Unmanned Aircraft System Traffic Management (UTM) Concept of Operations

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Many applications of small Unmanned Aircraft System (UAS) have been envisioned. These include surveillance of key assets such as pipelines, rail, or electric wires, deliveries, search and rescue, traffic monitoring, videography, and precision agriculture. These operations are likely to occur in the same airspace in presence of many static and dynamic constraints such as airports, and high wind areas. Therefore, small UAS, typically 55 lb and below, operations need to be managed to ensure safety and efficiency of operations is maintained. This paper will describe the Concept of Operations (ConOps) for NASA's UAS Traffic Management (UTM) research initiative. The UTM ConOps is focused on safely enabling large-scale small UAS (sUAS) operations in low altitude airspace. The UTM construct supports large-scale visual line of sight and beyond visual line of sight operations. It is based on two primary mantras: (1) flexibility where possible and structure where necessary (2) a risk-based approach where geographical needs and use case indicate the airspace performance requirements. Preliminary stakeholder feedback and initial UTM tests conducted by NASA show promise of UTM to enable large-scale low altitude UAS operations safely.

I. Nomenclature

ANSP = Air Navigation Service Provider
API = Application Programming Interface
ATM = Air Traffic Management
ATC = Air Traffic Control
ATD = ATM Technology Demonstration
BVLOS = Beyond Visual Line-Of-Sight
DSAA = Detect, Sense and Avoid
ERAM = En Route Automation Modernization
ICD = Interface Control Document
Kts = Knots (nautical miles per hour)
MACS = Multi Aircraft Control System
NM = Nautical Miles
NAS = National Airspace System
RTT = Research Transition Team
sUAS = small UAS
TRACON = Terminal Radar Approach Control
UAS = Unmanned Aircraft System
UTM = UAS Traffic Management
USS = UAS Service Supplier
VLOS = Visual Line-Of-Sight
V2V = Vehicle-to-vehicle

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I. Introduction

THE need for an Air Traffic Management (ATM) system in the United States emerged from a mid-air collision of two commercial flights over the Grand Canyon in 1956. All 128 people on those aircraft died in the crash making it, at that time, the deadliest aviation accident. Prior to that disaster, there were limited services to manage the overall traffic flow and moderate demand/capacity imbalances in the NAS. The skies were largely uncontrolled airspace, and pilots outside major cities relied upon see-and-avoid to maintain safety. A key lesson from this history is that increasingly congested air traffic needs an appropriate level of organization. A similar progression can be observed in the ground transportation system where roads, stop signs, lanes, traffic signals, synchronization of signals, dynamic lanes, bike lanes, rules of the road at intersections, pedestrian cross-walks, safety barriers, and other conventions are being used. These methods are intended to balance the needs of safety, efficiency, and equity. Regardless of the nature of the autonomy or the design of cars in the future, the ground transportation system will continue to use structure to ensure the desired level of safety, efficiency, and equity. As we postulate future demand for low-altitude small unmanned aircraft systems (UAS), historical experience indicates that we must have an organized approach to enabling these operations to balance efficiency and safety. Further, we also need to have systems in place that will scale to future densities and mix of vehicles. Currently, general aviation, gliders, and helicopters operate in the low altitude uncontrolled airspace. Accommodating new entrants in a safe manner along with pre-existing users is critical. There are many commercial UAS applications such as cell phone tower inspection that may operate within visual line of sight (VLOS). Further, many commercial UAS operators would like to fly their missions beyond visual line of sight (BVLOS) where economic value is greater as compared with the same missions (e.g., inspection of pipeline, electrical infrastructure, deliveries) using conventional manned transportation either through the air or on the ground. It is also expected that BVLOS vehicle operations will require autonomous capabilities.

In order to safely accommodate all manned, VLOS and BLVOS UAS operations in the low-altitude airspace, a systematic approach is needed, one that will scale to accommodate diversity and future demand. NASA envisioned this potential future and initiated research into UAS Traffic Management (UTM) based on decades of air traffic management research and development experience and insights[1]. Figure 1 sets the context for the UTM research and for the initial versions of the Concept of Operations[2]. As the small UAS (sUAS) industry with its use cases and technologies is rapidly evolving, the UTM concept also evolves. Many initial elements hold true, while roles and responsibilities and distribution of functions between the stakeholders are becoming more defined in NASA/FAA Research Transition Team meetings and the frequent discussions among all stakeholders.

Figure 1: Notional UTM scenario showing many use cases for small UAS

This paper will describe the current Concept of Operations (ConOps) for NASA's UTM research initiative. The UTM ConOps is focused on rapidly enabling large-scale sUAS, in presence of other traditional aviation, to safely operate at low altitude in uncontrolled airspace. Segregated UAS operations in controlled airspace will likely also be informed by this ConOps. It must be noted that, like other ConOps for any major enablers, this is a living document and should not be interpreted as the final characterization of how the operations may evolve. As analysis, studies, and tests are conducted, the UTM ConOps will be updated to reflect the up-to-date thinking.

II. Problem Statement

Many beneficial civilian applications of commercial and public UAS in low-altitude airspace have been proposed. Example applications include infrastructure monitoring, precision agriculture, public safety, search and rescue, disaster relief, weather monitoring, and delivery of goods (see Figure 2).

Figure 2: Applications of small UAS

As these UAS operations begin operating they will access areas that were originally only used by general aviation aircraft, helicopters, gliders, balloons, and parachutists. The safety of these existing traditional operations cannot be reduced by the introduction of the new UAS operations. However, airspace operations performance and integration requirements have not been developed to accommodate a large-scale mix of BVLOS, VLOS UAS and manned operations. NASA's research started with developing a concept of operations that defines how these operations in low-altitude uncontrolled and controlled airspace could be accommodated in a safe manner. Currently, the uncontrolled airspace (i.e, Class G airspace) is regulated but not controlled which means air traffic control or management services are not provided for routine operations. Hence, the fundamental barrier to large-scale UAS operations is the lack of airspace operations requirements, procedures, and support functions. There are many differences among manned aviation that operate in this airspace and the envisioned UAS operations. First, there is no pilot on-board the UAS to detect and avoid other vehicles. Second, there is a wide range of new and unknown performance characteristics in UAS. Third, sUAS often do not have the capabilities to carry heavy or power-intensive equipment. Fourth, separation standards and requirements for sUAS are very different to the traditional requirements. The biggest risk is to the people and assets on the ground and to manned aviation, while sUAS may fly very close to each other under certain circumstances. Because of their different performance characteristics, like their susceptibility to wind due to low mass, information needs to safely operate sUAS are very different than for traditional aviation. Finally, the density of operations in the airspace could easily be several orders of magnitude higher than in manned operations. For example the National Airspace System currently experiences about 5000 flights at any given moment[3]. According to the FAA's registration data base on May 12 2016 there were already 469,950 registered users of UAS in the US, mostly hobbyists as there are no rules yet enabling commercial use without exemptions. The FAA forecasts on the high end that for 2016 the potential sales of commercial small UAS requiring registration to be over 600,000, growing to 2.7 million per year by 2020[4]. The Teal Group has provided the FAA with a forecast that assumes that the commercial UAS market will take time to develop and forecasts the sUAS

fleet to be approximately 542,500 over a five year period. However, the top current five sUAS markets analyzed in this forecast do not include large scale BVLOS operations such as deliveries, which could add millions of operations once enabled. Accommodating this kind of scale for a wide range of performance characteristics, use cases, geographical and airspace constraints is a major challenge that UTM is facing.

