"Sense and Avoid" – What's required for aircraft safety?

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Abstract — The safe integration of unmanned aircraft into the national airspace is a topic receiving considerable attention. The US Congress has mandated that the Federal Aviation Administration (FAA) engage in rulemaking that will allow for civil operation of unmanned aircraft in the national airspace system (NAS), with a release of those rules in 2016*. Preparations are occurring simultaneously for the implementation of the FAA's NextGEN System on 1 January 2020, changing Air Traffic Control (ATC) in the US from one that relies upon radar to a GPS-based system. The introduction of Unmanned Aerial Systems (UAS) into the NAS is expected to be integrated with NextGEN. The availability of small, light ADS-B Out equipment (Autonomous Dependent System-Broadcast) is anticipated to facilitate that, and is discussed. Further, control of UASs will likely adhere to the procedural rules present in today's ATC System and in NextGEN, rules that require a pilot in the loop, making fully autonomous operation forbidden. UASs are therefore expected to employ additional systems and equipment to enhance their sense & avoid capability. Collision avoidance in manned aircraft was improved in 2005 when certain aircraft were required to use the Traffic Collision Avoidance System, TCAS II. The sense & avoid performance of UASs within the NextGEN-controlled airspace should similarly be enhanced by a new system called the Airborne Collision Avoidance System, ACAS. This TCAS replacement will have several variants for various aircraft types including UASs, and it will be capable of accepting data from various types of onboard sensors, making "optimal" use of that data when available. Thus collision avoidance on future aircraft should benefit from enhanced sensing devices such as LIDAR, Mode-S transponder interrogation, IR sensors, and possibly from that provided by the "Due Regard" radar system currently in test on the Predator UAS.

* H.R. 658—63 Sec. 332, Rulemaking -- FAA Modernization and Reform Act of 2012

Keywords—Federal Aviation Administration, NextGEN Air Traffic Control System, Automatic Dependent Surveillance-Broadcast, aircraft avionics, Global Positioning System, drone, remotely piloted vehicle (RPV), remotely piloted aircraft (RPA), remotely operated aircraft (ROA), Unmanned Aerial Vehicles (UAV), Unmanned Aircraft Systems (UAS), Air Traffic Control (ATC), and Certificate of Authorization (COA)

I. INTRODUCTION

This paper addresses technological aspects of aircraft collision avoidance realizing that the FAA must implement procedural changes to assure flight safety. The United States Federal Aviation Administration (FAA) regulates the operation of manned aircraft systems and specifies airworthiness requirements for a wide range of aircraft from gliders to high performance jets. Federal Aviation Regulations (FAR) and the Aeronautical Information Manual (AIM) are updated annually under the authority of Title 14 of the Code of Federal Regulations (14CFR), to become the basis for all aspects of NAS control in the USA. All aircraft operating in NAS must be registered, must have an airworthiness certificate, and must be flown by pilots who meet the FAA requirements. Unmanned Aerial Vehicles present new challenges for operation in the NAS.

Unmanned Aircraft Systems (UAS) are rapidly developing new commercial applications; however, all flights require an FAA Certificate of Authorization (COA) to operate in the National Airspace, and cannot operate in Class B airspace where large airports with high density passenger traffic are located, and where air traffic control provides "positive" control and separation to "all" aircraft operating under VFR and IFR (Visual and Instrument Flight Rules). Currently, UAS operations require observers to provide "see and avoid" capability to the UAS crew, thereby providing compliance with 14CFR Part 91.113. New FAA proposed rules may allow UAS weighing less than 55 pounds to operate at a maximum altitude of 400 feet, clear of manned air traffic. They also may not require specific flight Certificates of Authorization, of Airworthiness, or pilot certification. Beginning December 21, 2015, small UASs weighing between 0.55 and 55 pounds and operated for recreational purposes must be registered with the FAA. Table I shows the UAS categories by weight, typical maximum altitude and speed as defined by the U.S. Department of Defense (DoD).

The U.S. Congress passed the National Defense Authorization Act (NDAA, Dec. 2011), the associated Appropriations Act (H.R. 2055, Public Law No. 112-74, Dec. 2011) and the recent FAA Reauthorization and Reform Act (H.R. 658, Feb. 2012), which mandated the Federal Aviation Administration (FAA) to "develop a comprehensive plan to safely integrate commercial unmanned aircraft systems into the national airspace ... the plan shall provide

978-1-5090-2246-5/16/$31.00 ©2016 IEEE

for the safe integration of civil unmanned aircraft systems into the national airspace system as soon as practicable, but not later than Sept. 30, 2015." That mandate was not achieved by that date. Rulemaking for the integration of unmanned aircraft systems has been delayed due to complexity and safety issues and is now expected to be released in mid 2016.

