Implementation Consideration for Automatic Dependent Surveillance-Broadcast on Unmanned Aircraft Systems

J. Chris Moody, Jr* and Robert C. Strain †
The MITRE Corporation, Center for Advanced Aviation System Development, McLean, VA, 22102

There is increasing interest by the Unmanned Aircraft Systems (UAS) community in the technologies comprising Automatic Dependent Surveillance–Broadcast and its potential operational applications. However, there are significant weight, space, power and cost challenges to applying ADS-B to small UAS. The MITRE Corporation has been conducting research on ADS-B for many years and has recently been investigating applying ADS-B to small UAS. From this experience have emerged unique insights about the ADS-B technologies and considerations of interest to UAS and avionics implementers. This paper examines the technology, the key issues affecting weight and performance, and issues that impact UAS avionics costs.

I. Introduction

A. The Sense and Avoid Challenge for Unmanned Aircraft System

Numerous research efforts and standards initiatives are underway to help the Federal Aviation Administration (FAA) define the safety threshold and develop the policies, procedures and systems that would make routine Unmanned Aircraft System (UAS) access a reality. Before UAS operations become routine in the National Airspace System (NAS), assurances must be made that they can operate safely. Of the many challenges to enable routine access, securing a Sense and Avoid (S&A) capability for UAS is viewed by the FAA as paramount.[1] For manned aircraft, one of the most basic obligations of the pilot is to ―see-and-avoid" other aircraft.[2] The see-and-avoid procedure has the advantage of not relying on any ―cooperative" equipage in the ―threat" aircraft. While see-and-avoid is subject to human limitations, it is proving difficult to develop a practical suite of sensors that can provide anything nearly equivalent to human vision given the constraints of the UAS environment, particularly small UAS.

Many manned aircraft have transponders that offer cooperative detection by ground-based radar and airborne collision avoidance systems. Existing FAA regulations require the use of a transponder in certain airspace and when operating under instrument flight rules. There is, however, substantial national airspace where transponders are not required for operations. There are also many aircraft registered in the United States without a transponder or an altitude reporting transponder (about 46,000 or 21% of the active general aviation fleet) either because their aircraft cannot support them or their owners elected not to equip.[3] About half of these aircraft do not have electrical systems (e.g., some gliders, balloons, and classic aircraft). These non-cooperative aircraft are largely relegated to flying under visual flight rules and in lower altitude airspace (gliders are an exception), where many small UAS will likely want to fly. Even if UAS could count on all aircraft having transponders, cooperative detection of these transponders based on the TCAS design would require active interrogations and a directional antenna, both of which are likely not practical on a space and power limited small UAS platform.

Another and perhaps more practical approach to S&A is through a new means of cooperative surveillance—known as Automatic Dependent Surveillance–Broadcast (ADS-B). ADS-B can be thought as an electronic beacon that is continually broadcasting position, velocity, and ID information for the benefit of any receiver in range. If UAS could rely on all aircraft to have such a beacon, the physics of the S&A task is reduced to a simple receiver that decodes the ADS-B message. So the challenge is transformed from S&A detection physics to how to facilitate

* Communications Engineer, F044, N570, and AIAA Member Grade for first author.
† Communications Engineer, F044, N570, and AIAA Member Grade for second author.

near universal equipage with the ADS-B beacon. This is no small feat, but avionics costs are an important factor. General aviation aircraft owners and pilots are likely to be the most cost sensitive constituency, however, this group has shown a willingness to equip with technology they feel is affordable and provides them operational safety and efficiency (e.g., radios, Global Positioning System [GPS] receivers, moving map displays, etc.).