III. Current State-of-the- Art

Safe, large-scale VLOS and autonomous BVLOS UAS operations are not currently possible in low-altitude airspace. There is a global void for concepts, operations requirements, technologies, and a path towards safe large-scale operations in low-altitude airspace. Any concept for enabling large scale sUAS operations in low altitude airspace has to consider three main dimensions:

1. **Ensuring regional and national security**: It is critical that the national and regional security is ensured as sUAS operations are enabled in the low-altitude airspace. These security considerations include protecting key assets such as the White House, airport operations, and various valuable assets (e.g., monuments).
2. **Safe airspace operations**: It is important to enable sUAS operations in such a manner that they will operate safely in the presence of other UAS as well as in the presence of traditional aviation. Many UAS operations will have a large impact on people and structures on the ground. In some cases, UAS operations will occur all the way to the doorstep. Ensuring the safety of multiple operations as well as single flights is highly critical.
3. **Economic value of low-altitude airspace applications**: Using the airspace for commercial, public safety, and personal use by collecting data or transporting objects will provide a huge economic benefit. More than a billion dollars have already been invested by the venture industry to pursue these benefits.

These three considerations must be carefully balanced to achieve the maximum economic value of sUAS operations while ensuring security and overall airspace safety. NASA will focus its research efforts on the second part which is safe airspace operations and will leverage industry and other federal entities' investments associated with the security and applications.

There is a fundamental barrier to enabling access for large-scale UAS operations in the low altitude airspace: their acceptance. Acceptance of any new technologies or operations usually has multi-dimensional considerations. The fundamental barrier to large scale airspace access for sUAS operations can be further broken down into many aspects associated with acceptance. These include:

1. **Validated airspace operations and integration requirements**. The requirements associated with airspace configuration and geo-fencing; vehicle tracking; command, control, and communications; collision management; weather /wind prediction and integration; overall safety of design and operations; and overall needs based on the use case and geographical considerations which reflect the risks in the air and on the ground.
2. **Privacy considerations**. The very characteristics that make UAS so promising for commercial uses, including their small size, maneuverability and capacity to carry various kinds of recording or sensory devices, also may raise privacy issues.[5] The National Telecommunications and Information Administration (NTIA) with all stakeholders—industry, privacy advocates, government and academia is crafting voluntary Best Practices around privacy, transparency and accountability for the private and commercial use of UAS .
3. **Regional and National Security considerations**. There are three types of security considerations associated with cyber-physical security: the first one is related to uncooperative/rogue systems that are intended to cause damage to assets on the ground or in the air, the second is related to an authenticated system that becomes a fly-away into or near critical geo-fenced area without approval; and the third is related to an authenticated UAS that's been hacked and used to cause an intended or unintended damage.
4. **Environmental considerations**. The environmental considerations associated with noise stemming from vehicles in the low-altitude operations could influence large-scale acceptance.
5. **Public acceptance**. As the UAS are still being developed for civilian use, the public may be leery of accepting them until their civilian uses and benefit potential are well understood.

These barriers have to be broken down in order to enable large scale UAS operations in a trustworthy and sustainable manner.

III. Concept of Operations

This section describes the UTM Concept of Operations. First, the primary scope of this initial ConOps is provided low altitude uncontrolled operations, .Second, the overall approach to rapidly enabling sUAS operations in this environment is explained. Next, high-level principles to accelerate realization of these operations are defined. Lastly, the proposed architecture, and the underlying roles and responsibilities are discussed.

A. Scope

There are many different ways of characterizing the various operating environments. For the purpose of discussing the UTM ConOps scope, we are distinguishing the operating environment primarily with regard to the interactions with controlled aircraft. In that regard it can be expected that there will be at least three different operating environments within the airspace system:

1. UAS operations inside uncontrolled Airspace (class G): In this environment, no interaction with controlled air traffic will occur as the UAS operations are segregated from controlled airspace operations. However UAS share the airspace with other airspace users, such general aviation aircraft, helicopters, gliders, balloons, and parachutists.
2. UAS operations inside controlled airspace, but segregated from controlled air traffic. As many use cases of sUAS operations would benefit from operating near airports and inside controlled airspace, there could be segregated areas within the controlled airspace that can be made available for UAS operations. These could be transition tunnels or blocks of airspace that are made available depending on current airport and airspace configurations and other criteria related to controlled airspace operations.
3. UAS operations integrated into the controlled air traffic flows. When UAS are integrated into the controlled air traffic flows they are expected to behave exactly like traditional aviation and meet all the requirements set forth currently for operations in the controlled airspace classes. The requirements for this kind of UAS integration have been developed over the past few years and are laid out in the respective documents.

The focus of this ConOps and NASA's initial UTM research is on (1) where UAS operations occur inside uncontrolled low altitude airspace. The ConOps is intended to provide a seamless transition into segregated operations within controlled airspace, but does not yet address many of the issues related to those operations. Integrated operations have been subject of joint FAA/NASA/DoD research activities under NASA's UAS in the NAS program over the past years.[5]Next we will discuss the overall approach to enabling sUAS operations in uncontrolled low altitude airspace.

B. Overall Approach

It is expected that UAS will soon be able to safely operate in many weather conditions throughout both controlled and uncontrolled airspace without human intervention. UAS will use onboard detect and avoid systems to avoid other traffic, hazardous weather, terrain, and man-made and natural obstacles. While technology continues to advance towards this future scenario, UAS do not have all of these capabilities today. Advanced avionics, weather-sensing equipment, and terrain avoidance capabilities remain too expensive or too heavy for the sUAS expected to operate at low altitude. Meanwhile, certified detect and avoid systems do not yet exist for sUAS, and requirements for them are not defined. Therefore the overall approach to enabling sUAS operations follows an incremental risk-based model, starting in low-risk environments and progressing towards higher risk environments.

