and development needs.

Appendix A: Selected UTM Related Requirements
Appendix B: Selected UTM Related Research Questions

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Appendix A: Selected List of UTM System Requirements

System Requirements related to airspace design, geo-fencing, separation management/sense and avoid, trajectory management, contingency management, severe wind/weather avoidance, communication, navigation, and surveillance must be identified.

Authentication

1. Able to authenticate UAS that meet minimal equipage considerations
2. Able to detect UAS that are "rogue" and will not meet minimal equipage considerations
3. If there is a vehicle identification number (VIN) equivalent to all UAS then VIN should be verified

Airspace Design, Dynamic Airspace Adjustments, and Geo-fencing

1. Able to create airspace corridors and dynamically adjust them (e.g., lanes in the sky) with altitude for direction rules for nominal separation (similar to the right altitude for direction rules in the NAS) and efficiencies. In the beginning separation in 100 ft. height (number chosen by analysis) increments and could gradually decrease over time
2. Set up rules of the road and right altitude for direction of traffic based on changing needs
3. Able to dynamically create and adjust geo-fencing areas which will need to be avoided due to special needs such as community concerns, security, fires, etc.

Communication, Navigation, and Surveillance, Prediction and Separation Management including sense and avoid

1. Able to provide persistent communication, navigation, and surveillance coverage under day and night time (e.g., VMC and IMC) conditions
2. Able to provide coverage under poor visibility conditions. Able to provide communication, navigation, and surveillance coverage under all visibility conditions
3. Able to sense, detect and track every moving objects up to 10,000 ft. Most of the UAS for package delivery, wildlife monitoring, fire fighting, crop dusting, and other applications will operate much lower altitudes. A starting point is Class G airspace under 2000 ft.
4. Able to provide predict potential collisions between UAS, UAS and other moving objects including but not limited to birds, gliders, helicopters, model aircraft, general aviation, personal air vehicles, special purpose balloons, jet wind turbines, etc.
5. Predict the trajectory for next mile and/or within 5 minutes which ever is higher

6. Able to monitor separation among UAS and predict conditions where the crossing or separation minima will be violated. The horizontal separation minima be set to 1 mile in the beginning and will be reduced over time.
7. Able to provide persistent, redundant, coverage by sensors to areas where operations will be conducted

Severe Weather and Wind Monitoring, Prediction, and Integration

1. Able to real-time access and process data about winds and weather conditions and predictions
2. Able to send changes to the trajectories to avoid severe wind and weather conditions. The weather and wind severity conditions need to be defined which will need to be avoided by these UAS

Terrain, Man-made Objects Avoidance

1. Able to maintain update terrain, maps, tall structures, power lines, etc. data base that every UAS trajectory needs to avoid

Autonomicity Considerations

1. Able to self-configure system under the poor sensor/surveillance conditions due to reduced accuracy (e.g., sensors reduced accuracy in poor visibility, fog, etc. conditions) where the separation buffers could be increased
2. Able to operate on four key properties of autonomicity: self-configuration, self-optimization, self-protection, and self-healing. Self-configuration will be used to operate under most efficient or degraded conditions (higher separation minima, dynamic geo-fencing, etc.) Self-optimization will be used to generate most efficient trajectories given the demand and optimize overall throughput while maintaining individual vehicle level efficiencies. An extreme example of self-protection is the kill switch where the UTM system could not provide the necessary support for operations. It will involve detecting degraded conditions (e.g., severe weather, impaired synthetic visibility) letting self-configuration decide how it would operate under such degraded conditions. Self-healing will be gradually moving towards normalcy after an off-nominal event

Last 50 feet consideration (safety considerations to humans and other moving parts on the ground)

1. Last 50 feet consideration – Able to deliver the cargo safely and at a safe location without impacting any other objects or people in the vicinity. Need vision system on board or off-board at the receiving end. There may need a shake-hand and authentication to ensure the cargo is delivered to the right location

Business Models, Insurability and Underwriting

1. Able to insure the UTM system operations
2. Able to consider different business models where UTM could be operated by a third party vendor once the UTM system is certified

Contingency Management

1. Able to support a UAS find an appropriate and safe landing spot in case of UAS on-board emergency for events such as energy drop at UAS, cargo mis-handling, etc.
2. Able to return to home location when link is lost (special altitude zone may be needed for all lost link recovery, like a curb on highway)
3. Able to communicate with UAS and/or operations centers and monitor all UAS at once to provide a "all-land at once scenario" (e.g., 9/11) to the nearest safe place. This will ensure that that the rouge UAS be identified and appropriate action be taken to take the rouge UAS "out of the system" should a need arises

Congestion Detection, Prediction, and Management

1. Able to congestion prediction and management guidance to UAS (could be to the operator) so that alternative trajectories, speeds, and altitudes be provided and used
2. Able to provide sequencing and spacing under tight airspace corridors by creating required time of arrivals (schedule based system to strategically manage traffic and deconflict original trajectories)

Heterogeneous Mix of Vehicles

1. Able to accommodate UAS that are autonomous as well as non-autonomous and be dependent on the UTM to provide route/trajectory guidance
2. Able to generate nominally conflict-free and efficient trajectories based on arrival and departure locations (latitude/longitude) and any specified time constraints and/or able to accept business trajectories provided by the operator/owner/retailer/renter of the UAS – This functionality may be needed to support small UAS operators as opposed to fleet managers (Airline Operations Center vs Flight Service Station analogy)