TABLE I. UAS CATEGORIES PER DOD

UAS Category	Max. Gross Takeoff Weight (lbs.)	Normal Operating Environment (Feet)	Speed (knots indicated airspeed)
Group 1	0-20	<1,200 AGL	100
Group 2	21-55	<3,500 AGL	<250
Group 3	<1320	<18,000 MSL	any
Group 4	>1320	<18,000 MSL	any
Group 5	>1320	>18,000 MSL	any

Some unmanned aircraft are capable of operating in an autonomous mode, while others are remotely piloted using a data link to provide control. Currently, the FAA permits UAS operation only if it is controlled remotely by a pilot who can visually see the aircraft, and certain other limitations. As UAS operational rules evolve, it is reasonable to expect that UAS pilots be required to receive traffic alerts or Resolution Advisories. With the pilot in the loop, response procedures for evasive actions could be similar to that for piloted aircraft. Operation of UASs in an autonomous mode would require precise knowledge of the concept of operations, operating environment, and uncertainty of responses to unknown conditions such as false alarms and system failures [16].

Presently, as the rules for operation of UASs are in development, we are governed by US PUBLIC LAW 112–95, called "The FAA Modernization and Reform Act of 2012". This law provides regulations for the NextGen Air Transportation System and Air Traffic Control Modernization for manned aircraft, and changes ATC from a radar to GPS location sensing. Full NextGen implementation is scheduled for 1 January 2020. The Automatic Dependent System-Broadcast (ADS-B) IN/OUT is a critical component of the overall NextGEN system, providing Flight Information Service-Broadcast for weather awareness and Traffic Information Services-Broadcast to enhance situational awareness. Safety and efficiency improvements are the major benefits of NextGen and ADS-B, achieved through more direct routing and more precise aircraft tracking with over 100 ground stations in operation in 2015. Airport Surveillance Radar systems will continue to operate to identify aircraft that are not properly equipped, but overall number of radars is expected to be reduced which will save significant operation and maintenance costs. Also, decommissioning numerous ground based navigational aids such as Very High Frequency Omni-Directional Range (VOR) and Distance Measuring Equipment (DME) further reduce FAA operating costs.

A. *Abbreviations and Acronyms*

ACAS – Airborne Collision Avoidance System
ADS-B – Automatic Dependent Surveillance- Broadcast
ATC – Air Traffic Control
CAS – Collision Avoidance Systems
FAA – Federal Aviation Administration
FIS-B – Flight Information Service-Broadcast
GPS – Global Positioning System
ICAO – International Civil Aviation Organization
IFR – Instrument Flight Rules
NAS – National Air Space, specifically in the United States
NextGEN – FAA program to upgrade the Flight Control within the United States over the time period 2013-2020
RA – Resolution Advisory
TA – Traffic Advisory
TCAS – Traffic Alert and Collision Avoidance System
TIS-B – Traffic Information Service-Broadcast provides real-time weather briefing for pilots
VFR – Visual Flight Rules

II. PRIMARY RADAR AND THE GENIUS OF ATCRBS FOR SECONDARY RADAR

Primary Radar simply refers to a directed Radio Frequency source being reflected by an airborne object to a highly directional receiver that can graphically depict a range and azimuth from that source. While primary radar is adequate for military early warning systems in an environment where the only thing airborne is a threat, WWII quickly added the requirement to assign an identity to a radar return. This resulted in the development of the Military IFF (Identify Friend or Foe) Radar Beacon System where an airborne "transponder" issues a coded reply to interrogation by a primary radar source (ground or airborne). The returned coded reply is processed by a SSR (Secondary Surveillance Radar) system and, in the case of the modern Mode 3/A Air Traffic Control Radar Beacon System (ATCRBS), provides a coded aircraft identification (4 digit octal) and a Mode C pressure altitude. ATCRBS sends a directional interrogation signal during the radar volume scan on a 1030 MHz carrier frequency and expects a Mode 3/A (and Mode C) reply in the 1090 MHz band. The advent of denser air traffic has resulted in the need for a greater volume of data from the target transmitter (primarily for more detailed identification) and considerably faster and more reliable digital processing has given birth to a solution in the form of the Mode-S transponder standard [2].

While the Mode-S standard continues to utilize the 1090 MHz response band, it does so much more quickly (up to twice per second) but the fundamental discriminator between ATCRBS and Mode-S is the manner in which aircraft can be addressed. ATCRBS interrogates all aircraft within the projected volume of the interrogation (as the beam sweeps, every azimuth within range receives an interrogation). In contrast, the Mode-S equipped target can be individually addressed by the interrogator. Furthermore, each interrogator can be identified and responses can be individually tailored by the responding unit. Thus the 1030 MHz interrogation can be addressed to each specific aircraft by identification code and need not include all targets in an intended search volume (which could provide an unwelcome data storm in a high traffic density environment).

While the original deployment of Mode-S was in 1988, the standard was designed to be highly extensible and has now resulted in a system that includes an extensive interrogation response vocabulary (Extended Surveillance), an interactive communication capability with both ground and airborne interrogators (TCAS), and ultimately a non-interrogated "broadcast" of identification and status data (ADS-B), see Section V.