The initial UTM Concept of Operations (ConOps) is focused on rapidly enabling sUAS to operate at low altitude starting in Class G airspace. It uses a combination of airspace design, flight rules, operational procedures, ground-based automation systems, and vehicle capabilities to enable safe use of the NAS by these new vehicles. There are seemingly unlimited potential applications for these UAS operations, and many do not require fully autonomous capabilities. Therefore, the UTM ConOps identifies an incremental series of procedures and capabilities that allow the types and numbers of UAS operations, as well as the extent of airspace used to conduct those operations, to increase over time.

Initial UAS operations are enabled with minimal impact to the NAS. Safety is maintained by segregating these operations from other potential users of the NAS in areas with few people and little property on the ground. Next, existing technologies are used to enable UAS operations in areas of limited interaction with other NAS users and extend into the BVLOS range. Procedures provide safe separation between UAS operations. Alerts to nearby NAS users ensure their awareness of the presence of UAS activity. Finally, expected future technologies, such as advanced detect and avoid systems, allow UAS operations in congested areas over densely populated communities. In-flight separation services are provided by automation systems and contingency procedures are used to handle both small- and large-scale off-nominal events.

C. High-Level Principles

This section describes the high level principles guiding the UTM ConOps in three areas: (1) the guiding principles to accelerate airspace access, (2) the operating principles for sUAS (3) the mantras underlying the operational characteristics

1. Guiding principles to accelerate airspace access

The initial UTM effort is intended to accelerate the UAS use of Class G airspace by safely, efficiently, and equitably managing all of the UAS operations.[7] There are five high-level guiding principles: safely accelerate beyond visual line-of-sight UAS operations in Class G airspace, provide transparency regarding these UAS operations, accommodate a diverse inventory of UAS, allow markedly different UAS operators to access Class G airspace, and enable new types of future missions. These objectives are discussed in this section and reflected throughout the UTM ConOps that follows.

UTM will enable BVLOS UAS operations in Class G airspace. Today, such UAS operations are planned and conducted in a tedious, often ad hoc, manner in the few remote locations that allow them. NOTAMs are used to alert pilots to potential UAS activity in the airspace. These NOTAMs must be filed 48–72 hours in advance, so on-demand operations are not possible. In some locations, these NOTAMs are not even available to all UAS operators sharing the airspace. UAS operators often coordinate with each other by sending electronic mail. The UAS operation's start and end time, planned path, and operating area are generally the only information shared. This limited coordination is inefficient and eventually a safety risk when scaled to more UAS operations by more UAS operators. The problem is further exacerbated when the UAS operations are conducted in airspace already used by manned aircraft.

UTM will provide an appropriate level of transparency of the UAS operations being conducted in Class G airspace. Key concerns of the public regarding UAS operations are privacy (their own), security (their own), and accountability (the operators'). An important element of mitigating these concerns is easy access to information regarding who is conducting the UAS operation, why they are operating, and where they are approved to operate. At the same time, the proprietary and sensitive information about the UAS operators needs to be protected.

UTM will accommodate a diverse inventory of UAS. The expected vehicle configurations include fixed-wing airplanes, helicopters, multi-copters, and hybrids that can take off and land like rotary wing aircraft but fly like fixed-wing vehicles. The power sources of these vehicles will include traditional engines using fossil fuels, battery-powered motors, and other systems. These vehicles will have different capabilities in terms of their autopilots, navigation systems, detect and avoid systems, command and control links, performance envelopes, and payload packages. Some vehicles will be launched and recovered by hand, while others will takeoff and land without any human intervention. Finally, the vehicles will span the entire spectrum of control mechanisms from remotely piloted to command-directed and fully autonomous systems. Accurate modeling of the behaviors of these UAS is more challenging than modeling the behavior of traditional manned aircraft, but it is necessary to support the anticipated traffic densities of the UAS operations.

UTM will be flexible with respect to the UAS operator's required capabilities. Operator requirements should be specified in term of desired level of performance of the UAS operation rather than human-computer interface design specifics. The UAS operators may choose to conduct only one UAS operation (e.g., a simple worksite inspection) or many concurrent operations (e.g., a large package delivery service). A single remote pilot might control one UAS or the UAS operator might use an automation platform to control many UAS simultaneously.

UTM technologies will use available information from non-traditional sources – information from other UAS operations, for example. A key attribute of the UTM ConOps is sharing of traffic, weather, and terrain information between the UTM and UAS services and the UAS operations. Analogous to the information shared by crowd-sourced traffic applications, the UTM eco-system must facilitate sharing of information between UAS operations.

[7] However, UTM is not intended to directly manage the manned aircraft in uncontrolled airspace.

This paradigm is critical to address the inherit limitations of surveillance of non-cooperative manned vehicles, low altitude weather forecasts, and vehicle obstruction maps. Means for verifying and validating these non-traditional information will have to be put in place, which is a challenge in itself.

UTM will minimize the regulatory impacts on existing users of uncontrolled airspace. The UTM ConOps does not propose the creation of a new class of airspace; nor does it propose the active segregation of UAS operations from traditional aviation. Instead, the UTM ConOps follows a staged approach. UAS operations are first permitted in areas where interactions with traditional aviation are rare and only limited services and infrastructure are required. Then, UAS operations are expanded to areas of greater numbers of traditional aviation by introducing a growing number of services and infrastructure.

Finally, UTM will be scalable to future operational scenarios. It must safely and easily allow the introduction of new types of UAS missions. Many near-term applications of sUAS are focused on short duration, on-demand flights. Current endurance limits are generally less than one hour at speeds up to 60 knots. However, long-term predictions envision vehicles capable of remaining airborne for hours and flying at much greater speeds.

NASA, in close collaboration with the FAA, leads the research efforts related to airspace operations performance requirements and collaborates with other government entities, industry, and academia for other considerations.

2. Operating principles for small UAS

In order to safely enable sUAS operations in the low-altitude airspace, the following operating principles are postulated.

1. Only authenticated UAS and operators are allowed to operate in the airspace
2. UAS stay clear of each other
3. UAS and manned aviation stay clear of each other
4. UAS, their operators or support systems have awareness of all constraints in the airspace and of people, animals and structures on the ground and UAS will stay clear of them
5. Public safety UAS should be given priority over other UAS and manned aviation.

