Inert and Alert: Intelligent ADS-B for UAS NAS Integration

Concept of Operations

Executive Summary

Over the course of the last few years, Automatic Dependent Surveillance – Broadcast (ADS-B) has been debated in articles and industry panels as to whether it will be a suitable cooperative surveillance solution to prevent mid-air collisions between manned and unmanned aircraft.

ADS-B technology is an international aircraft surveillance standard and is one of the FAA's NextGen initiatives to increase the safety of the National Airspace System by replacing sole dependency of legacy radar tracking with the much-improved tracking capabilities provided by the satellite-based GPS system. In the United States, the ground based infrastructure has been built out and is fully operational, while any aircraft that will fly in controlled airspace is required to have the equipment onboard by January 1, 2020. Internationally, various forms of ADS-B mandates exist in Australia, New Zealand, the EU, Hong Kong, Indonesia, Singapore, Sri Lanka, Taiwan, and Vietnam with several other countries in the process of rulemaking. In the fall of 2017 the first of a constellation of satellites was launched to bring space-based ADS-B to Air Navigation Service Providers (ANSPs) globally without the need for a ground-based system like the U.S. has deployed.

A potential problem comes from the speculative numbers of Unmanned Aircraft Systems (UAS) a.k.a. "drones" that could be flying in our airspaces in the next decade or so. A recent paper published by MITRE Corporation's Center for Advanced Aviation System Development (CAASD) titled "ADS-B Surveillance in High Density SUAS Applications at Low Altitudes[i]" explores a scenario where 14,000 small UAS (sUAS) are operating at low altitude within a 32-mile diameter airspace. In this scenario, MITRE modeled the sUAS transmitting on UAT at a transmission power of 1 Watt and broadcasting at an interval of once every 10 seconds. Even in this reduced transmission scenario, the MITRE study found that "initial results for an SUAS scenario with high density suggest a measurable increase in ADS-B co-channel interference that may negatively impact aircraft-to-aircraft ADS-B performance between civilian aircraft."

Several industry articles, panelists, and speakers have used this report to indicate that ADS-B is an untenable solution for a future safety technology for UAS, but have offered no alternative. Yet the MITRE report goes on, concluding "Several opportunities exist to mitigate the impact of SUAS use of ADS-B by refining the messaging structure, information transmit updates, output power, and other strategies. However, unconstrained use of current ADS-B for large fleets of closely clustered SUAS does not appear advisable."

In previous articles[ii], uAvionix has advocated for the use of low-power ADS-B for UAS at transmission powers ranging from 0.01W-1W, at which levels a follow-on report by MITRE CAASD titled "ADS-B Surveillance System Performance with Small UAS at Low Altitudes[iii]" indicates may be acceptable according to CAASD simulations.

This Concept of Operations (CONOPS) document outlines an additional spectrum mitigation approach called "Inert and Alert (I&A)," which is an intelligent ADS-B transceiver system which mitigates concerns raised by MITRE CAASD, regulators, and industry by monitoring the UAS ownship position relative to controlled airspace, TFRs, altitude, and other aircraft conditions in order to ONLY transmit when transmission is determined to be necessary for safety or compliance purposes.

Through a combination of an onboard database, communications with the UAS autopilot, GPS position, receipt of ADS-B, ADS-R, TIS-B transmissions, receipt of Mode A/C/S transmissions, integration with other onboard sensors such as primary radar, and monitoring of FIS-B transmissions, the I&A ADS-B Transceiver will remain dormant in "listen mode" only until one or more of the following conditions is met:

- The UA detects nearby traffic within 7NM and within 2000ft of altitude.
- The UA exceeds 400ft Above Ground Level (AGL) in altitude.
- The UA breaches or approaches Temporary Flight Restriction (TFR) boundaries.
- The UA breaches or approaches controlled airspace boundaries.
- The UA enters a "Lost Link" state where positive control by the PIC is compromised.
- The Remote Pilot-In-Command (PIC) manually commands transmission.

The scenarios identified above and described in this CONOPS require various forms of complexity and integration with onboard systems ranging from "standalone" capabilities requiring no integration to full integration with the autopilot and/or other sensors.