B. The Advent of Automatic Dependent Surveillance–Broadcast in the National Airspace System

ADS-B is a cooperative surveillance service that involves aircraft broadcasting their location, speed, and direction to Air Traffic Control (ATC) and other airspace users within transmission range, in effect creating a common traffic picture for both controllers and pilots.[‡] It is considered a linchpin in the FAA's plans for a Next Generation Air Transportation system, a system concept to improve capacity and efficiency of the NAS over the next 25 years without decreasing aviation safety. While radar-based systems will remain, it appears ADS-B will play a more significant role in cooperative surveillance between aircraft and for ATC separation services. This is because ADS-B has several distinct benefits relative to the radar/transponder scheme:

- Greater position accuracy with integrity
- Higher information update rates
- Increased situational awareness to those who equip (assuming others also equip)
- Availability of radar-based traffic information through the Traffic information Service-Broadcast (TIS-B), which is coupled with the ground system component of the ADS-B service
- Reduced ground station installation, operation, and maintenance costs
- Reduced voice communications and dependency on ATC for flight following
- Reduced search and rescue period in areas of ground station coverage

ADS-B can be implemented in two forms. —ADS-B Out” is the term given to installations that only transmit. —ADS-B In” is the term used for installations that include a transmitter, receiver, and a graphical display to present the received traffic information to the pilot.

In October 2007, the FAA issued a Notice of Proposed Rulemaking (NPRM) for aircraft to have at least ADS-B Out capability by 2020.[4] The airspace being considered for this requirement is consistent with the airspace within which transponders are currently required.[§] The early segments of the FAA's ADS-B program are focused on supporting ATC separation assurance services, which depend on aircraft transmitting ADS-B but do not require aircraft to receive ADS-B. Advisory services available aircraft-to-aircraft are also supported in the program, but it is left up to the individual aircraft owner/operators to decide whether to equip with ADS-B In.

ADS-B has been operating continuously since 2000 in the FAA's Alaska Capstone program, and a developmental system is currently deployed in areas of the Conterminous United States (CONUS). In July 2007, the FAA awarded a contract to ITT Corporation for a nationwide ADS-B surveillance service including the necessary ground infrastructure. This will promote early use of ADS-B in the NAS and begin to formalize its role as the FAA's primary cooperative surveillance technology. The ground infrastructure rollout began in 2008. Deployment is scheduled through 2013 resulting in coverage from approximately 800 radio sites. ADS-B coverage will be at least as comprehensive as radar coverage is today with some areas of the country having better coverage.

C. The Data Links

Based on an internationally coordinated decision on ADS-B datalink technology, the FAA has decided aircraft operators in the NAS have the option to equip with either or both of two ADS-B radios. The 1090 MHz Extended Squitter (1090ES) was selected for world-wide interoperability given its lineage to Mode Select (Mode-S) transponders carried on all commercial airline aircraft and on many business and charter aircraft. These aircraft and any other aircraft that fly in high altitude airspace (Class A) will be expected to install at least a 1090ES transmitter. General aviation aircraft and all aircraft flying exclusively at lower altitudes in the NAS (below Class A) are expected to equip with the Universal Access Transceiver (UAT). In addition to ADS-B, both links support TIS-B. TIS-B enables a nearly complete traffic picture (within radar coverage) for ADS-B In users equipping in the near term. For further incentive, weather and aeronautical information—known as Flight Information Services-Broadcast

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[‡] ADS-B can use any navigation source that meets the ADS-B performance requirements. GPS-based systems, however, are the only practical systems at this time.

[§] Class A, Class B, and Class C airspace; airspace within 30 nautical miles of a Class B airport (i.e., the Mode C veil); and airspace at least 10,000 feet above mean sea level (with some exceptions).

(FIS-B) is being uplinked on UAT. In addition, the ADS-B ground infrastructure will enable aircraft operating with dissimilar data links to see each other through a ground based rebroadcast function—referred to as ADS-Rebroadcast (ADS-R).

Even with these capabilities and user benefits, not all aircraft operators will equip with ADS-B. Equipage rates are expected to be equivalent to or better than that of transponders in the fleet today and do so in the next five to ten years. Currently available ADS-B systems for general aviation aircraft that satisfy the requirements of the NPRM retail for over $5,000 plus the cost and aircraft downtime for installation.

