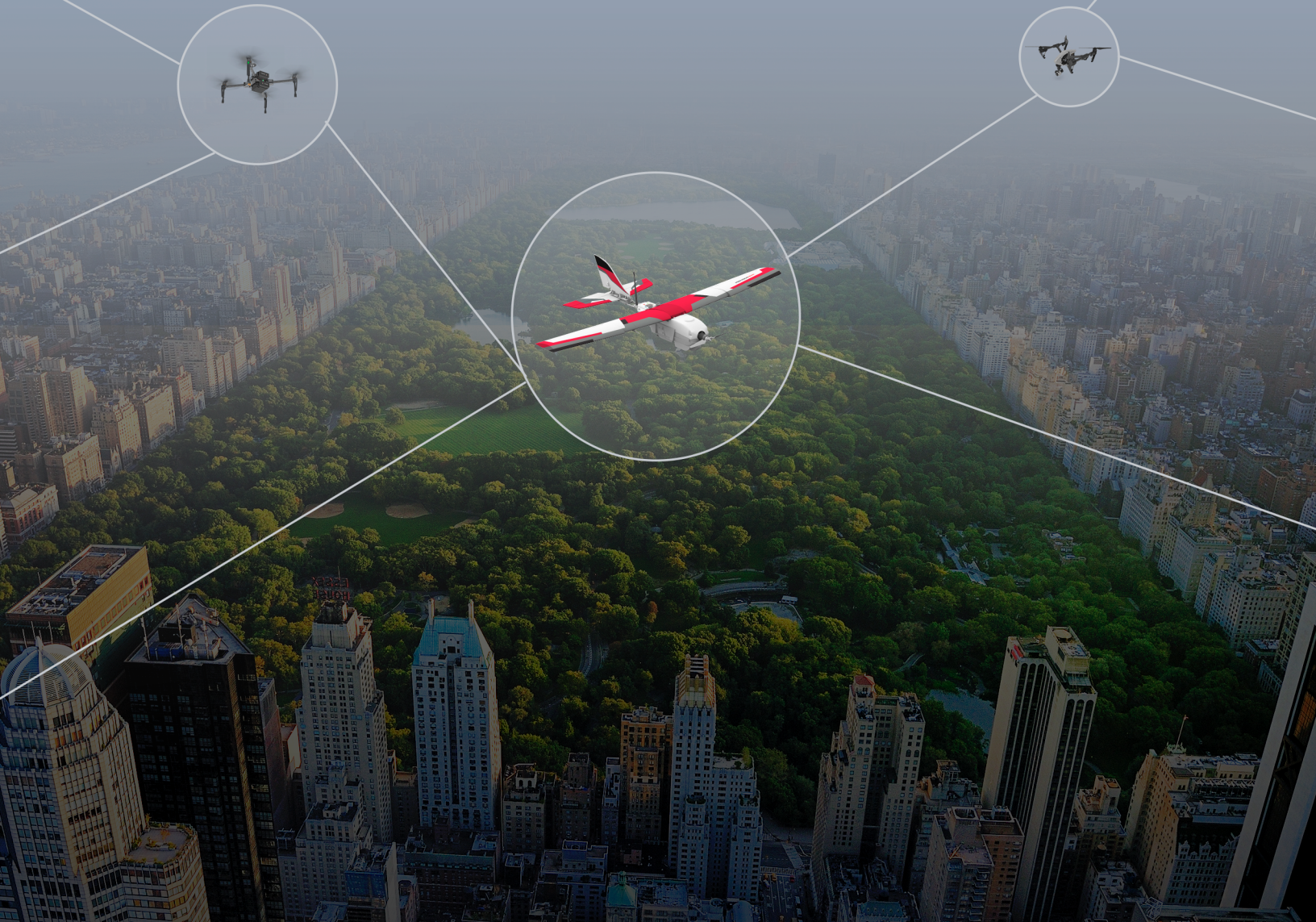# BREAKING THE PARADOX OF SAFETY AND SCALABILITY:

UAS INTEGRATION IN THE NAS

PRECISIONHAWK

ABSTRACT

Current projections indicate that the number of commercial UAVs in the US airspace may grow to as much as 500,000 by 2020. In order to fully enable commercial UAS operations, a scalable solution to airspace integration that accommodates the rapid influx of UAS is crucial, or the system is likely to be unable to respond to demand. Fortunately, novel technologies are available which open up the possibility of meeting both safety and scalability requirements with no need for compromise as a result of fast, reliable data transmission and advanced data processing capability. The remaining action, therefore, is to understand potential failure modes of these technologies and the systems which propose to use them, along with the level of risk any potential failure introduces into the NAS. While predictive analytics and conditional probability models, validated by field experiment where possible, can provide initial estimates to make the safety case for allowing a degree of operation, ultimately the true test is a functioning, nationwide system. The present work proposes such a system, the Unmanned Service Volume (USV), as a subset of Class G airspace; a reasonable first attempt at constructing a scenario in which routine beyond VLOS operation on the necessary scales can be achieved, while minimizing or entirely removing disruption to existing aviation operations in controlled airspace. With the support of experimental results from the Pathfinder Initiative and existing high-quality research, it is our belief that a suitably risk-mitigated concept of operations can be defined in the near-term to enable nationwide USV operation. From there, progress can be made towards achieving the joint goal of the FAA and the UAS industry: a safe, scalable, fully integrated airspace.

1. INTRODUCTION

Unmanned Aerial Systems, or UAS, have the potential to enable new capabilities, increase efficiency, expand innovation, and improve safety impacting public and commercial industries across the United States. Proposed use cases for UAS include such varied applications as public safety and emergency support, control of land or sea-based autonomous vehicles, package delivery, and a wide variety of remote sensing functions from precision agriculture to surveillance of critical infrastructure. To realize the potential of these use cases commercially, it will involve a variety of UAS spanning all sizes, equipage and other potential differences.

The exciting diversity of applications and the unmanned vehicles to carry them out presents regulators worldwide with a weighty task: *How do we routinely incorporate UAS operations into civil airspace without degradation in the overall system safety?* This seemingly simple question has a wealth of underlying intricacy:

1. The only way to ensure zero risk from UAS operation is to not permit operation at all; this is not a viable solution given the potential for public benefit and economic development. What level of risk is acceptable? Is that acceptable level achievable? Under what circumstances?

2. The requirement for routine incorporation recognizes that an air traffic management system must be put in place that can ensure UAS operations can accomplish their missions while meeting any restrictions necessary to achieve the necessary level of safety. What functionality and safeguards must this system have to safely accommodate the anticipated variety of UAS and mission objectives?