ADS-B Background

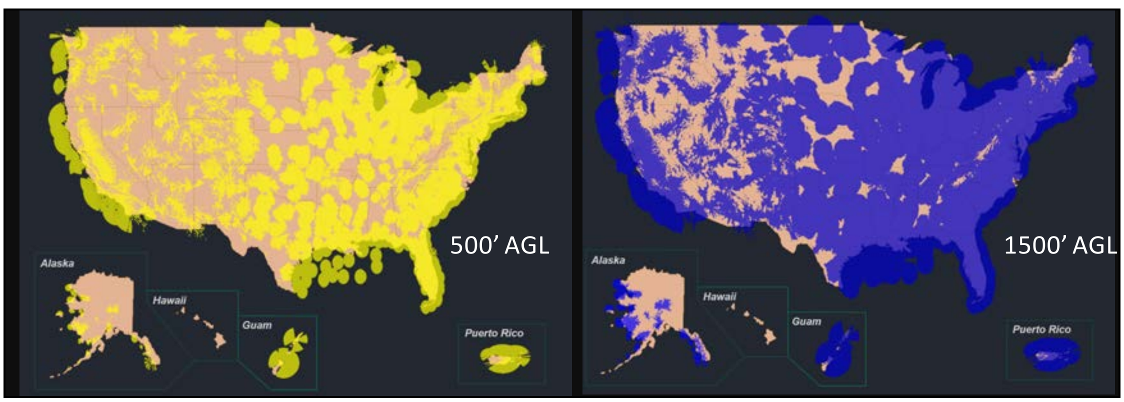
Automatic Dependent Surveillance – Broadcast (ADS-B) technology is an international aircraft surveillance standard and one of the FAA's NextGen initiatives to increase the safety of the National Airspace System. ADS-B is a precise satellite-based surveillance system. "ADS-B OUT" uses GPS technology to determine an aircraft's location, airspeed and other data, and broadcasts that information directly to other aircraft and to a network of ground stations, which relays the data to air traffic control (ATC) displays and to nearby aircraft equipped to receive the data via "ADS-B IN." In the United States, operators of aircraft equipped with ADS-B IN can receive weather and traffic position information delivered directly to the cockpit.[iv]

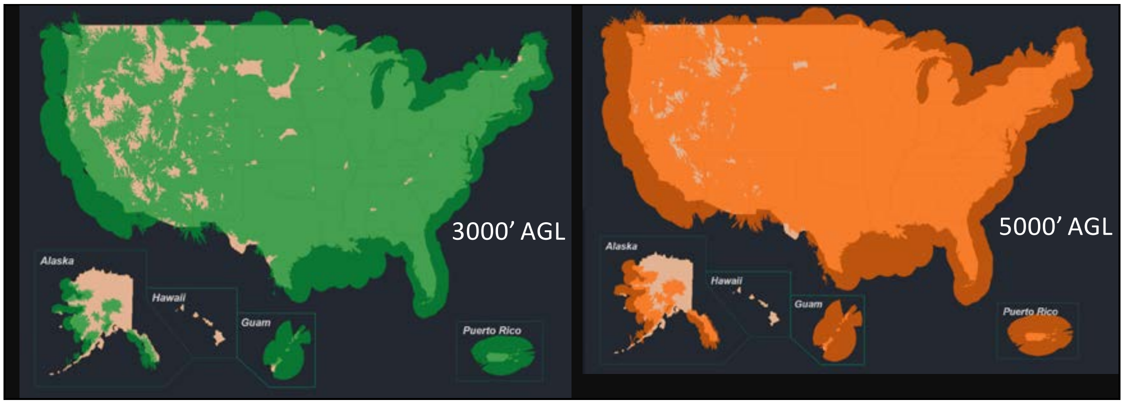
Also, in the United States, the ground-based infrastructure has been built out and is fully operational, while any aircraft that will fly in controlled airspace is required to have the equipment onboard by January 1, 2020. Internationally, various forms of ADS-B mandates exist in Australia, New Zealand, the EU, Hong Kong, Indonesia, Singapore, Sri Lanka, Taiwan, and Vietnam with several other countries in the process of rulemaking. In the fall of 2017 the first of a constellation of satellites was launched to bring space-based ADS-B to Air Navigation Service Providers (ANSPs) globally without the need for a ground-based system like the U.S. has deployed.