II. Universal Access Transceiver Beacon Radio Research

MITRE is researching low-cost, lightweight radio technology capable of providing ADS-B services to small UAS, aircraft/airspace users without engine-driven electrical systems (e.g., gliders, balloons, and skydivers), and supporting other aviation applications. These applications may include: rapidly deployable surveillance for search and rescue, aerial firefighting, or disaster/national emergency relief efforts.

An outcome of the research is the UAT Beacon Radio (UBR) prototype. Such a system would potentially enable small UASs to operate in national airspace where all aircraft are suitably equipped. This cooperative approach to surveillance will improve visibility of a UAS to proximate aircraft. The prototype radios use the UAT waveform developed by MITRE in the mid-1990s. The UBR has a modular architecture, enabling it to operate as a portable unit or to be integrated with other aircraft electronics. By proving the technology, demonstrating the benefits to small aircraft operators, and transferring the technology, the UAT Beacon Radio will stimulate the ADS-B avionics marketplace across many facets of aviation.

The first version of the UBR—referred to as “UBR-TX”—is a transmit-only unit that is now a mature design that has undergone extensive laboratory and flight testing. In addition to the ADS-B transmitter, UBR-TX contains a Global Positioning System (GPS) receiver, pressure altitude sensor, and can use internal power from four AA batteries or external direct-current power. When using AA lithium batteries in nominal temperature, the unit operates at least 12 hours. This is largely due to the low transmit duty cycle of the UAT, but also the relatively low transmit power (7 Watts) of the UBR. Initial flight testing was performed using a Piper Lance general aviation aircraft with UBR-TX placed on the glareshield as shown in Fig. 1.

Figure 1. UBR-TX in-place on the glareshield of a piper lance.

The testing focused on verifying the correctness of the ADS-B message payload and the air-to-ground link performance at various aspects from the aircraft. ADS-B message payload correctness was verified by having the test aircraft transmit from an installed Garmin GDL90 ADS-B system and the UBR-TX simultaneously throughout the testing.[**] This ability to simulcast ADS-B in a flight environment proved very useful in assessing correctness of the UBR-TX ADS-B message payload.

Since 2003, the FAA has operated a network of about 50 demonstration ADS-B ground stations throughout CONUS, which is convenient for our testing. Fig. 2 contains air-to-ground link performance results from the UBR-TX to FAA ground stations. The range and message success rates are good, but as expected there is some sensitivity to aspect angle on the air-to-ground link performance due to the less

[**] The GDL90 is an FAA certified ADS-B system that has been tested heavily by FAA as part of the Alaska Capstone program. Aircraft in Alaska with this unit are provided ATC separation service from Anchorage Center based only on ADS-B.

than optimum UAT antenna attached to UBR-TX internal to the aircraft.[††] Particularly off the tail of the aircraft, it can be seen there is blockage of the UBR-TX antenna due to the blockage from the aft fuselage. Nonetheless it can be seen that even at this worst-case aspect a 20 NM usable range is still achieved. Off the nose where there is little blockage, it can be seen the air-to-ground range is much better at over 80 NM.