3. Current projections indicate that the number of commercial UAS in the US airspace may grow to over 500,000 for small UAS alone by 2020 [1]. Figure 1 offers a sense of scale of manned aircraft operations today, with approximately 10,000 aircraft simultaneously flying in United States airspace on any given mid-day. Safe integration of 10,000s to 100,000s of UAS to this airspace is a daunting task. Solutions to integration issues must also be immediately scalable: capable of handling the range of possible mission objectives of UAS operations for potentially millions of aircraft in the next 10 or 20 years.

Existing regulation varies widely across the globe and is outside the scope of this paper, but an interactive graphic is available [2] which summarizes known international regulations. In the United States, the Federal Aviation Administration (FAA) published a five-year roadmap in 2013 [3] that details the proposed pathway to integration of UAS into the US National Airspace System (NAS). This roadmap recognizes the need for review and revision of many policy, guidance, and regulatory products to specifically address UAS integration into the NAS. Most importantly, it calls for quantitative risk-based assessment to drive these revisions, particularly in the cases of aircraft design requirements applicable to UAS; minimum standards for Sense and Avoid (SAA), Command and Control (C2), and separation assurance as well as training requirements for UAS crew members.
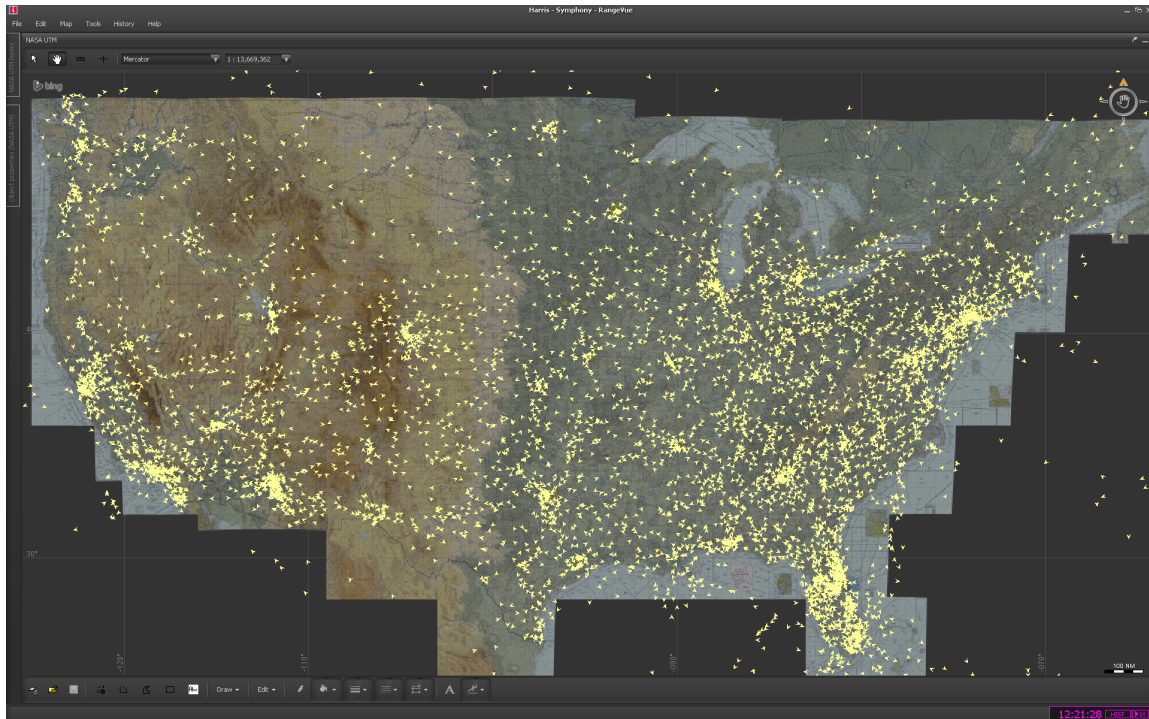
Figure 1: Flight map created from NextGen surveillance data

The necessity for a quantitative understanding of risk, encapsulated in the achievable level of safety, poses a conundrum for researchers and regulators alike. Measurement of the frequency of incident using traditional inferential statistical approaches is generally only possible when operations occur over a very long term. But of course long-term operation will not be truly possible until we understand the achievable level of safety, and regulators working with industry can decide if the achievable level is acceptable. This leaves a couple of possible pathways to resolve the apparent chicken-or-the-egg problem:

1. Create a predictive model for the achievable level of safety based on minimal assumptions and known data (i.e. frequency of fatality due to mid-air collisions depends on the density of air traffic, frequency of fatality due to ground impact depends on population density) [4].

2. Perform limited operations where risk is mitigated by safety-based restrictions or redundancies to permit for "live" evaluation of unknown quantities (i.e. visual line-of-sight operation of a small UAS with a required two-person team of pilot-in-command and observer allows for gathering of data on C2 link vulnerabilities and latency of flight control messages, as well as development of potential emergency procedures) [5].

In general, the best strategy utilizes both of these options to efficiently and effectively assess potential risks. Predictive modeling can guide regulators in decision-making when contemplating allowing a new operation or technology in the field. In-field operation is crucial for both validating and updating the models as understanding evolves. For the latter, the FAA has created a number of opportunities to gather in-field operational data, including the six designated UAS Test Sites [6], the Alliance for System Safety of UAS through Research Excellence (ASSURE) Center of Excellence [7] and the Focus Area Pathfinders Initiative [8]. The Focus Area Pathfinders Initiative in particular was set up to specifically address three

areas identified as being of critical and immediate interest to industries wishing to use UAS capabilities:

1. **Newsgathering:** Visual line-of-sight operations in urban areas (CNN)

2. **Precision Agriculture:** Extended visual line-of-sight operations in rural areas (PrecisionHawk). The Association for Unmanned Vehicle Systems International (AUVSI) identified precision agriculture as the top projected use case for UAS. [9]

3. **Critical Infrastructure Surveillance:** Beyond visual line-of-sight in rural/isolated areas (BNSF Railway).

2. SAFE AND SCALABLE

We must consider the ability of the system to scale to handle an arbitrarily large number of UAS and UAS missions, at reasonable cost, at this time in the regulatory development. While safety is of the utmost importance, it is also true that the imposition of mitigation strategies in the name of ensuring an acceptable level of risk *prior to the effectiveness of the proposed strategy being quantitatively evaluated* can have a significant detrimental impact on the ability of the system to respond to demand. As a specific example, consider the concept of "well clear" for aircraft (manned and unmanned) operating in a given volume of airspace.