The benefits of ADS-B are derived from its increased location precision and transmission rate, as compared to Air Traffic Control (ATC) radar, as well as its air-to-air capability to allow aircraft to communicate and display local air traffic directly without ground system intervention, increasing situational awareness and “see and avoid” capabilities.

The primary intent for the ADS-B system is to increase the capabilities of the NAS and ATC system, and as such, the initial coverage deployments were designed to match existing ATC radar coverage, which varies by location and altitude. Generally speaking – ADS-B ground system coverage can begin at the surface but may not be available until higher altitudes. See Figure 1 for the FAA’s coverage map for ADS-B at various altitudes.

Figure 1: ADS-B Coverage Map at Various Altitudes[v]



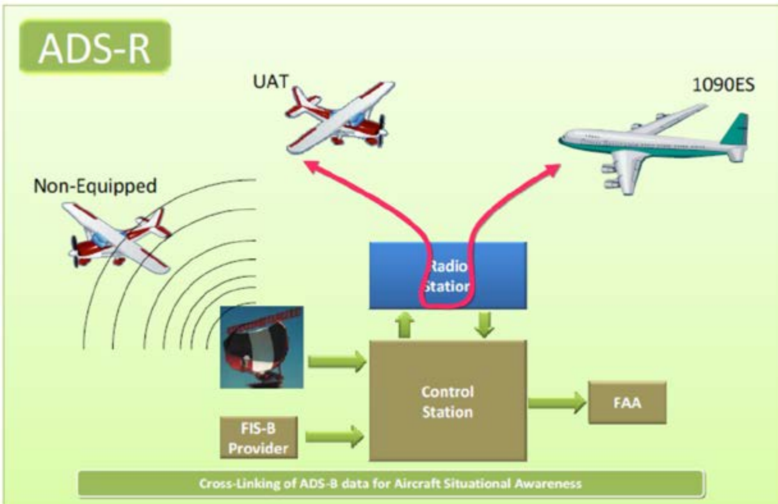


For this reason, the utility of the ground-based ADS-B system onboard UAS flying below 500ft AGL is somewhat limited if dependent upon the ground infrastructure for service or communication. However, there is significant potential for the technology to be used in an air-to-air context as a means to increase safety for both UAS and manned aircraft to communicate positions for increased situational awareness.

In addition, the dual-frequency or dual-band nature of the U.S. ADS-B system is a complicating factor. In the U.S., all aircraft who will fly above 18,000 ft. Mean Sea Level (MSL) are required to equip with 1090MHz ADS-B Out frequency, while those that exclusively remain below 18,000 MSL can choose to equip with either 1090MHz or 978MHz ADS-B Out frequency. The 978MHz frequency is also called Universal Access Transceiver (UAT). UAT was devised to mitigate frequency congestion concerns in the 1090MHz frequency, which is also used for the air-to-air Traffic Collision Avoidance System (TCAS). This dual-band nature inhibits some of the air-to-air benefits of the system since two aircraft on the separate frequencies will not "hear" one another's position reports. To mitigate this, many ADS-B IN avionics listen on both 1090MHz and the 978MHz frequencies, even if they broadcast ADS-B OUT one frequency only. In addition, the ground based system also includes a component called Automatic Dependent Surveillance – **Rebroadcast** (ADS-R) which will translate and rebroadcast a position report from one frequency to the other if it detects two aircraft in proximity to one another operating on different frequencies. ADS-R is dependent upon coverage from the ground stations for both aircraft and also incurs additional latency associated with the receipt, translation, and rebroadcast of the signal.

See Figure 2 for a graphical depiction of ADS-R.

Figure 2: Automatic Dependent Surveillance - Rebroadcast (ADS-R)[vi]



ADS-B Safety Benefits for UAS

When looking for a solution to increase situational awareness between both manned and unmanned operations, ADS-B at first glance appears to be a good choice. The availability of an existing standard, existing equipment, mandatory equipage requirements, and decreasing Size, Weight, Power and Cost (SWaP-C) have contributed to many early UAS operations and testing to include ADS-B equipment. The non-encrypted nature of the protocol lends itself to private ADS-B receive networks to augment existing coverage, and the technology has become a component of many Detect/Sense and Avoid (DAA/SAA) systems and tests. Some examples:

- Two of the FAA's Pathfinder Initiatives (PrecisionHawk and BNSF Railway) leveraged ADS-B in their deployment of systems as one of many mitigations to reduce the risk of Beyond Visual Line of Sight (BVLOS) operations.
- Under the FAA's UAS Center of Excellence – at least two of the initial task orders are studying ADS-B as a component of the overall surveillance and DAA solution. North Carolina State University is leading a "Surveillance Criticality" study for the COE – and the University of North Dakota is leading a "Small UAS DAA" study.
- The FAA has signed and completed a Collaborative Research and Development Agreement (CRDA) with uAvionix and others to study low-power ADS-B avionics.
- Google and Amazon.com have promoted ADS-B and "ADS-B like" concepts in their public communications regarding future airspace usage concepts.

- NASA's UTM and UAS Integration into the NAS have both incorporated ADS-B as a key component to system testing and flight demonstration activities.

ADS-B Spectrum Congestion Concerns

If ADS-B technology is promising in this space, the objective then becomes how to leverage the system without degrading the existing and intended use – to aid ATC in keeping the NAS safe while simultaneously increasing density and capacity, a key objective of the FAA's NextGen programs. It is noteworthy to mention the increased density and capacity projections did not include any projections for UAS.

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uAvionix proposes a concept called **Inert and Alert (I&A).**

Inert and Alert (I&A) Concept

The MITRE CAASD report modeled a scenario consisting of a population of 14,000 sUAS at or below 230ft AGL uniformly distributed within a 32 NM diameter airspace. This translates to about 17 UAS aircraft per square mile. UAS UAT ADS-B transmissions were occurring at 10 second intervals with a 1 Watt transmitter and found "initial results for an SUAS scenario with high density suggest a measurable increase in ADS-B co-channel interference that may negatively impact aircraft-to-aircraft ADS-B performance between civilian aircraft. … Lower numbers of ADS-B-equipped SUAS have a limited effect and the sensitivity increases as density of SUAS increases."

The density scenario described above may or may not be realistic, but it does highlight a "breaking point" within the system. The challenge then becomes how to reduce the number of UAS transmitting, and to transmit at a lower power setting.

The I&A concept employs multiple strategies to reduce frequency congestion concerns. At its highest level, these can be summed up as follows:

1. Low Power (1/2 watt) transmissions which have limited range and therefore limited impact on NAS spectral capacity.
2. Intelligent monitoring of multiple data sources to only transmit when required.

Narratively, the I&A system monitors its position relative to controlled airspace, TFRs, and altitude and other aircraft in order to ONLY transmit transmission is determined to be necessary for safety or compliance purposes. This strategy significantly reduces spectrum while still taking advantages of the ADS-B safety benefits.

Some of the strategies outlined in the CONOPS can be implemented relatively simply with "standalone" or "payload" solutions, while others require deeper integration into onboard autopilot or sensor systems.

Low Power Transmissions

The first method to reduce frequency congestion further is to simply transmit at a low power setting. The MITRE CAASD report modeled sUAS with 1 Watt transmission power at 10 second intervals as a mechanism to reduce spectrum.

uAvionix has the capability to transmit at ½ watt which would provide a range of ~7NM. A 7NM range would provide a manned aircraft travelling at 150kts on a direct head-to-head collision course with a sUAS traveling at maximum allowed Part 107 speed of 87kts 1.77 minutes to execute an avoidance maneuver. Lower transmission output power is possible as low as 0.01W.

While the I&A concept may include low-power transmissions at some time in the future, the time required to research and update standards may be prohibitive to fielding equipment quickly as compared to rule-compliant power settings, whereas a precedent already exists for geofence/location-based ADS-B transmissions in the airport vehicle ADS-B program which selectively transmits based on the vehicle's location with respect to FAA approved transmitter maps[x].

Further, a more advanced system with dynamic power control would allow for higher power transmissions when required for greater distance transmission or compliance within controlled airspace while allowing for lower power transmissions in other scenarios.

Intelligent & Selective Transmission

Reducing the power of transmissions however would reduce the spectrum usage a fraction of what can be achieved through selective and intelligent transmissions.