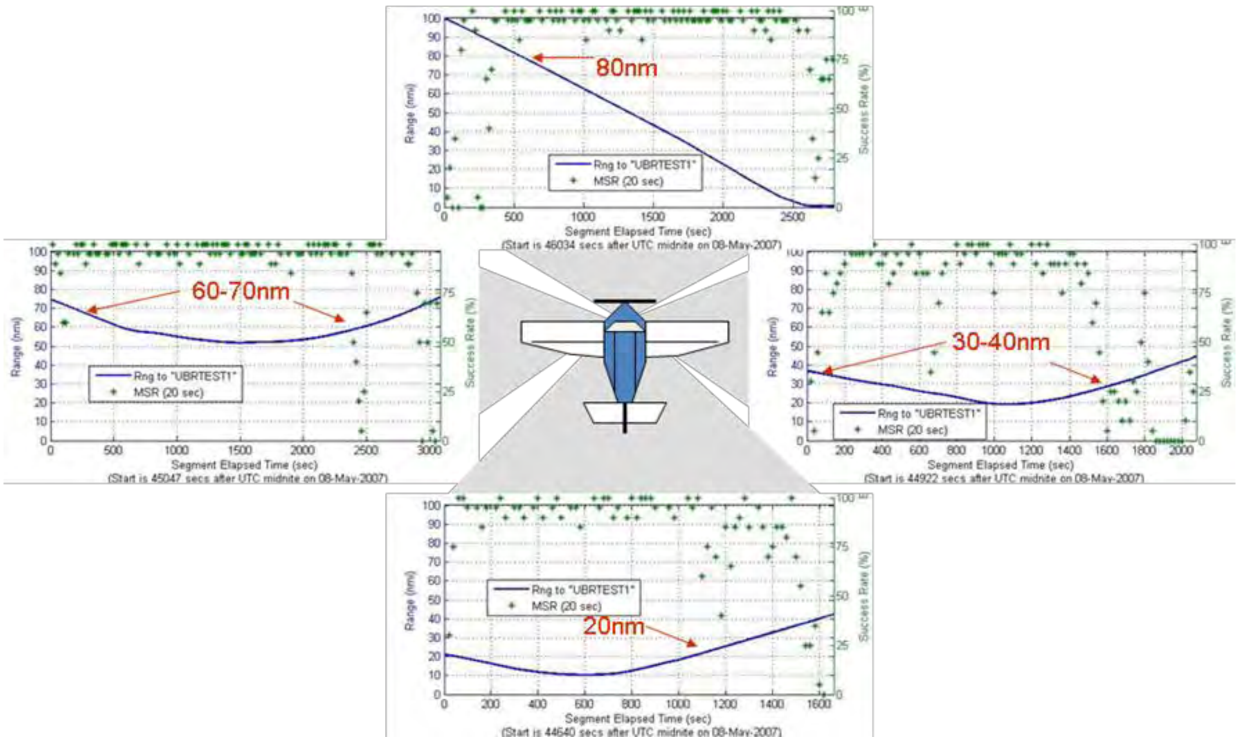

Figure 2. UBR-TX air-ground reception performance in each quadrant.

Upon completing radio performance verification tests, MITRE partnered with AeroVironment Corporation to test fly the UBR-TX on their PUMA UAS. On August 22, 2007, the first flight in known history of ADS-B on a UAS was accomplished. The PUMA is a 12.5 pound man-portable aircraft with a two pound payload capacity. The flight test was conducted in an approximately one square mile test box area at the Rosamond Dry Lake Bed at Edwards Air Force Base, California. Fig. 3 shows the self-contained UBR-TX temporarily attached to the PUMA for the test (taped under starboard wing root). A permanent installation of the UBR-TX on this aircraft would be inside the payload section or in one of the two battery holders on the fuselage and would likely only use the six ounce UBR-TX integrated circuit board.

Figure 3. UBR-TX attached to PUMA UAS.

The PUMA was flown at 2500 feet above ground level (AGL) in a closed rectangular pattern that exposed the receiver to all aspects of the airframe/UBR-TX combination. An ADS-B receiver was mounted in a car and driven about 20 NM downrange. Fig. 4 shows the air-ground range performance with reception rates consistently high for all aspects, as would be expected for this mostly radio transparent

[††] The blue line shows range to the ground station, the green —* show the message success rate in fixed 20 second epochs based on continuous ADS-B transmissions at 1 Hz.

airframe. Initially the vehicle installation employed an aircraft blade antenna on a ground plane mounted to the car. At about 1200 seconds into the test, this assembly separated from the car. Some downtime is evident in the results while a makeshift antenna was fashioned. Of note here is that even with an imperfect antenna, the performance was acceptable.