Security

1. Secure software/hardware from cyber security threats, must be able to detect that an intrusion has occurred and to the extreme operations will need to be halted.
2. Able to provide redundant operations, should one system is unable to provide functionality
3. Protect business confidential trajectories
4. Able to operate without human intervention for sustainable operations but allow human to stop the operations should there be an event that needs kill switch

Overall UTM Design

1. Able to provide redundant operational support
2. Able to be minimalistic
3. Able to record trajectories of operations for research, analysis, and operationally challenging events
4. Able to connect with other NAS airspace to support operations in/out of low-altitude UTM managed airspace and other National Airspace System

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Appendix B: Selected Research Questions

Comprehensive research questions must be compiled for both near-term 1-5 year accelerated implementation as well as long-term 10-15 year estimated massive volume, and scalable operation.

Note: Research will address how the requirements can be met, when there is more than one way to address same requirement or operational need, or feasibility is unknown we translate that into a research need.

Airspace Design, Geo-fencing

1. Where do focus low-altitude airspace operations initially– Class G, up to 2000 feet?
2. Where do we need airspace restrictions, direction of traffic, arrival/departure/cruise corridors?
3. Where do we need geo-fencing? Do we need to completely avoid Class A, B, C, D, and E airspace?

UAS Equipage Considerations (there are many activities and standards that are being developed so we can leverage that work)

1. What is the minimum equipage requirement on the UAS?

Separation Management/Sense and Avoid (there are many activities in this area which we will leverage solution/designs)

1. What is the minimum separation between UAS and other operations in the airspace?
2. How do we maintain safe separation among UAS, gliders, helicopters, model aircraft, general aviation, and in future personal air vehicles?
3. What is the separation minimum among different types of UAVs, UAV and general aviation and other vehicles operate in the same airspace?
4. What is the (minimum) requirement on UAS for detect/sense and avoid and collision avoidance?
5. What are different designs (ground-based and UAS based) for sense and avoid, and how they would work together?
6. What are different sense and avoid architectures to provide persistent coverage to area?
7. What are different sensor options, redundancies, sensor data integrity needs?

Weather and Wind Detection, Prediction, and Modeling for low-altitudes

1. What is the low-altitude weather modeling and prediction system required to accurately detect and predict eddies, wind shear, speed and direction among urban and remote areas?

Contingency Management

2. What are the procedures to manage emergencies including energy depletion?
3. What are the procedures and technology solutions to manage lost-link scenarios?
4. What are to procedures to handle bird-strike to an UAS?
5. What are the procedures to manage multiple vehicles crashing into each other? When is it a real accident?

Policy, Community, and Business Model Considerations

1. What community concerns that must be addressed and what are different ways of addressing them?
2. What are the concerns about insurers and how to satisfy them?
3. What the concerns about privacy and liability, and how must be they be addressed particularly from vehicle design, certificate of approval, and UTM's conformance monitoring?
4. What are different business models (e.g., commercial fee for service) that should be considered in developing and maintaining UTM infrastructure?
5. Should there be any clear approval of applications that UAS and UTM support? Should these applications verification (self-reported) be part of the UTM system?
6. Should there be a limit on the cargo weight and type, if so, what's the maximum cargo load allowed?

Communication, Navigation, Surveillance

1. Is the aviation-approved frequency coverage a requirement, can other CNS architectures and capabilities be leveraged?
2. What are different ways to provide communication, navigation, and surveillance of the UAS operations? – cell, satellite, low-altitude radar, etc.
3. Will the aviation frequency spectrum be a limiting factor to accommodate future demand?

Overall System Design

1. What is the level of redundancy needed?
2. What are the functional allocation and architecture options for UAS, UTM, and networked/cloud system?
3. What is the minimum functionality of the UTM in terms of airspace design, geo fencing definition, self-configuration, weather/wind integration, congestion management, trajectory management, and separation assurance? What are inputs, outputs, and processing functions of UTM?
4. How portable UTM and persistent UTM differ in their functionality?
5. What are different architectural alternatives to build and maintain UTM system?

6. What kinds of safety and cost-benefit analysis need to be conducted for UTM system and its operational value in enabling low-altitude airspace and UAS operations?

Contingency Management, Authentication, and Security

1. How should authentication be performed to ensure that unauthorized UAVs are identified? How should these unauthorized UAS be managed?
2. How would the large-scale cyber security physical intrusion (e.g., 9-11 equivalent) be addressed procedurally, technically, and operationally?
3. What kind of alerting, emergency management (e.g., parachutes) should be part of the UAS?
4. What are cyber security related considerations for UTM system and operations? Does it need a “kill” switch to shut off operations in case of extreme intrusion? How would operations gracefully degrade under those conditions?

Last 50 feet Descent Operation

1. What are the most effective ways (e.g., technology, authentication, receptacle design) of managing the last 50 feet of descent to the ground in the safest manner? What are different ways of accomplishing in first 1-5 years and how would it look like in 10-15 years from now?

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