A precedent already exists within the NAS for geofence based ADS-B transmissions. At least 22 of the nation's largest airports have deployed airport vehicle-based ADS-B transponders which broadcast the airport ground vehicles' locations if they fall within the geofenced regions defining the airport surface movement areas. As these vehicles exit the geofence boundaries, ADS-B transmission ceases.

In a normal operational mode, the UAS I&A ADS-B avionics will be in the "Inert" state, a "listen and monitor" state, where the I&A system compares its own position with that of other aircraft, airspace boundaries, and altitude ceilings. The received traffic information from manned aircraft, in addition to flight information data when available, would always be made available to UAS operators to enhance situational awareness and provide early stage conflict mitigation. Once the relatively simple system parameters have determined that transmission is necessary, the avionics enter the "Alert" state whereby ADS-B transmissions begin and continue until the parameters determine that transmission is no longer necessary for safety.

The following scenarios are organized in increasing order of complexity in terms of integration required with onboard autopilot or sensor systems. The "Standalone" scenarios require no such integration and therefore could be implemented quickly without 3rd party coordination. The "Integrated" scenarios require integration with the autopilot or additional systems to take full advantage of the capability described.

Standalone Scenarios

Standalone scenarios require no integration with onboard autopilot solutions and can be integrated into existing uAvionix products with relative ease or minimal development.

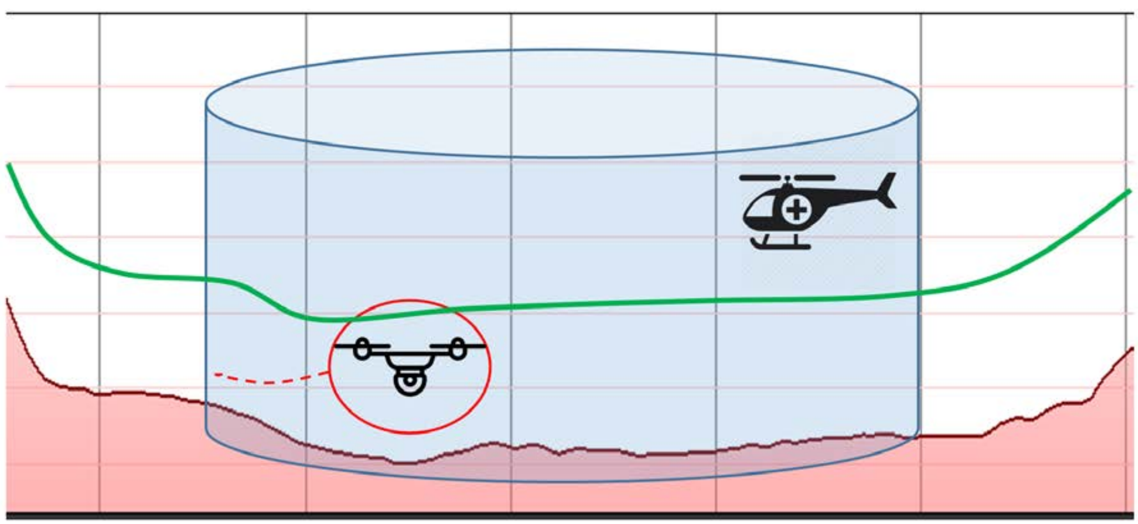
Nearby Air Traffic

ADS-B messages from nearby traffic would be monitored and ADS-B transmission would begin if aircraft (manned or unmanned) were to encroach predefined thresholds such as within 7NM and +/- 2000ft altitude. In order to reduce ADS-R transmissions from the ground system and reduce latency effects, the I&A ADS-B system would decode the incoming ADS-B message to determine which frequency (1090MHz or 978MHz) with which to respond.

Mode C or Mode S transmission messages could also be monitored. Although Mode C/S transmissions do not include position information, they do include altitude information. If a Mode C/S aircraft within range that does not correlate with and ADS-B target is broadcasting an altitude within 2000ft altitude (for example) – I&A ADS-B transmissions would begin. Although a non-correlated Mode C/S target would not have a native capability to “hear” the ADS-B transmissions, it is possible that a portable ADS-B IN system would be in use by that aircraft which would be able to hear and display the UAS traffic.

Further integration with onboard non-cooperative radar would also be possible to transmit in the vicinity of a non-cooperative target.

Figure 3: UAS with Encroaching Traffic – The I&A ADS-B solution would begin transmission once the encroaching aircraft breaches predetermined boundaries.