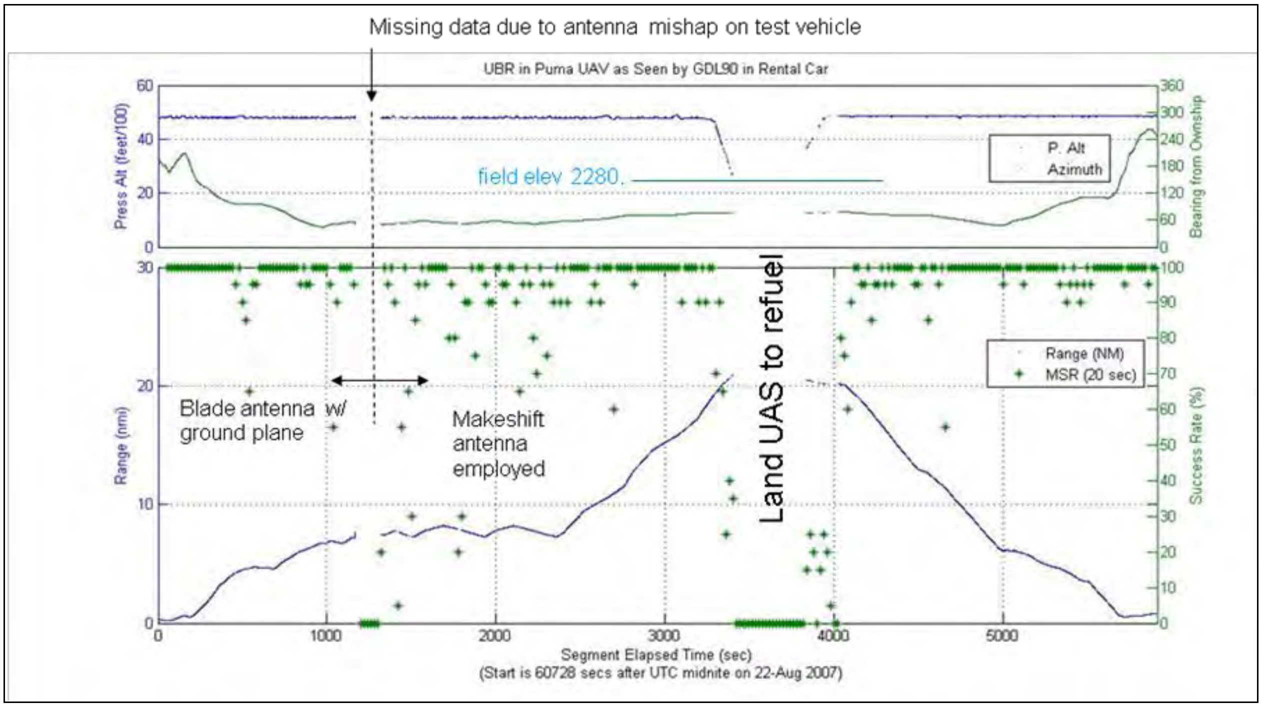

Figure 4. ADS-B surveillance performance of PUMA UAS from rental car downrange.

The UBR-TX has also been installed on the University of Alaska's A-20 Insight UAS. This aircraft is a variant of the 35 pound Boeing ScanEagle the University of Alaska uses to conduct research and perform specialized missions in Alaska. Alaska is a good place for the use of ADS-B on small UAS since there are many aircraft equipped with UAT ADS-B and traffic displays, even though they should not ever come in close proximity. As shown in Fig. 5, the UBR-TX is mounted on one of the boards stacked inside the round fuselage. The aircraft's GNSS antenna provides a signal shared amongst several avionics including the UBR-TX. A dedicated UAT antenna is mounted on the aircraft externally since the material used for the aircraft skin does not pass radio frequency signals well. Power for the UAT-TX is provided by the aircraft's 12 Volt battery.