3. Basic Mantras

In addition, the operators need more flexibility than afforded traditional operations today. In order to offer such flexibility, operational characterization is based on two basic mantras:

1. **Flexibility where possible and structure where necessary**. In this mantra, much flexibility is offered to operators and operations where there is no demand and no capacity imbalance. When the demand is over capacity as in case of multiple UAS wanting to operate at the same airspace at the same time, then structures such as corridors, altitude for direction, and crossing restrictions will be incorporated.
2. **Risk based approach where geographical needs and use cases will dictate the performance requirements for airspace operations**. In this mantra, based on the risks on the ground or in the air (e.g., remote airspace vs. congested urban airspace) as well the area of operations needed to support the use case (e.g., surveillance of pipeline or electric wires vs. deliveries all the way to the door step) indicate the airspace performance. In remote areas with no other operations or obstacles in the vicinity; the requirements may be different than urban airspace with many other operations and obstacles in the vicinity. The UAS performance requirements for track and locate, and to manage large-scale contingencies such as cell and GPS outage, as well as trajectory conformance monitoring would be different for each condition.

D. Proposed Architecture

Based upon many discussions with our partners a general architecture has emerged that could provide the required scalability and honor the principles set forth above. The architecture is based upon a primary distribution of roles and responsibilities that has three main components at the center of the UTM ecosystem:

- UAS Operators
- UAS Service Suppliers (USS)
- Air Navigation Service Providers (ANSP)

Figure 3 depicts one option for a high level organization. Public safety and public access are depicted in Figure 3 as representatives of other stakeholders that will interface with the main components.

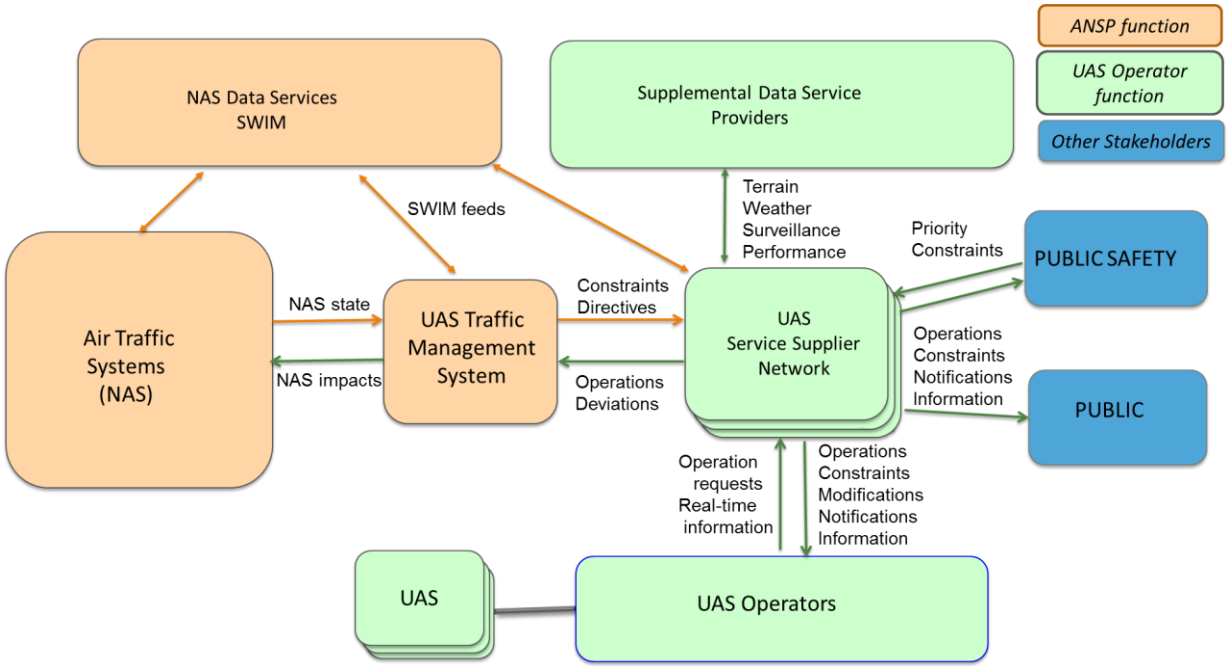

Figure 3: Potential architecture and information flow between major components of the UTM ecosystem

In this architecture the UAS Traffic Management System (UTMS), which is operated by the ANSP (the FAA in the United States) would interface with the other NAS systems and provide directives and constraints to the UAS operations via the UAS Service Supplier (USS) Network. The USS could be operated by the UAS operators, other commercial or government entities. The operators use the USS to organize and coordinate their operations and meet all constraints and directives from the ANSP systems. The ANSPs UTM system has access to all operations and is informed about any deviations that could have an impact on the NAS.

E. Roles and Responsibilities

One of the most important parts of the ConOps is defining the roles and responsibilities of the primary entities in the UTM ecosystem. There are many stakeholders associated with the operations, including UAS operators, UAS services suppliers, air navigation service providers (ANSP), public safety entities, and general public. This ConOps focuses on the first three stakeholders.

The first primary distinction is the question on distributing the roles and responsibilities between the ANSP and the UAS operator. From an ANSP standpoint the USS is considered part of the UAS operator responsibility and therefore there is no distinction in these general responsibilities.

Table 1 summarizes the roles and responsibilities of the UAS operator (and USS) and the ANSP in this concept:

Table1: Roles and Responsibilities of UAS Operator/USS and of ANSP

ANSP Responsibility	UAS Operator /USS Responsibility
• Set performance based regulatory environment • Define and update airspace constraints • Foster collaboration among UAS by setting up architecture for data and information exchange • Define data and information exchange specifications for collaboration among multiple stakeholders/operators • Real-time airspace control if demand/capacity imbalance is expected • Provide notifications to UAS operators and public • Set static and dynamic geo-fence areas • Provide flexibility as much as possible and structures (routes, corridors, altitude for direction, crossing restriction) only if necessary • Manage access to controlled airspace and entry/exiting operations	• Register UAS • Training and qualification of operators • Avoid other aircraft, terrain, and obstacles • Don't harm people and animals • Respect airspace constraints • Avoid dangerous and incompatible weather situations • Follow performance based regulation • Broadcast identity – no anonymous flying • Broadcast intent • Provide access to operations plans • Detect, sense and avoid manned aircraft predicated on right of way rules • Status and intent exchange according to ANSP standards • Participate in collaborative decision making • Contingency planning and response (large-scale outages – cell, GPS, security, an unanticipated severe weather)

1. ANSP

The ANSP sets the performance-based regulatory environment for the operations and establishes the performance requirements based upon use case categories, operational environments and other factors. The ANSP defines and updates the airspace constraints as necessary in real time, for example if airport configurations change or certain airspaces have to be closed. The interactions between the ANSP and UAS operators/USS will be primarily governed through Interface Control Documents (ICD) and Application Programming Interface (API) based integration of the components. This will create an architecture that will foster collaboration and information exchange among multiple stakeholders. The ANSP may add static or dynamic geo-fences or other means of airspace control and provide notifications to operators and other stakeholders. The ANSP will also manage access to controlled airspace.