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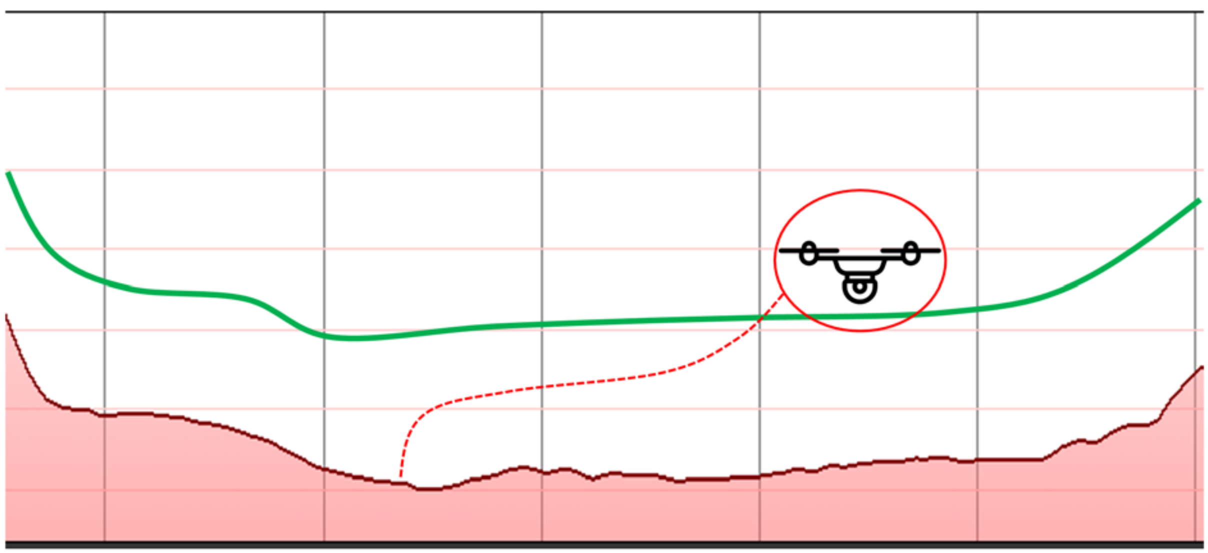
Altitude Ceiling

An altitude ceiling can be programmed such that if the UAS exceeds the 400ft AGL altitude, it begins transmitting its position. This AGL information would either be derived from an onboard barometric sensor as included in uAvionix products. The barometric sensor would be able to determine a rough estimation of AGL based upon the recorded altitude of the launch position. Further integrated solutions could provide greater accuracy calculations of AGL, to include integration with a radar altimeter, the autopilot, or an updatable terrain database cross-referenced with current GPS position.