Current operational definition of well clear, as indicated in the second FAA Sense-And-Avoid (SAA) workshop [10] defines well clear as the state of maintaining a safe distance from other aircraft that would not normally cause the initiation of a collision avoidance (CA) maneuver by either aircraft. Therefore this is a crucial parameter necessary for the creation of any SAA system; well clear is a "decision threshold" used by the separation assurance function to determine what action is necessary to remain an acceptable distance from other aircraft. The concept is simple but actually defining an appropriate well clear threshold remains elusive. The metric governing loss of well clear could be distance, or time, or perhaps a logical combination of both. Additionally, this threshold could be highly specific for each intruder based on closure rate, performance characteristics, encounter geometry, and other variables [11]. The dependence on multiple variables that are not necessarily spatially symmetric or static in time indicates that the well clear threshold may also lack spatial symmetry and evolve during the flight.

2.1. SIMPLE ≠ OPTIMAL

The temptation at this point, in the name of simplifying the problem, is to represent variables affecting well clear that have complicated functional dependencies on time and space with a single value. This value is generally taken as the value from the larger distribution that represents the worst-case scenario, which is a reasonable choice when the only constraint on system design is safety. But it does mean that for the majority of the cases, the well clear threshold is an over-estimate of what it really needs to be to assure a given level of safety. A simple thought experiment can help to illustrate this: Consider the City of New Orleans, which has a population of approximately 400,000. We can define a circular region of interest around the city with a radius of 10 nm, which encloses about 400 sq. mi. in area (Figure 2):
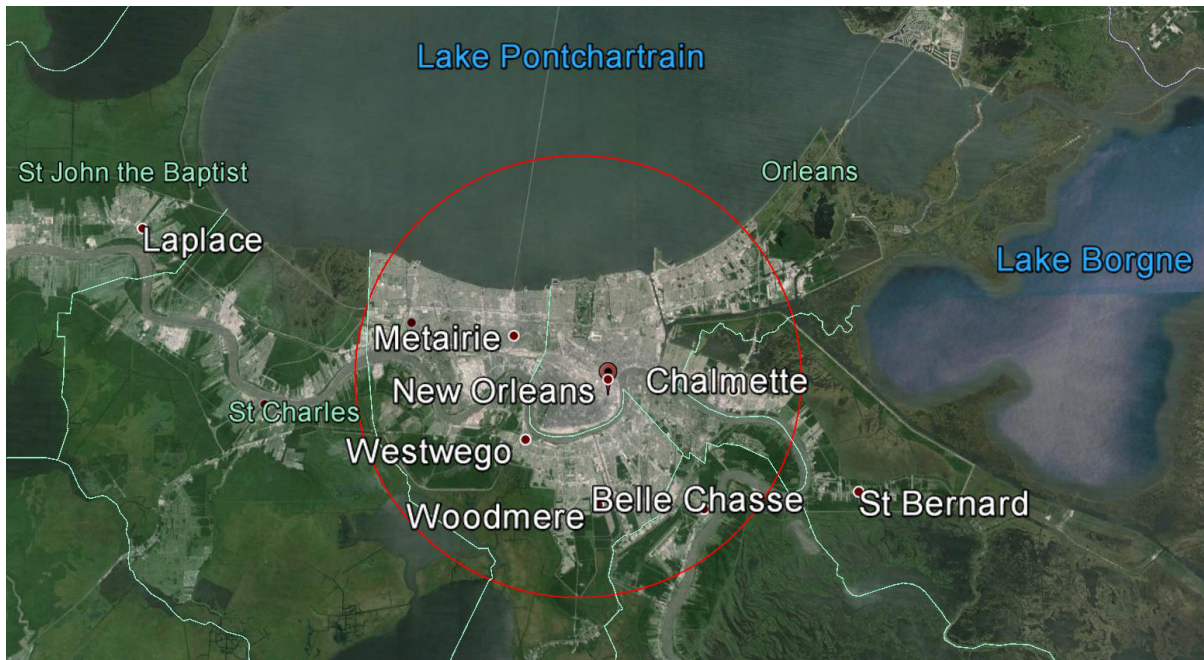

Figure 2: Region of interest around the City of New Orleans. Radius = 10 nm. Enclosed area approximately 400 sq. mi.

Assuming a simplistic, distance-based threshold for loss of well clear has the practical effect of drawing a "hockey puck" around each aircraft (manned or unmanned) operating in the airspace (Figure 3):

Figure 3: Conceptual diagram of simple distance threshold for well-clear. Not to scale. (Inset) Near-Mid Air Collision Zone and possible NMAC trajectory as defined in the text.

If we densely pack these hockey pucks into our region of interest, how many will fit? This represents an *upper limit* on the number of aircraft that can occupy the space at any given time. Considering low-altitude airspace (below 500 ft. above ground level, or AGL) the problem effectively reduces to two dimensions: the reference for defining a collision "event", referred to as Near Mid-Air Collision (NMAC) is also a cylindrical zone of height = 200 ft as shown in the inset for Figure 3. Allowing multiple layers below 500 ft. AGL is therefore unlikely to be possible: The vertical well clear distance will be > 200 ft. by definition and there is still the requirement to avoid structures on the ground.

Figure 4 shows the effect of increasing the well clear distance threshold on the number of available "spots" in the region of interest. Distance thresholds chosen were based to cover the range of existing estimates from simulation efforts [12][1]. As Figure 4 illustrates, the number of aircraft in the sky decreases substantially as the well clear threshold is increased.

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[1] Note that the simulations were not specific to UAS-UAS well clear distance thresholds, so the remainder of the analysis of the thought experiment will refer to "aircraft" and not "UAS".

Region of Interest:
20 Nautical Miles in Diameter (415 Square Miles)

Well clear: 2,500 feet
1855 aircraft

Well clear: 5,000 feet
460 aircraft
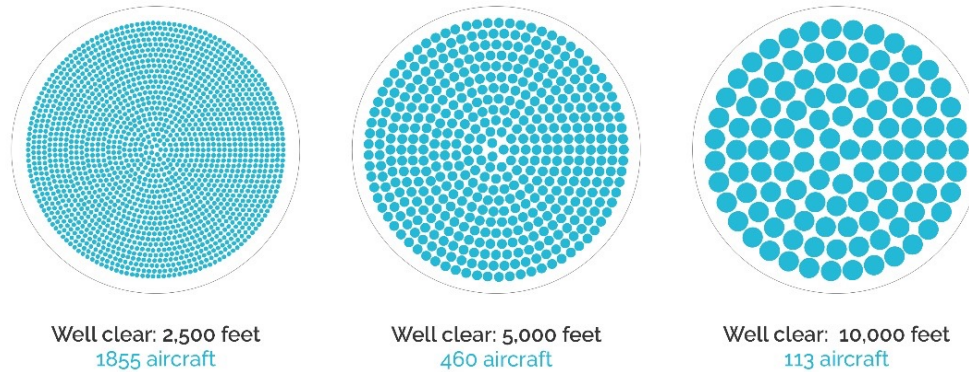
Well clear: 10,000 feet
113 aircraft

Figure 4: Effect of increasing simple well-clear radial distance threshold on the number of aircraft that can be supported within a given low-altitude airspace volume. Maximal packing density assumed.