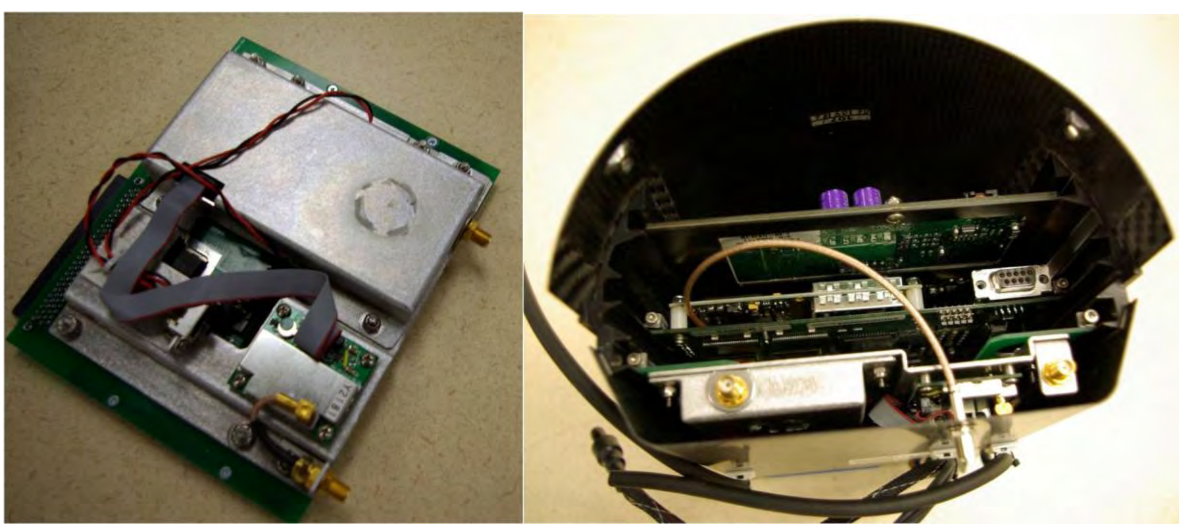

Figure 5. UBR-TX installation in an Insight A-20 UAS.

III. Universal Access Transceiver Beacon Radio (Transceiver Version)

The next version of UBR is being developed as a transceiver (UBR-TVR). The design objective is to add an ADS-B receiver while also reducing the unit's size and weight. The power requirements are greater than the UBR-TX unit because the receiver needs to be on all the time. Fig. 5 shows the UBR-TVR in a portable unit form factor. The small integrated circuit board, which contains the transmitter, receiver, and positioning sources, gets its power from either an internal lithium battery or an external supply (10-40 Volts) provided by the UAS. UBR-TVR also has an interface to convey the received information to a user display, autopilot or telemetry system that will use the data. UBR-TVR enables testing of the air-to-air ADS-B performance between UBR devices and other UAT compliant ADS-B systems. Flight testing is expected to begin in spring 2009.

Figure 5. UBR-TVR portable form factor.

IV. Major Research Findings

A. Low Cost Transmitter

The UAT operates on a frequency of 978 MHz, which makes the use of hybrid power devices for the Global System for Mobile telecommunications (GSM) cellular phone market viable. These devices are attractive due to their low cost, high gain, and the consistent performance. Also in the UBR application, these devices can operate at higher than rated peak power due to the extremely low transmit duty factor of a UAT transmitter (~0.04%). The power output achieved with a combination of two devices meets the minimum power level required in the RTCA standards.[‡‡] [5]

B. Global Navigation Satellite System Sensor

The use of a Global Navigation Satellite System (GNSS) receiver certified for aviation use is not practical for a low-cost device at this time. Based on a MITRE market survey done in late 2006, there is a significant cost, size, and power consumption gap between sensors certified for aviation applications versus those developed for the consumer market. A limitation of the consumer receivers is their inability to directly provide an integrity indication in the event of a GPS satellite failure. We do not believe this is a significant void at this time, as the advisory-use ADS-B applications (e.g., ―Enhanced Visual Acquisition") are not expected to require this integrity indication.

When integrating within a UAS, a common problem with the GNSS receiver emerges. The UAS manufacturer may be required to use an aviation certified receiver for navigation. If this becomes the case, a common receiver may be utilized as long as the interface to the UAT is carefully considered. For instance, the UAT relies on a discrete signal from the GNSS receiver at the beginning of each second to synchronize its transmission intervals. There are also latency requirements on the position data, to which the integrator needs to adhere.