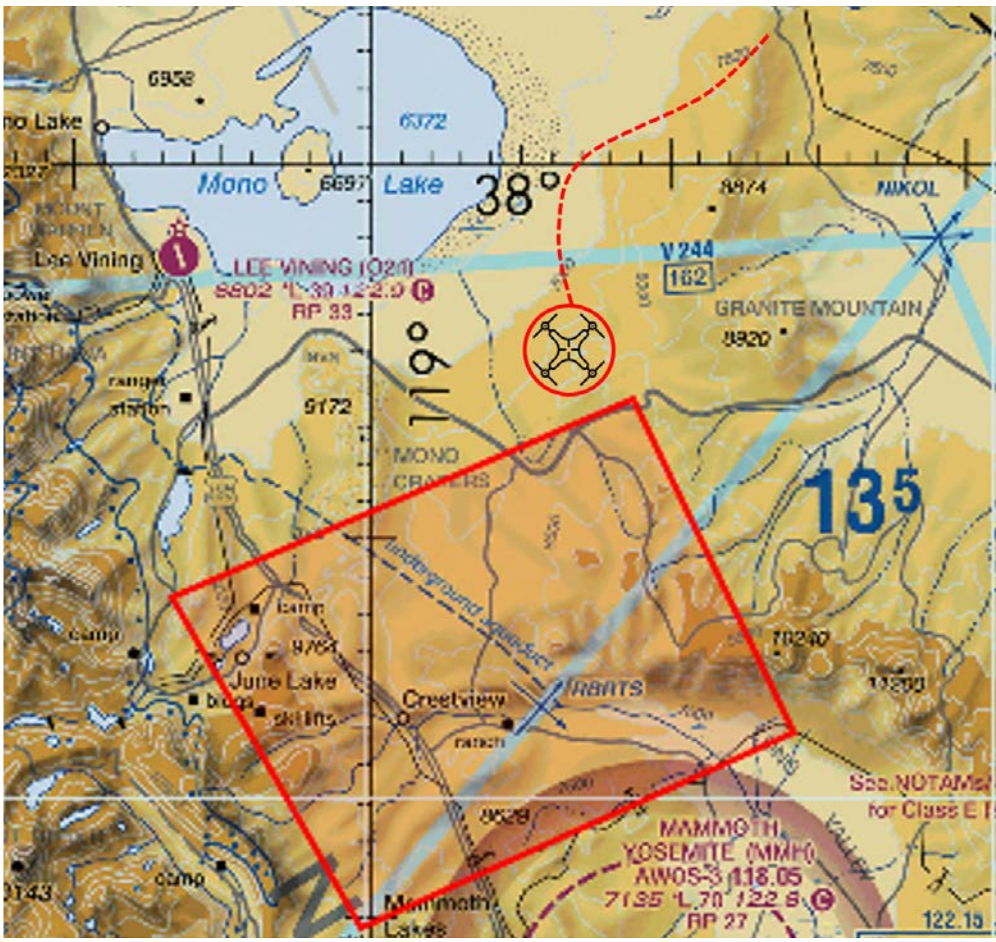
Figure 4: UAA Exceeding 400ft AGL Ceiling



Temporary Flight Restrictions

The I&A system can monitor Temporary Flight Restrictions (TFRs) locations and be made to transmit if TFR boundaries are approached or breached. TFRs could be loaded into the device prior to flight through the uAvionix mobile configuration application, or if FIS-B service is available in the operating airspace, TFR information can be extracted from the received FIS-B messages.