Recall, also, this simple calculation assumes the maximum density possible; what does that situation actually mean, operationally? Consider an aircraft in the interior of this densely packed scenario. If it moves some horizontal distance, it will create well clear violations amongst any aircraft with well clear thresholds within that distance. Resolving those violations is likely to create additional well clear violations with yet more aircraft. As the airspace boundary in this conceptual exercise is not actually a fixed region, the system would eventually "relax" to a lower density. Therefore it is highly unlikely that the final number of supported aircraft would correspond to the maximum density available. Over populated areas in particular, the requirement for safety is more stringent, but the demand for additional vehicles in the sky for such municipal applications as city infrastructure monitoring, surveillance for law enforcement and emergency response as well as consumer services is correspondingly high.

2.2. TOWARDS THE OPTIMAL SOLUTION

We now have the classic optimization problem of two opposing constraints:

1. Risk-based requirements, which often seek to minimize risk by minimizing the density of UAS in the sky (i.e. minimize the number in a given volume of airspace).

2. The need for scalability, which acts to maximize the number of UAS permitted to fly in a given volume of airspace.

Fortunately, a solution is within our grasp due in part to evolving technologies uniquely suited to enabling a safe and scalable UAS-integrated airspace.

Specifically, the real requirement that needs to be satisfied is one of minimized risk, not one of minimized complexity in calculation or defined dimensions. Remaining with our example of well clear as a crucial parameter driving requirements for any airspace management system that includes UAS, this implies we can maintain a specified risk threshold and still allow for maximum scalability by retaining the multifaceted nature of the calculation. The safety/

scalability requirement is then best satisfied in this context by allowing well-clear to remain a "state," which may have dependencies on an extensive set of parameters rather than reducing it to a simple time or distance threshold that represents the worst case scenario. Technologies that have become prevalent in the last 5-10 years make this approach viable in a number of ways described in the following sections and diagrammed in Figure 5.
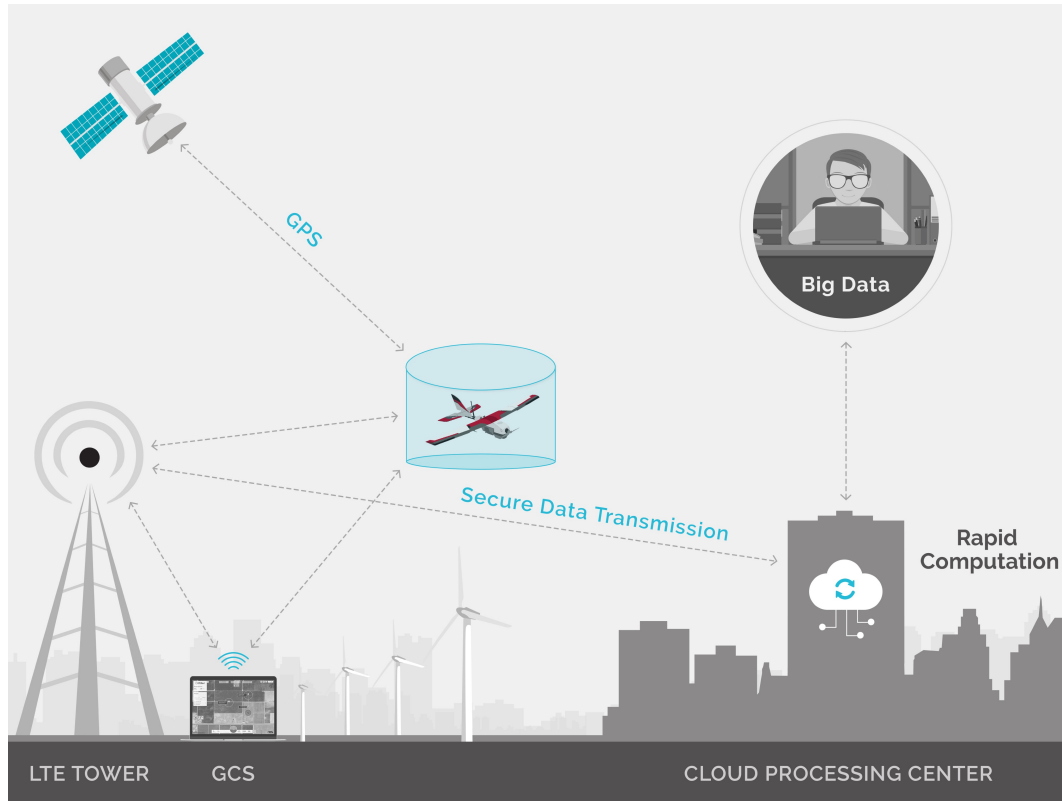

Figure 5: Conceptual diagram linking enabling technologies. The UAV receives positional information from the GPS satellite, which is relayed to the ground control station (GCS) via the C2 link. This data, along with any other relevant parameters, is sent via LTE tower to the cloud processing center to perform any necessary computation for traffic management. Note that UAVs equipped with LTE can communicate directly with the LTE tower to send data. Advanced analytics enable a collective real-time overview of the system.

2.2.1. Increased accuracy and availability of GPS networks

Selective availability, which added pseudo-random noise to GPS signal received by unauthorized users, was disabled in 2000, substantially improving the accuracy of GPS data for civilian use. In addition, advances in aviation certified GPS and augmentation systems, namely WAAS, have also improved the vertical accuracy and integrity monitoring. This, along with the parallel miniaturization of computer electronics has created a corresponding boom in demand for mobile GPS devices and the infrastructures to support them. Therefore data layers containing positional information over time can be created accurately and rapidly.

2.2.2. Increased capacity, speed and security of data transmission

The increasing availability of LTE and other high-capacity networks makes it possible to send larger parameter sets from low-altitude traffic rapidly and securely to a cloud-based processing engine to perform the necessary calculations. The security advantages of a cellular based airspace management system have been diagrammed in a recent whitepaper by Google [13].

2.2.3. Increased capability and robustness of data processing and storage infrastructure

In order for any separation assurance service, which depends on the accurate evaluation of the well clear state, to be effective, it must be able to perform the calculation and return an actionable result to the aircraft with minimal latency. In addition to enhanced performance, processing engines are also now able to achieve high levels of reliability, ensuring minimal downtime and no single point failures for critical systems.