C. Pressure Altitude

Use of barometric pressure altitude is firmly entrenched in aviation. Alternatively, use of geometric altitude—derived from the GNSS sensor—would have many advantages in this application, including the fact that it is available from the GNSS sensor. However, the legacy of pressure altitude use in aviation makes

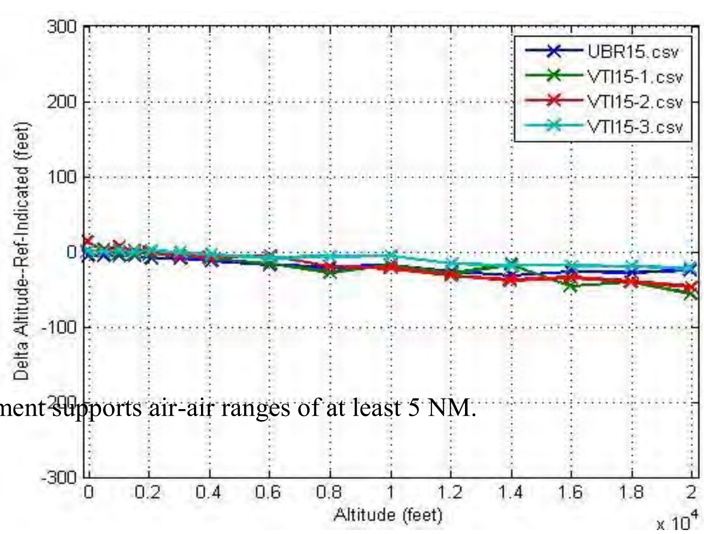

Figure 6. UBR pressure sensor.

[‡‡] Minimum RTCA power level for airborne equipment supports air-air ranges of at least 5 NM.

transitioning to geometric altitude unlikely. Therefore, a temperature compensated pressure altitude sensor has been included in the UBR design. While this sensor has not been certified for aviation use, our own laboratory testing has found it meets FAA accuracy requirements of a certified pressure sensor over temperature. Tests were conducted with this sensor along with several common certified encoding altimeters and a high-precision reference sensor. Measurements were taken for temperatures, -20C, +15C and +55C over a range of altitudes from 0 to 18,000 feet. These ranges of temperature and altitude were selected as typical operating conditions for which UBR may be appropriate. Fig. 6 shows test results for the +15C case.

All existing aviation-certified pressure altitude sensors rely on a connection to the aircraft's static port on the fuselage to ensure the pressure reading is minimally influenced by airflow over the aircraft fuselage. A stand-alone UBR would not have access to this external static port available. However, venting the pressure sensor to the cabin of small aircraft flying at low altitudes and low airspeeds (i.e., below 10,000 feet and less than 150 knots) we do not believe will incur a significant error. However, the magnitude of this error—and the possibility to calibrate it out—may be examined as part of future research efforts.

D. Power Source

The system design of the UBR-TX device can be supported by four AA batteries with an expected endurance of about 12 hours depending on the ambient temperature and battery technology used. This is possible through the low duty cycle of the transmitter, techniques for storing energy from the battery for each transmission, and through conservation of power during the considerable off period of the transmitter each second. UBR-TVR will have the additional demands of the receiver which must run at 100% duty cycle. Our measurements indicate that a 6.8 Watt-hour lithium-Ion battery provides approximately five hours of endurance between recharging.

Alternatively, both UBRs may be powered externally with an unregulated direct current supply of 9-40 Volts. This will be the most likely configuration when the UBR is integrated with an existing avionics/electronics suite on a UAS.

E. Costs

The UBR research focused on developing a system with minimal parts cost among other factors. Keeping costs low was possible due to the large number of components available for cellular, consumer electronics, and automotive markets. The aviation industry is extremely small relative to these industries, so utilizing common parts is vital to keeping the cost reasonable. The material cost for the UBR-TX is approximately $175 and the UBR-TVR is around $400. These are estimates based on at least 1,000 units purchased. The major cost drivers in the UBR-TVR beyond the additional parts for the receiver and external data interface include: the GPS receiver, Field Programmable Gate Array (FPGA), pressure sensor, and lithium battery.