2. UAS Service Suppliers (USS): Federated Service Supplier Network

Role

The role of the USS is to offer support for safe airspace operations. The organizations that provide airspace support may or may not operate UAS themselves. For all intents and purposes to consider performance based airspace operations these functions are considered separate from the main purpose of UAS operators. USSs will share information about their supported operations (without confidential information) to promote safety and to ensure that each USS has a consistent view of all UAS operations and thus enable UAS to stay clear of each other. Information would be shared through a common API that everyone agrees to. The interoperability among USSs will be agreed upon for data exchanges and exception handling. All communications among various actors need a common communication protocol. USSs will have to agree to an authentication scheme that will be followed by all to ensure consistency and cyber security

Airspace Operations Relevant Data

With regard to airspace operations relevant data USSs are expected to agree to use the same or compatible data for minimum functionality to ensure route planning and de-confliction and airspace use, which will include but not be limited to the information that all airspace users are required to consider: (a) Temporary flight restrictions (TFR), Notice to Airmen (NOTAMS), Special Use Airspace (SUA), and other airspace activities, (b) Airspace classes and boundaries (e.g., Class D, C, B airports) and (c) Weather/wind (actual and forecast) Terrain and obstacle database USSs may provide additional information related to: Geo-fence information for static and dynamic areas, higher resolution 3-D constraints and obstacle data, community needs for a specific activity or period. While the raw data

sources could be different, certain criteria must be agreed upon for consistency, update rate, granularity based on applications. USSs will also agree on security protocols and data integrity

Separation Management

USSs will de-conflict operations which may include notification of joint airspace use (when two planned trajectories overlap) in a consistent manner using a construct that is repeatable and predictable. This can include real-time de-confliction or near-tactical methods (it could be as simple as first-come-first-serve notification with prioritization for public safety, or emergency operations). USSs and their supported operators will collectively agree to airspace usage (airspace reservation or notification to others) that is fair, equitable and does not restrict entry to any authorized users. Cooperation on use between USSs cannot extend to de facto management of the airspace by third party entities. USSs may offer strategic de-confliction by avoiding areas that are being used, or planned to be used by other UAS. They could also push notifications to operators of potential conflicts. In very high density areas, to balance efficiency and safety – collectively agreed upon altitude for direction type considerations may be used. USSs and their supported operators would have to agree on a method to resolve in-flight tactical conflicts in part based on vehicle type and agility. Real-time collision avoidance is best handled directly between UAS in conflict. In this case, performance criteria will need to be set and multiple technology paths that detect and avoid such as position broadcast, vehicle to vehicle communications, wireless options, satellite based systems, vision, laser-based sense and avoid need to be considered. Collectively, performance criteria will be established for distance and/or time and avoidance procedures (e.g., which vehicle moves in case of a collision potential)

External Interfaces

USSs will provide publicly accessible mission specific information, including items like type of operation (e.g., BVLOS/VLOS), intent for the next few minutes, Public Safety Drone Status, and other information. If the USS has any sensitive personally-identifiable information then it will be safeguarded. They will provide full information regarding operations, including full route and operator identity as required and legally required by law enforcement, the FAA, and other govt. agencies. USSs will interface to the ANSP systems as needed and defined by the ANSP. USSs will secure entry clearances for operations that transit from uncontrolled into controlled airspace prior to entry

3. UAS Operator

The UAS or their operators provide position/telemetry updates to the collaborative USS network. Collectively, performance related to reliability, frequency, accuracy and persistence will be agreed. Multiple technology paths such as cell/wireless, ADS-B, satellite Ku band, beacon based systems, and others may offer such reporting. The reporting requirements will be based on the risk assessment, in remote areas and over water reporting may be less frequent or not needed at all; whereas near congested airspace or airports and within urban airspace, reporting requirements may be different. Independent of the USSs strategic de-confliction, the UAS must be able to sense and avoid other vehicles and obstacles in the airspace. Recreational users will use recreational VLOS guidelines. For BVLOS operators, additional performance requirements (such as detecting a ½ in thick wire from 50 meters, or detecting another UAS from 50 meters) must be collaboratively agreed. Various technology options such as but not limited to ADS-B like transceivers, vehicle-to-vehicleV2V communication, on-board laser/optical/acoustic sensors could then be used as long as they meet the performance requirement. Regardless, performance and minimum standards for detect, sense and avoid DSAA and maneuvers for de-conflictions will have to be agreed upon. The use of non-aviation spectrum for command, control, and communication for sUAS may be required. UAS operators will have requirement on reporting accidents and incidents, such as fly-aways and the USSs will support the operators in fulfilling these reporting requirements efficiently.

F. Additional Attributes

Once the architecture and the roles and responsibilities are defined the following key attributes have to further developed and established.

- Services: The type of services that UAS operators and other entities in the UTM eco-system will need to ensure successful operations.
- Data and information exchange: For every UAS operation to be successful in terms of avoiding all constraints while ensuring their business objectives; data and information is needed. These could be related to weather, 3D maps, other UAS operations, manned operations, and other obstacles.
- Performance: UAS operations will occur from remote areas to urban areas. Considering a risk-based approach, which is risks on the ground and vicinity assets, and the particular use case (e.g., all the way to

the door step for a delivery or surveillance of key assets) may dictate the performance required to operate in that airspace. For example, the risks in the urban airspace and use case of operation all the way to door step are different than a over water and whale watching surveillance. Such a risk-based approach will allow initiation of operations in the low risk environments sooner

The FAA/NASA Research Transition Team will continue to work to lay out these attributes and guide the research that will need to be conducted to develop and evaluate the concepts and technologies.

IV. Research Considerations

FAA and NASA are working together closely on the UTM research through a joint Research Transition Team (RTT). Further, NASA also collaborates with the Department of Homeland Security, the Department of Defense, and the Department of Interior to identify use cases and needs for safe airspace operations. NASA is also collaborating with many industry and academic institutions in refining the concepts. NASA continues to conduct in house research and collaborates actively with industry and academia in the areas of track and locate, sense and avoid, last/first 50 feet, vehicle design, airspace configuration, geo-fencing definition and conformance, GPS free or degraded operations, and overall roles/responsibilities considerations.

NASA is also spearheading the development of a UTM research platform that instantiates application programming interface (API)-based coordination of UAS operations and services into a research software environment. Certain executable research software components are shared with partners under project release agreements. NASA uses the research platform with its partners to test and evaluate increasingly complex UAS operations and associated UTM technical capability levels (TCL). The research results at each TCL provide insight and guidance into concepts and technologies for the respective UTM eco-system and use-cases and will be a central part of the research transition products generated for the NASA/FAA RTT.