2.2.4. Novel developments in "Big Data" analytical approaches

As the number of UAS grows, so will the quantity of operational data fed back to any airspace management system. In addition to efficiently performing low-latency calculations to support real-time operations, this data can be used to aid in decision-making for system level concerns: quality metrics, statistical examination of collective behavior, large-scale predictions and more sophisticated alerting, appropriate collation of data to provide to human analysts and updating of risk-based models (the latter being especially important in early stages of operation). The current interest in novel predictive analytics and data science strategies has created a host of tools and algorithms to support these applications.

There is a perception that simplicity lends itself well to regulation, but regulators can still work with complex definitions by continuing to focus on risks and outcomes rather than setting specific quantitative limits, similar to current procedures for manned aircraft. For the present example, further work [11] based on the FAA workshop report suggests that when defining the well clear standard, interoperability implementation principles should be considered, all of which are desired outcomes that do not speak specifically to the need for a simple definition. Namely, separation between aircraft should be such that the system:

1. Avoids corrective maneuvers from intruders,

2. Minimizes traffic alert issuances, and

3. Does not result in excessive concern for VFR pilots in the vicinity

While interfaces between operations in uncontrolled airspace and those in controlled airspace will need to be elucidated so as not to require any significant changes to existing controlled airspace procedures, the listed considerations could certainly be satisfied by the type of technology-enabled system described above.

In current aviation practice for manned aircraft, the risk is mitigated by relying on the expertise of the pilot and air traffic controller (for controlled airspace). Understanding where and when it is appropriate to rely on technology in this scenario is a major challenge for policymakers because years of operation have led to a degree of understanding of the various failure modes (as well as substantial observational data to evaluate level of safety). As described in the Introduction, ultimately the only way to demonstrate safe operation is to operate, safely at a large enough scale that the data collected during the operations is sufficiently representative to be useful for informed decisions. Creating such a large-scale operation will require an incremental course of action, and a number of steps have already been taken (i.e. Section 333 exemptions) or will occur in the near future (proposed Part 107). In order to propel the industry forward, subsequent steps must begin to expand beyond the limits of visual line-of-sight small UAS operation so that all stakeholders can reach the ultimate goal of safe and scalable full integration.

In the next section, an approach for enabling near-term nationwide operation that satisfies the dual constraints of safety and scalability is presented.

3. UNMANNED SERVICE VOLUME: A WAY FORWARD IN THE NAS

In order to make large-scale beyond visual line-of-sight operation routinely possible, a workflow for UAS missions is required for all aspects of the flight, from flight planning, through in-flight monitoring to separation assurance and collision resolution that ensures within an acceptable level of risk that the UAS can accomplish its mission and safely land.
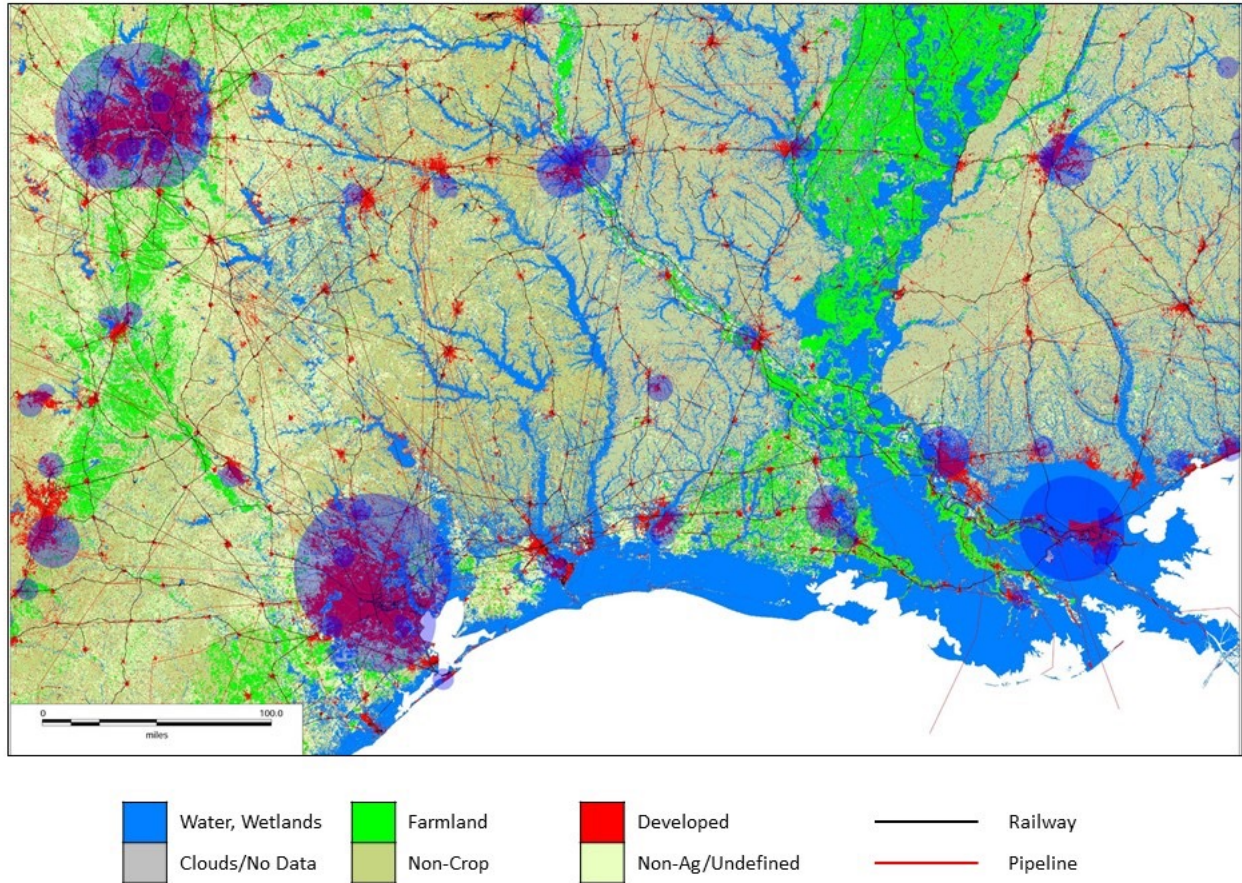
To satisfy the need for scalability in the future, this workflow will have to function without significant changes across multiple existing airspace classes, supporting an assortment of equipage types and performance characteristics, while enabling different mission deliverables (i.e. not necessarily only point-to-point travel). This means that that early stage decisions must be made carefully to avoid creating additional constraints that would require major changes as the system expands into new scenarios. Restrictions against operations that may be allowable in the future should be in place only until sufficient data has been collected that regulators have the ability to make risk-based decisions, not because anything in the underlying workflow infrastructure prevents these operations from occurring.