Significant cost drivers in developing systems are the non-recurring engineering expenses associated with hardware design, fabrication, assembly, software development and testing. Additionally, the aviation industry is sensitive to system integrity requiring vendors to follow a labor-intensive process of certifying their system meets a specified design assurance. These costs are not factored into these cost estimates, but the work MITRE has done developing these prototypes and transferring the technology to commercial industry significantly reduces these costs.

The FAA may want to consider the use of consumer devices in low-cost ADS-B systems that are used strictly for supplemental use in visual meteorological conditions. Furthermore, widespread adoption by the general airspace users is imperative if ADS-B is to take hold as the FAA's premier cooperative surveillance service. These two conditions are inextricably tied to one-another.

V. Conclusion

MITRE's initial research has focused on demonstrating an affordable ADS-B transmitter using the UAT waveform and pursuing an operating concept whereby such a device is technically, operationally, and economically viable to the degree that it makes sense to carry it on all small UAS. The UAT technology is mature, standardized and has been demonstrated for ADS-B in the NAS for over eight years. UAT has been assigned an operating frequency of 978 MHz, which resides in protected Aeronautical Radio Navigation Spectrum and has international adoption for use worldwide. The MITRE UAT Beacon Radio demonstrates that a small, lightweight device with low power consumption can efficiently produce sufficient transmission power to achieve air-air range objectives, complies with aviation standards, and is expected to achieve the operating requirements for the ADS-B Enhanced Visual Acquisition application.

Coupled with a receiver, this device has the potential to simplify the S&A equation and provide operators of small UAS with a means to facilitate integration of their unmanned assets in civil airspace. If our research results in products in the marketplace, operators of general aviation aircraft without electrical systems or transponders may find the UBR equally attractive.

MITRE does not believe a portable device such as UBR can or should satisfy the FAA NPRM requirement for equipage in ―rule” airspace. However, the presence of a low cost portable ―ADS-B In” platform like UBR-TVR on the market in the near-tem could significantly stimulate equipage in the UAS and general aviation communities earlier if it could be sold at a price these communities found affordable. An uncertified, portable ADS-B In system could be useful in any airspace prior to the 2020 effective date and could be used by those that operate exclusively outside rule airspace post 2020 with the intent to support only the Enhanced Visual Acquisition advisory application of ADS-B. With enough near term equipage and low cost equipage options, it may be possible for UAS and general aviation to share certain designated airspace based on the mutual UAS and general aviation air-to-air awareness provided. These initial products would also serve as a revenue stream for companies to further their development and mature their products. Longer term, the transmitter and receiver design of the UBR-TVR could form the basis for certified industry products suitable for installation on both general aviation and UAS operating at lower altitudes. These systems could be designed for interfacing to certified GPS and pressure altitude sensors thus fulfilling the requirements of the NPRM. From the UAS perspective, these systems could form the basis for autonomous avoidance of any ADS-B equipped manned aircraft, thus paving the way for more general airspace access for UAS.

The research will continue through 2009. First and foremost, MITRE will be conducting flight tests of the UBR-TVR to characterize aircraft-to-aircraft performance between UBR installations. Options for verifying the integrity of GPS position information from non-aviation mass market GPS sensors will also be investigated.

Finally, a device like the UBR poses some dilemma for FAA. Since it would not be a required piece of equipment on aircraft for which it is intended, or be permanently attached to the aircraft, FAA currently has no regulatory mechanism to ensure it meets any basic requirements. Some certification of such devices might be desirable, at a minimum, to have the manufacturer demonstrate its conformance to standards and provide reasonable assurance the unit will not transmit misleading information. A new mechanism to cover devices such as this may be needed.

References

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[5] RTCA, Inc., Minimum Operation Performance Standards for Universal Access Transceiver (UAT) Automatic Dependent Surveillance-Broadcast (ADS-B), DO-282A, 29 July 2004.