NASA plans to test each TCL at two stages. The first stage test will be conducted by NASA to understand the initial feasibility and the second stage test will be conducted by NASA in close collaboration with the FAA and FAA test sites to understand wider feasibility. In this section we will first describe the research platform and provide an example case for an operation.

A. UTM Research Platform Description

1. Overview

The UTM research platform provides a proof-of-concept implementation of the elements outlined in Figure 3. The research platform is used to instantiate the functions in a research environment that is accessible by NASA and its partners in order to facilitate the evaluation of UTM concepts, technologies and procedures. It enables NASA and its partners to conduct the research required for determining the operational characteristics for roles and responsibilities, architecture and information flows, services, and performance requirements . The UTM research platform is not designed as a system that is intended for operational use. It is expected that the data and experiences gathered from developing and evaluating operations with the research platform will be useful in defining and developing operational systems. Any research technologies developed by NASA will be transitioned to the FAA and other stakeholders in the same way that NASA has transitioned many ATM technologies from research to the FAA and others before.

The UTM research platform, will facilitate interactions between seven main components: the UTM core, USS functions, UTM clients, UAS, external data services, FAA systems, and other stakeholder systems (non-FAA). This architecture is illustrated in Figure 4.

At present only a subset of the components are actually needed and accessible in the research platform. For example, there is a connection to the SWIM feed, but no interaction with actual FAA ATM systems. The current primary focus of the research platform is on the interactions between UAS operators, UAS support services, changing ANSP constraints and providing example displays and applications for the public and other stakeholders. Many of these components communicate via the UTM application program interface (API) as well as specialized APIs of the external systems. The UTM API is described in the UTM ICD[5] document.

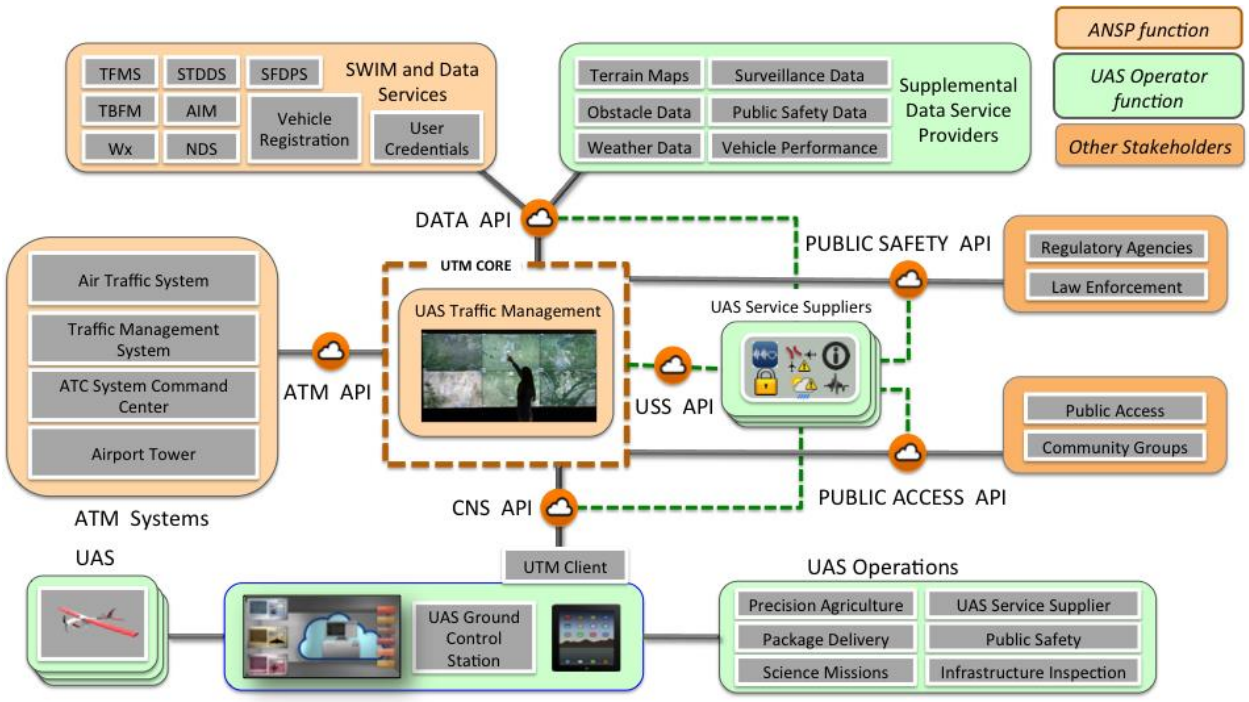

Figure 4: Complete UTM Architecture. The research platform currently implements a subset of these components

NASA has developed proof-of-concept software services for vehicle registration and user authentication, flight planning and constraint management, and conformance monitoring and is adding research capabilities as the complexities of the simulation and field trial increase.

External data services provide terrain maps, obstacle data, weather data and impact models, and airspace definition information. These external data sources also provide operational data like surveillance data and NOTAM information.

Each UAS operator participating in UTM research implements a UTM client to access the UTM research platform's services during operations. A UTM client is a software application used to access the services provided by the UTM research platform. All UTM clients communicate with the UTM research platform via the same standardized message protocols. An objective of the UTM research is to help define information requirements within the UTM eco-system. Standardized and internationally recognized protocols are used when possible. By adhering to established protocols and standards, integration of the UTM research platform within existing and future systems is expected to be easier. The primary data sets shared between the UTM research platform and UTM clients are geographic in nature. Thus, standards published by the Open Geospatial Consortium (OGC) are part of the implementation of the UTM research platform and the definition of UTM requirements.

Operations within the UTM research platform can be visualized through various displays and mobile applications developed at NASA and available for our partners. Figure 5 shows a scene from the UTM simulation lab that uses iPad and laptop displays, and three- dimensional renderings to visualize UTM operations. The UTM research platform is designed to make full use of live, virtual and constructive capabilities. Since all interactions with the UTM core and the USS are governed by APIs, these services are agnostic to which type of component, live virtual or constructive is connected. A more comprehensive description of the simulation capabilities is provided in[ref]

Figure 5: UTM research lab

A. Example test case

The research platform enables NASA and its partners to evaluate many of the steps that are envisioned if sUAS operations were conducted along the concepts and paradigms described in this paper. A sample sequence that is exercised during the field trials is described in Figure 6.