The proposed Unmanned Traffic Management (UTM) system currently under concept development by NASA, in collaboration with a large number of industry participants, is an excellent example of just such a potential workflow infrastructure. The design philosophy incorporates lessons learned from air traffic management in manned aviation, and proposes the development of a number of potentially valuable services such as "airspace design, corridors, dynamic geofencing, severe weather and wind avoidance, congestion management, terrain avoidance, route planning and re-routing, separation management, sequencing and spacing, and contingency management" [14]. Additionally, it adopts the perspective that in an end-state, human operators will not be required to monitor every vehicle continuously, reserving human intervention for top level tasks.

In order to realize this vision while mitigating unknown risk, we can define a UAS service volume within a subset of Class G airspace with low population density that extends nationwide, but initially restricts operations to areas that also qualify as one of the following:

1. Areas designated for agricultural use

2. Areas containing infrastructure and rights of way such as railroads or pipelines

This service volume has the advantage of addressing two of the three critical business cases identified for the Focus Area Pathfinders Initiative: Precision agriculture and infrastructure surveillance (the third focus area, news-gathering, is likely to be majority covered under the Part 107 regulations). Allowing beyond VLOS operations in this "unmanned" service volume (USV), with some additional UTM type capabilities, therefore also accomplishes an important near-term goal for the UAS industry within the United States. A visualization of the USV for an area in Texas and Louisiana is shown in Figure 6:

Water, Wetlands

Clouds/No Data

Farmland

Non-Crop

Developed

Non-Ag/Undefined

Railway

Pipeline

Figure 6: Suggested Unmanned Service Volume (shown here for Texas and Louisiana) would be comprised of areas in Class G airspace (other classes indicated by blue circles) designated as farmland and other undeveloped areas, as well as critical infrastructure. Non-Crop designates areas such as forests and shrubland, Non-Ag/Undefined indicates the area has no agricultural designation.

Similar visualizations are shown below for Iowa (Figure 7), for the area centering on the IAD-DCA-BWI airport cluster (Figure 8) and the DCA-JFK corridor. As expected, with substantially more development and the presence of three major airports the space available is more restricted than the Iowa example. However, pathways are still available that meet the suggested definition.
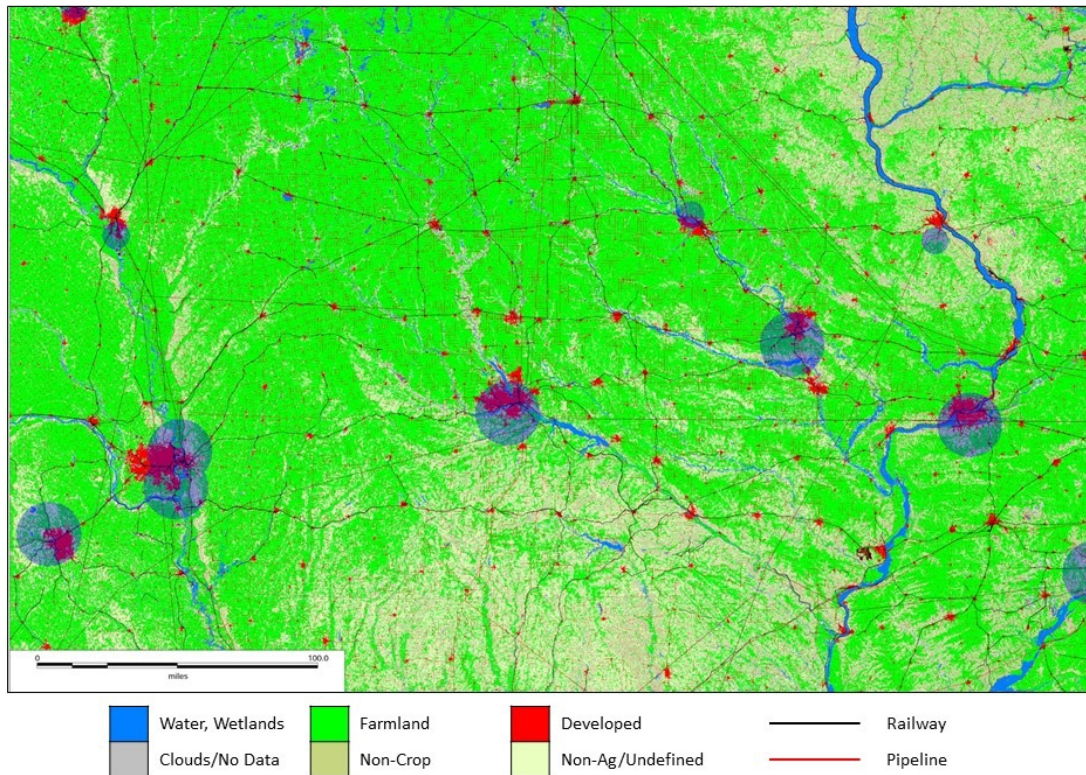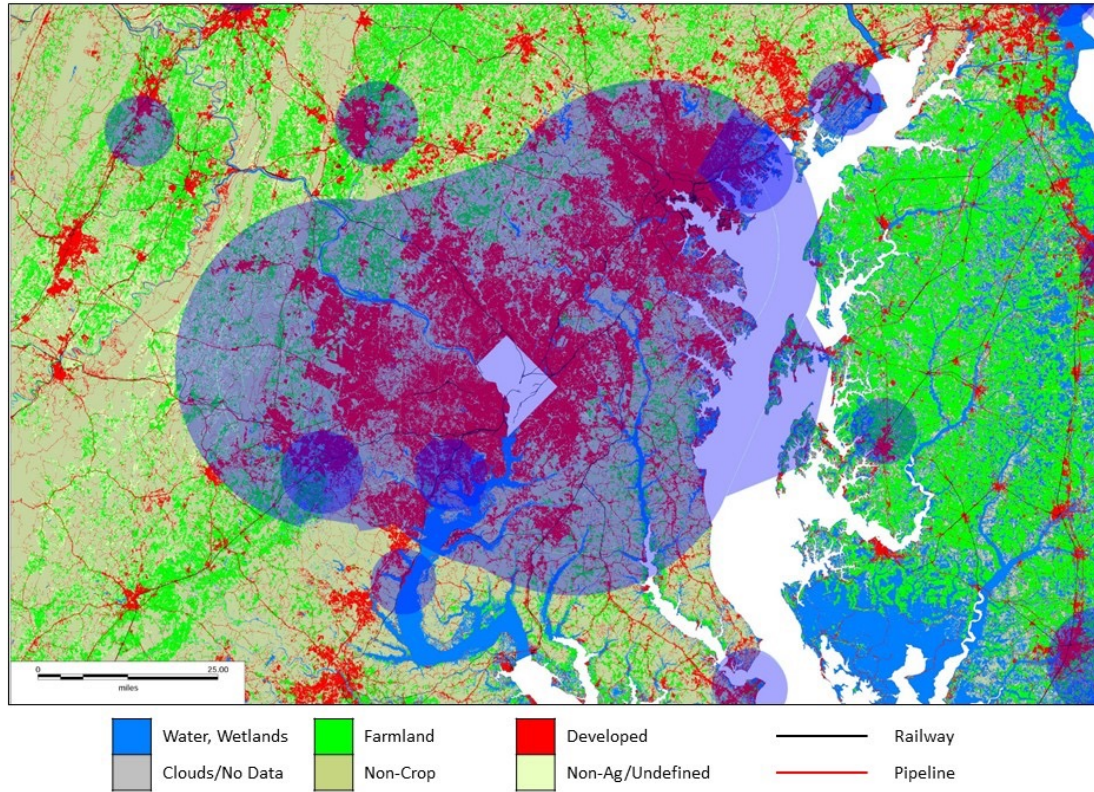
Figure 7: USV as in Figure 6 for Iowa