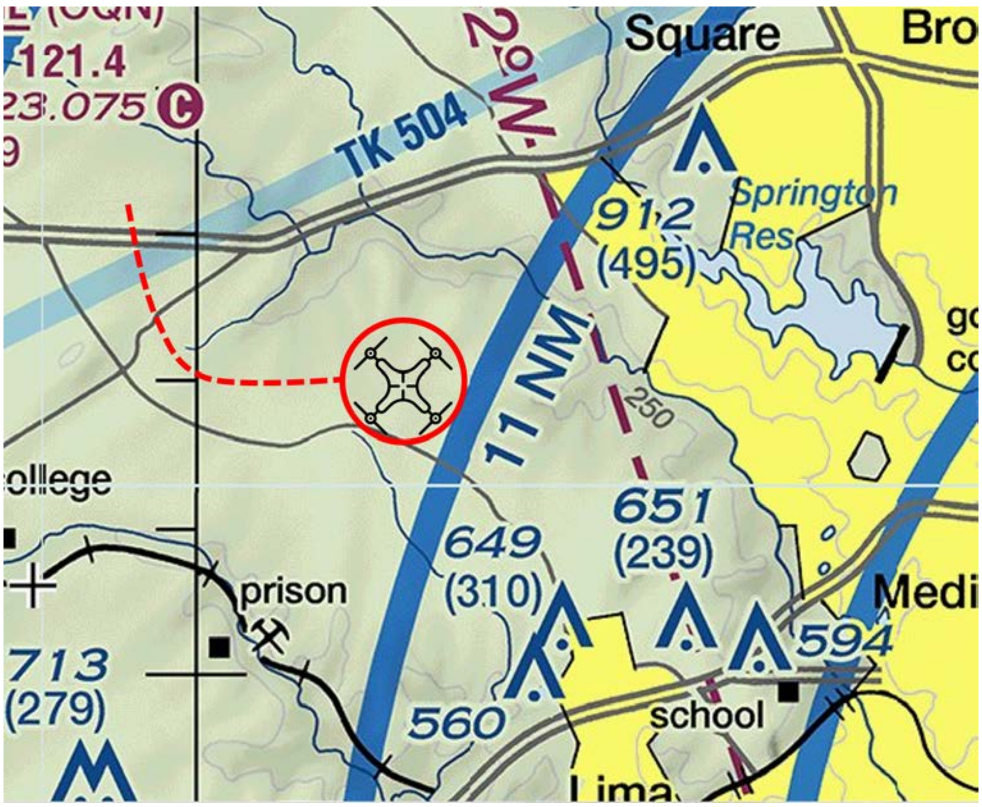
Figure 5: UAS Approaching TFR Boundary



Controlled Airspace Boundaries

Onboard the I&A system, an internal database of controlled airspace boundaries is used to begin transmitting at a compliant rate and power setting for the airspace requirements prior to entry. An appropriate geospatial buffer would be implemented to ensure the system is transmitting prior to entry into the airspace.

Figure 6: UAS Approaching Controlled Airspace Boundary



Integrated Solutions

The integrated solutions described below require communication with the autopilot or with the pilot in command (PIC).

Lost Link

A "Lost Link" situation occurs when the PIC no longer has positive control of the aircraft due to a lost Command and Control (C2) communication with the Ground Control Station (GCS). In these conditions, the I&A ADS-B avionics would trigger an ADS-B transmission until the C2 link is reestablished.

Manual Transmission

While the intelligent algorithms described above provide a certain level of safety, there is no substitute for PIC decisions. As such, the I&A ADS-B System should have the capability to be manually commanded to transmit through the autopilot interface by the PIC.

Emitter Category

An argument might be made that the proposed system will reduce spectral capacity in low sUAS density airspace, but in high-density sUAS airspace the sUAS operating in close proximity will trigger one another to transmit, causing a chain reaction that would flood the spectrum, potentially causing interference issues. There is a mitigation for this concern.

Within the ADS-B message, there is a field called "emitter category" which defines the type of aircraft, one of the valid types is "UAV". By leveraging the emitter category, the I&A ADS-B system can be programmed to only respond to manned aircraft in close proximity, and "ignore" unmanned aircraft. More complex algorithms could be derived leveraging the emitter category to limit geographically the "spread" of I&A ADS-B transmissions in high density scenarios. This scenario assumes other technologies might be employed for V2V or remote identification purposes to avoid conflicts between multiple unmanned aircraft.

The end result would be that in a high-density sUAS airspace, only the sUAS within the response volume (for example 7NM and +/-2000 ft. of altitude) would respond with transmissions, and not trigger a chain reaction.

Summary

In conclusion, ADS-B offers the highest potential to provide situational awareness communications between manned and unmanned aircraft. While the initial intent for the ADS-B system did not include the low-altitude small UAS use cases, the technology can be adapted in a non-disruptive manner to enable enhanced safety while mitigating concerns of system degradation due to overuse. The system described in this CONOPS requires an onboard database and microprocessor to process data inputs and make the algorithmic decisions which would enable the functionality described. Even so, the SWaP required would still be small enough to fit on small unmanned aircraft. An operating precedent already exists within the NAS for conditional/geofence based ADS-B transmissions in the ground vehicle ADS-B transmitter program.

Such a system as described here would significantly reduce the spectral capacity of UAS ADS-B systems as compared to the MITRE CAASD report, take advantage of existing investments in NextGen technology, and provide a system with broad cross-platform compatibility.

[i] https://www.mitre.org/publications/technical-papers/ads-b-surveillance-system-performance-with-small-uas-at-low-altitudes
[ii] https://www.uavionix.com/blog/the-case-for-low-power-ads-b/
[iii] https://www.mitre.org/publications/technical-papers/ads-b-surveillance-system-performance-with-small-uas-at-low-altitudes
[iv] www.faa.gov/nextgen/programs/adsb
[v] www.faa.gov/nextgen/programs/adsb/ICM
[vi] www.faa.gov/nextgen/equipadsb/ins_and_outs
[vii] https://www.mitre.org/publications/technical-papers/ads-b-surveillance-system-performance-with-small-uas-at-low-altitudes
[viii] https://www.uavionix.com/blog/the-case-for-low-power-ads-b/
[ix] https://www.mitre.org/publications/technical-papers/ads-b-surveillance-system-performance-with-small-uas-at-low-altitudes
[x] https://www.faa.gov/nextgen/programs/adsb/vehicle_transmitter_maps/