The example describes a delivery operation. The UAS operator submits an operation plan with waypoints or airspace volumes, start and end times, vehicle information and operator data to the UTM research platform that mimics the USS. The USS checks the UAS vehicle registration number (UVIN) and retrieves the vehicles performance data. It then checks the static constraints. If the plan does not violate any of those it checks the dynamic constraints, such as weather, conflicts with other plans and whether the operation appears feasible based upon the aircrafts performance. The USS (instantiated through the research platform) then returns an approval, rejection and/or notifications and constraint information back to the operator. If the operator decides to go ahead with the operation, she initiates it and the operation information will be shared with the UTM system that symbolizes the ANSP portion. When new airspace constraints arise, the operation will be checked again and potentially be terminated or rerouted. In case any failures or problems occur, such as a geo-fence breach or a loss of the command and control (C2) link , the USS will help facilitate contingency procedures. If none of these problems arise the operation will be successfully completed.

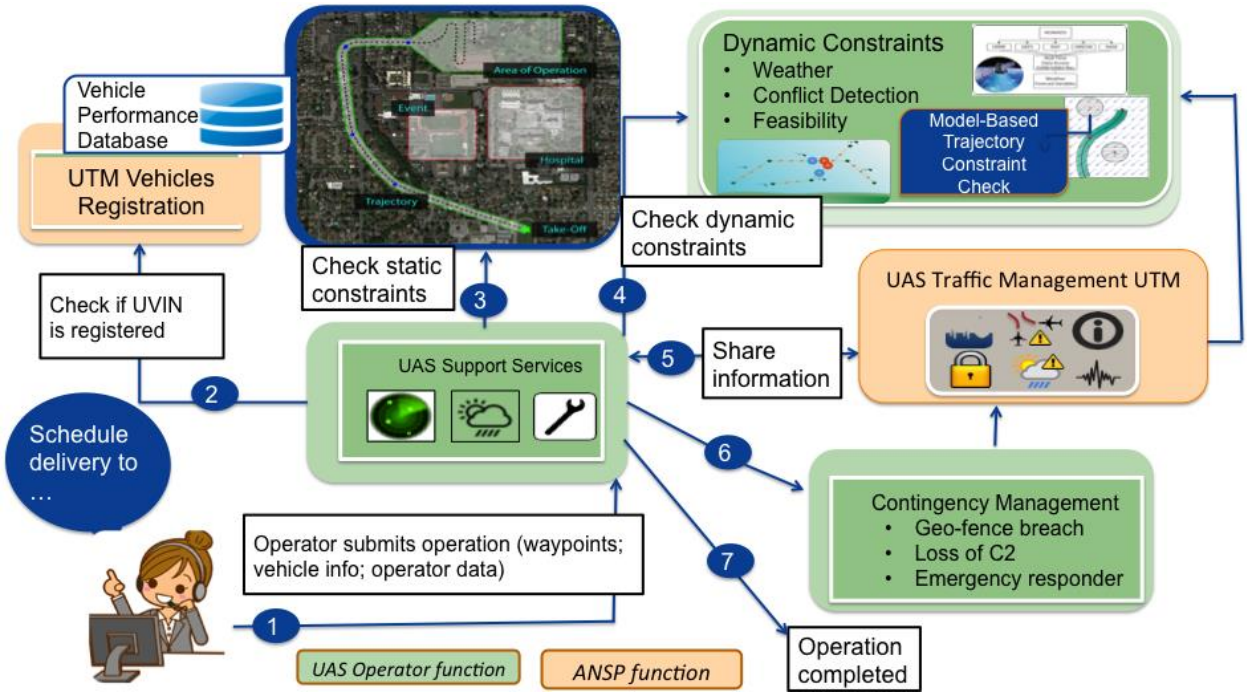

Figure 5: Example Sequence of Events

IV. NASA Development and Testing Approach

Spiral development of the UTM research platform is described in terms of successive UTM TCLs. Each new TCL extends the capabilities of the previous TCL. The number of services provided and types of UAS operations supported increase. As a set, the successive iterations support the entire range of UAS from remotely piloted vehicles to command-directed UAS and fully autonomous UAS. The TCLs are staged based upon four risk-oriented metrics: the number of people and amount of property on the ground, the number of manned aircraft in close proximity to the UAS operations, and the density of the UAS operations. Each capability is targeted to specific types of applications, geographical areas and use cases that represent certain risk levels. The pace of development targets a new UTM TCL every 12–18 months to be tested and evaluated in simulation and field trials. Figure 6 summarizes these capabilities and the test schedule.

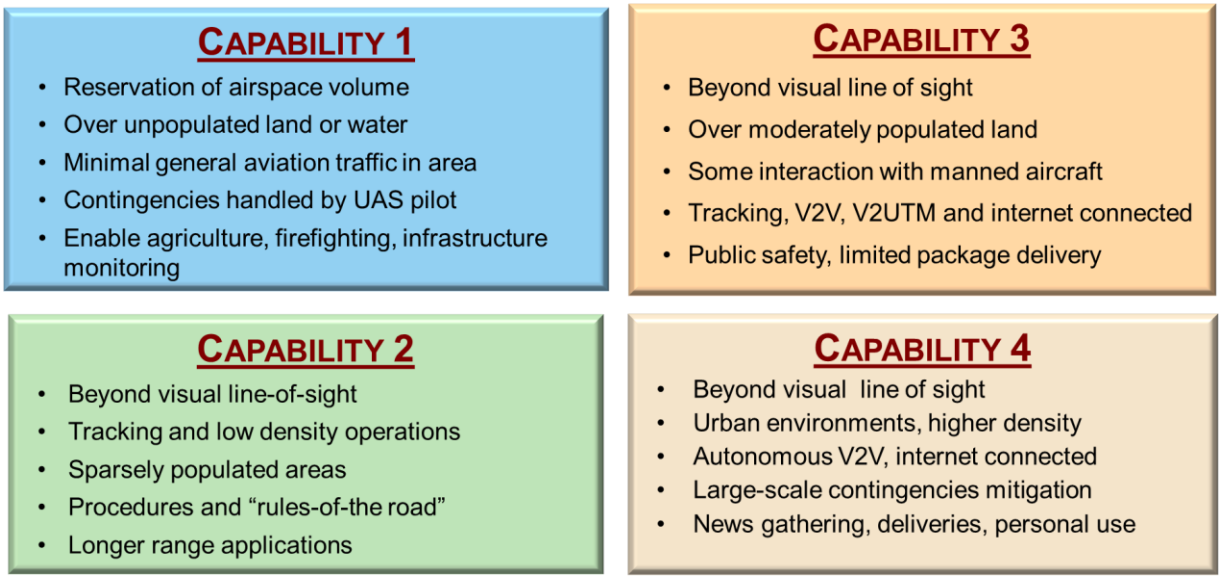

Figure 7: UTM Research Technical Capability Levels

The tests are joint efforts involving NASA and its government, industry and academic partners. NASA assumes primary responsibility for the test coordination, conduct and data analysis and the development of the supporting UTM research platform and its associated APIs and Interface Control Documents (ICDs). Its partners provide vehicles, mission scenarios, advanced data services, surveillance assets, and additional supporting technologies that interoperate with the core UTM research platform.