Legend:
- Water, Wetlands
- Clouds/No Data
- Farmland
- Non-Crop
- Developed
- Non-Ag/Undefined
- Railway
- Pipeline

Figure 8: USV as in Figure 6 for the IAD-DCA-BWI cluster.

Legend:
- Water, Wetlands
- Clouds/No Data
- Farmland
- Non-Crop
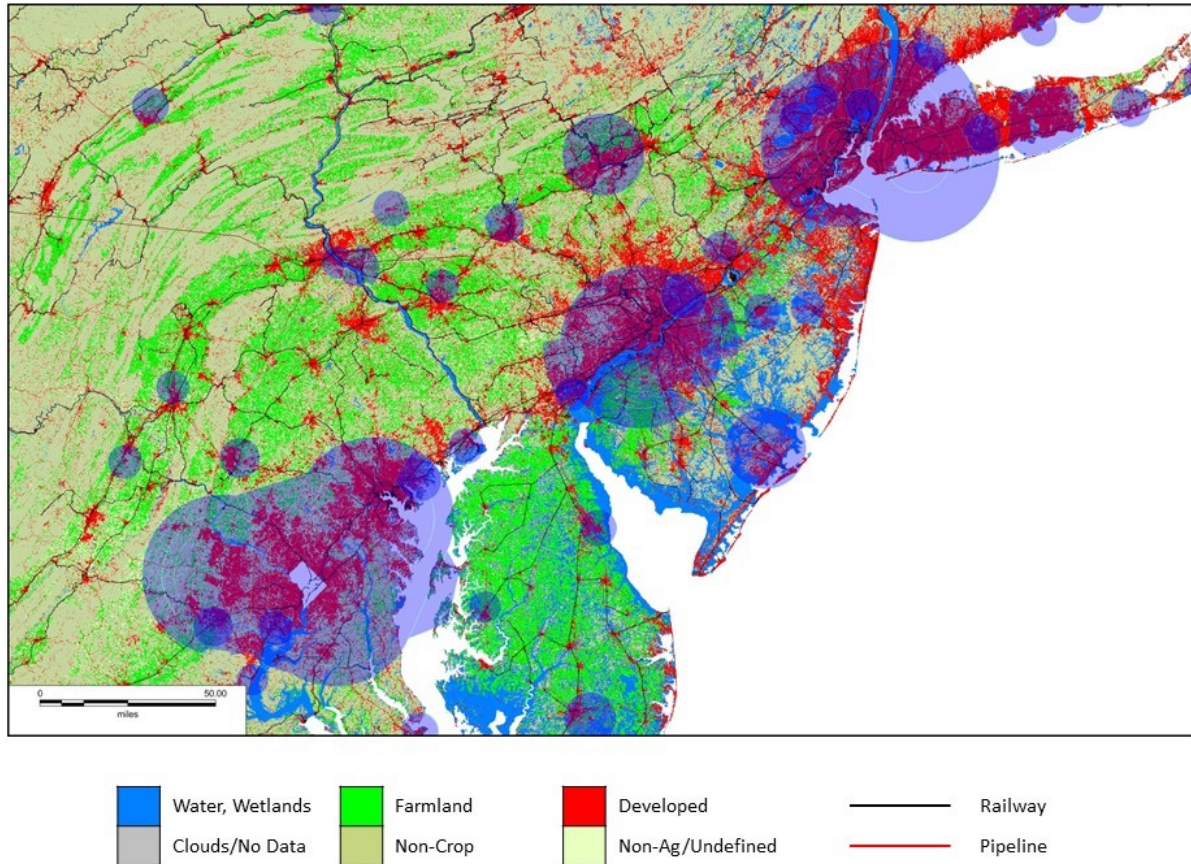- Developed
- Non-Ag/Undefined
- Railway
- Pipeline

Figure 9: USV as in Figure 6 for the DCA-JFK corridor

Constraints on this service volume for UAS are consistent with those presently in existence for VLOS operation, but the introduction of a traffic management system enables beyond VLOS applications. Because this traffic management system will depend crucially on the technologies described above, data gathering regarding risk and potential failure modes on a large operational scale will be necessary to inform future efforts to integrate into controlled airspace. This operation within a subsection of Class G allows for this data gathering to begin without having to disrupt services within controlled airspace in keeping with stated integration goals from the FAA [3]. For example, as industrial applications planned to occur within the USV are the focus of the currently ongoing Pathfinder Initiatives, data from those trials can be utilized to provide initial estimates of risk for safety panels.

3.1. LATAS: TECHNOLOGY IN-THE-LOOP

One final piece of the puzzle is needed to complete the picture of initial nationwide civilian access to beyond VLOS operation: a cohesive platform that integrates the necessary technologies. PrecisionHawk has developed LATAS the platform, a combined set of geospatial, software, and hardware tools to facilitate safe UAS operation. Operating over the world-wide cellular networks and satellites, the LATAS platform integrates technologies enabling scalable airspace management to provide necessary services such as sense and avoid, geofencing and aircraft tracking, into a service package for commercial and recreational drone operators and may evolve into a system for regulators and air traffic controllers. Engineered with privacy

and security protections, LATAS promotes compliance with privacy and data security requirements. A map of the LATAS ecosystem is diagrammed in Figure 9.