Capability 1 has been field tested in August 2016 2015 at Crows Landing Airport in California and also at the six FAA UAS test sites in April 2016 where all sites conducted UAS operations concurrently.. It provided interactive planning and constraint management capabilities to manage multiple UAS operations in low risk rural areas within visual line of sight (VLOS). The field demonstration details and results will be published in a separate report. Capability 1 used a simple airspace reservation system to segregate UAS operations with geo-fences in areas of low risk to people and property on the ground and provides user authentication and vehicle registration services. Displays and mobile applications created for the capability were made available to the FAA UAS test sites for further use and evaluation. Capability 2 will extend capability 1 to support beyond visual line of sight (BVLOS) operations and permits increased traffic density by allowing segmented and altitude separated flight plans. The focus will be the development of procedural rules-of-the-road to maintain the safety of beyond line-of-sight operations when UAS operations share airspace. Contingency management will be automated for individual vehicles. UTM research capability 3 will extend capability 2 to permit UAS operations in the vicinity of manned aircraft over moderately populated areas. The focus will be the development of in-flight separation services, trajectory conformance monitoring, and automated contingency management involving multiple vehicles. Capability 4 will include the ability to handle large-scale contingencies involving all UAS vehicles simultaneously. The focus will be the development of procedures and technologies to handle "all land" scenarios or widespread surveillance outages

These TCLs capture the conceptual progression from sparse UAS operations in rural areas to dense UAS operations in urban environments. The primary research capabilities are not meant to capture every possible combination of UAS services. In practice, each specific UAS operation will only be permitted when the necessary services are available and performance requirements are met. These sets of required services do not need to be exact matches of the described TCLs. For example, the requirements to allow multiple UAS to monitor a traffic accident on a crowded rural interstate highway (all within close proximity to each other, and directly above the people and vehicles on the ground below) might need some but not all TCL 4 capabilities that would allow a similar operation in an urban setting.

V. Beyond UTM: Learning From sUAS Operations: Revolution Through Evolution

NASA has been conducting air traffic management related research for decades. In the 1990s, NASA developed a concept called Distributed Air-Ground Traffic Management (DAG-TM). The basic premise of the DAG-TM was a better redistribution of roles and responsibilities among air traffic controller and ground systems, pilot and flight deck, and dispatcher and airline operations center.[8,9,10] Benefit studies indicated that scalability could be achieved through DAG-TM. Borne from DAG-TM were concepts that integrated scheduling, trajectory-based operations and advanced flight deck functions.[11] After ten years of research and development on these concepts the Terminal Sequencing and Spacing (TSAS) research product was transitioned from NASA to the FAA, progressing towards widespread operational implementation by 2020.[12,13] NASA also continued significant research on highly automated airspace operations that would transfer many of the controllers separation responsibilities to ground-side or airborne automation[14,15,16]. The research results indicate that such changes could dramatically improve the efficiency of the airspace operation and certain mixed operations were feasible[17]. However, such a reorganization of responsibilities require such a huge change in the existing roles and technologies of ANSP, flight decks and airline operations centers that it is practically impossible to be implemented directly into the current NAS without tremendous cost and safety risks. The emergence of low altitude UAS operations provides a unique opportunity to examine how the roles and responsibilities and supporting functionalities can be distributed among UAS operators and their automation systems (where there is no pilot in the cockpit), vehicle capabilities, USS which will provide many services such as authentication, track and locate, weather, 3D mapping, etc, and the ANSP. UTM offers an interesting test case for an instantiation of the DAG-TM construct.

Safely enabling large-scale unmanned systems which will operate autonomously and beyond visual line of sight is revolutionary. Perhaps, NASA's build-a-little-test-a-little approach allows to accomplish that revolution through evolutionary steps based on a risk-based approach through four TCLs and yet enables the scalability for anticipated future operations.

V. Conclusion

NASA developed the UTM concept based on lessons learned from aviation history, prior research in Distributed Air-Ground Traffic Management and the emerging need to safely accommodate large-scale UAS operations in the low-altitude airspace. Fundamentally, the UTM principles include – only authenticated UAS are allowed to operate in the airspace, UAS will stay clear of each other, UAS and manned aviation will stay clear of each other, UAS operator and/or systems will have complete awareness of all constraints in the air and all the way to ground, and public safety UAS will have priority. The two main mantras of UTM include (1) flexibility where possible and structure where necessary and (2) a risk based approach where geographical assets and UAS use cases will indicate the performance required to operate in the airspace. UTM is envisioned to provide much flexibility to users by allowing them to connect through a common application protocol interface such that information about all airspace constraints and other operations are known. This allows operators to create a trajectory that is ideal for their business needs while meeting all required constraints. NASA's UTM research evaluates operations at four technical capability levels. These technical capability levels represent increasingly denser and complex environments starting from remote areas to urban airspace. In order to conduct the UTM research, NASA is developing a UTM research platform where UAS operators, UAS support service provider, and air navigation service provider roles; data and information exchanges; and scalable architectures can be examined. The UTM research platform includes functions for authentication, track and locate, weather integration, 3D maps, demand capacity balance, and large-scale contingency management. NASA is working closely with many collaborators which include the FAA, DOD, DHS, DOI, FAA test sites, the FAA's UAS Center of Excellence, industry and academia stakeholders to refine and validate the UTM concept. NASA has conducted preliminary tests of technical capability level 1 in close collaboration with six test sites. UTM provides a path to scalability. There has been much interest from the international community as well.

VI. Acknowledgments

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The support and feedback from the UAS stakeholder community in NASA's UTM efforts to date have been invaluable. NASA and FAA has established a Research Transition Team (RTT) where NASA and FAA jointly identify the UTM requirements and refinements. The FAA's support and participation in the UTM research is instrumental in ensuring the realism and next steps. Further, NASA recognizes significant contributions of many industry and academia stakeholders who have been instrumental in providing continuous feedback and support

UTM research related ideas. We also acknowledge strong relationships with FAA test sites and FAA Center of Excellence to test UTM construct and provide feedback. We also acknowledge on-going discussions and efforts by researchers at NASA Langley, Glenn, and Armstrong research centers. This work is funded by NASA's Aeronautics Research Mission Directorate (ARMD) as part of Airspace Operations and Safety Program (AOSP).

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