Specifically, LATAS is currently comprised of:

1. Geospatial layers accessible through an API that can be integrated into a drone or ground control station to enhance the situational awareness of the UAS operator.
    a. Ground Data: Buildings, Trees, Terrain, Towers
    b. Airspace Data: Boundaries, Temporary Restrictions, No-Fly Zones
    c. Traffic Data (Live Feeds): Manned/unmanned aircraft

2. Low-cost cellular-based hardware modules that can be installed on even small UAS without incurring a significant loss of power or adding substantial weight.
    a. Modules use GPS to yield accurate positional tracking of UAS
    b. UAS OEMs have the option of incorporating the LATAS module with their autopilots to enable autonomous response to traffic management system advisories when regulation permits.

LATAS may evolve to include additional surveillance sources (e.g., position from the GCS), critical level network capabilities, and further flight information as required to meet system safety requirements.
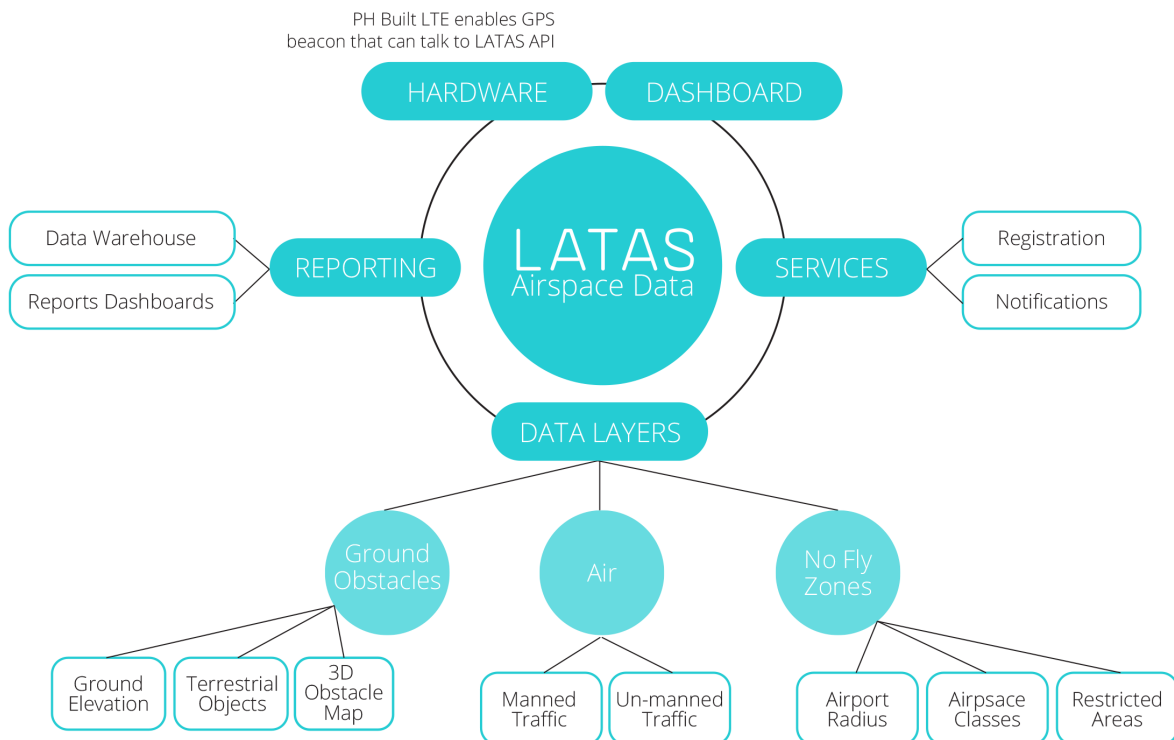

Figure 9: Top level LATAS ecosystem diagramming the various services provided and current inputs.

3.2. QUALITY DATA FOR QUALITY SITUATIONAL AWARENESS

As described above, data quality is of paramount importance. Data layers available through the LATAS system will be designed to meet or exceed the safety-based requirements, once defined, on accuracy, timeliness and reliability to support the needs of UTM.

The air traffic surveillance data provided by Harris is the same data that is used by the FAA for Air Traffic Control (ATC). With direct connectivity to over 425 FAA radar systems, 650 FAA ADS-B ground stations, 35 ASDE-X airport surveillance systems, and 3 large Wide Area Multilateration (WAM) systems, the Harris dataset consists of the largest air traffic surveillance data network in the world. Meeting the high criticality and availability standards of the FAA, the data provided by Harris is the same data that appears on ATC displays and in every cockpit equipped with ADS-B technology as part of the Traffic Information System – Broadcast (TIS-B) service.

3.3. LTE NETWORK CONSIDERATIONS

Several tasks must be accomplished in order to create a viable concept of operations in the USV described above. Probably the most significant infrastructure issue to be addressed is one of LTE network availability; traditionally, the low population density areas proposed as part of the USV are those where network coverage is poor. With UAS creating a new user base beyond mobile phones or tablets for LTE technology, network planning can be readjusted to meet this new demand.

In addition to availability, it is also important to understand the regulatory perspective on utilizing cellular technology for this task. This will require input and understanding from both the FAA Spectrum Office and the FCC to evaluate current regulations and changes (if any) that will need to be made around cellular use from existing applications.

4. NEXT STEPS: CLEARED FOR TAKEOFF

In summary, this review suggests that safety and scalability are equivalently important constraints to consider when designing an integration approach for UAS in the NAS. This does not imply safety is less important than scalability, only that scalability of the system must be equally considered in any proposed design – or the system is likely to be unable to respond to demand and therefore in need of redesign sooner than anticipated, which represents a significant burden for regulators and industry alike.

Fortunately, technologies are available which open up the possibility of meeting both safety and scalability requirements with no need for compromise as a result of fast, reliable data transmission and advanced data processing capability. PrecisionHawk's LATAS system blends these technologies into a seamless integrated whole, providing necessary services to traffic management systems like UTM as well as end-users of those systems.

The remaining action, therefore, is to understand potential failure modes of these technologies and the systems which propose to use them, along with the level of risk any potential failure introduces into the NAS. While predictive analytics and conditional probability models, validated by field experiment where possible, can provide initial estimates to make the safety case for allowing a degree of operation, ultimately the true test is a functioning, NAS-wide system. The critical service volume proposed in the previous section represents a reasonable first attempt at constructing a scenario in which routine

beyond VLOS operation on the necessary scales can be achieved, while minimizing or removing disruption to existing aviation operations in controlled airspace.

With the support of experimental results from the Pathfinder Initiative and available high-quality research performed over many years, it is our belief that a suitably risk-mitigated concept of operations can be defined in the near-term to enable nationwide USV operation. From there, progress can be made towards achieving the joint goal of the FAA and the UAS industry: a safe, scalable, fully-integrated airspace.

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