III. Mode-S Transponder operation

It is fortunate that Mode-S was developed as such an extensible standard in that it is now used for not only the fully addressable replacement for the legacy ATCRBS but as a foundation for the Airborne Collision Avoidance System (ACAS) and the datalink standard for ADS-B.

As stated above, the motivation for the original standard was as a more spectrum efficient replacement for legacy ATCRBS. Utilizing the same spectra with considerably more efficient data transfer of aircraft location, identification and altitude was just the first step. Mode-S includes a fully addressable radar beacon interrogation and reply structure (for elementary surveillance or ELS) as well as an extended reply structure for enhanced surveillance (EHS) [3]. The additional parameters available under EHS facilitate enhanced ATC awareness of not only instantaneous aircraft position but also an extrapolation of aircraft track. Consolidated Primary Radar, ATCRBS and Mode-S replies are woven together to predict airborne conflicts with much greater opportunity to prevent those conflicts than was available before.

With an eye toward the future of not only surveillance but also air to air and air to ground communication, Mode-S includes both standard length message and extended length message fields, as well as message delivery acknowledgement and broadcast (which does not require receipt confirmation). The straightforward application of the available uplink and downlink messages has enabled implementation of EHS; with the addition of Surveillance Identifier (SI), the air traffic system mandated by EUROCONTROL is capable of managing the incredibly dense airspace environment present in Western Europe.

With the mandate to decrease the cost and increase the efficiency of the present air traffic control system, the member states of the International Civil Aviation Organization (ICAO) proposed a system of interconnected airborne communicating agents that would identify their own geographic location to each other and a central control facility (ATC) with the aid of a Global Navigation Satellite System (GNSS). Leveraging the Mode-S standard with some modest extensions for data communication, including GNSS (GPS in the United States) for geolocation and a purpose built ground infrastructure, the ADS-B recommendation was born [4].

IV. Airborne Collision Avoidance System – ACAS-X

In the 70's, MIT Lincoln Laboratory developed for the FAA a system designated the Beacon Collision Avoidance System (BCAS), an active, airborne system designed to enable aircraft to surveil their surroundings for the purpose of collision avoidance. MIT's approach was to minimize the need for new avionic hardware by making use of the transponders already in use for ground based Air Traffic Control (ATC). Instead of interrogations from ATC Ground Stations, the BCAS system would issue the interrogation from the aircraft on which it was being carried, receiving replies from aircraft in the vicinity carrying an associated ATC transponder, that being the Air Traffic Control Radar Beacon System (ATCRBS). Replies from the ATCRBS contain a message with that aircraft's altitude, and enable the BCAS to estimate the range to the responding aircraft. Given this information, BCAS determines if the target aircraft poses a collision threat.

The Traffic Alert and Collision Avoidance System (TCAS) built on the successful BCAS concept of active, airborne interrogation of transponder equipped aircraft, adding new features, some made possible when target aircraft also carry their own TCAS. The interrogating TCAS, like BCAS, receives back the target aircraft altitude, and from measured time delays, computes the slant range to the target. TCAS also requires oscillators having sufficient accuracy to enable the measurement of Doppler frequency shift, and thereby the range rate. From this data, and successive messages, TCAS estimates the time at which the two aircraft will pass each other with minimum range, or the Closest Point of Approach (CPA), and the time to reach the same altitude, or co-altitude. TCAS analyzes this information and when necessary issues alerts to the pilot, who combines this information with what he is observing visually to decide if and how to react. For example, during VFR flight, the correct evasive action to be taken when another aircraft flying at the same altitude is on a head-on collision course, then both pilots are to immediately turn right 90 degrees. If both aircraft have TCAS systems, when flying at the same altitude and on a collision course, a coordinated response will be given for one aircraft to climb and the other aircraft to descend to maintain a safe separation.

There are two types of advisories: Traffic Advisories and Resolution Advisories. Traffic Advisories (TAs) alert the pilot to a potential threat and aid in his visual search for the intruding aircraft. Resolution Advisories (RAs) are recommended maneuvers that if followed should resolve the impending problem. TCAS versions I, II, and III differ in their ability to issue advisories. TCAS I only provides TAs. TCAS II incorporates the RAs, providing recommendations pertaining to the altitude of the aircraft and whether to take action to change or hold altitude. TCAS III will add horizontal maneuver recommendations as well. TCAS deployment dates were as follows [1]:

- As of Jan 2000, all civil fixed-wing turbine powered aircraft weighing 15000 kg or more, or having 30 passengers must use TCAS II ver. 7.0
- As of Jan 2005 the above was extended to include all aircraft weighing 12,566 lbs. (5,700 kg) or more, or having 19 passengers

The TCAS-II functional diagram is shown below in Figure 1.

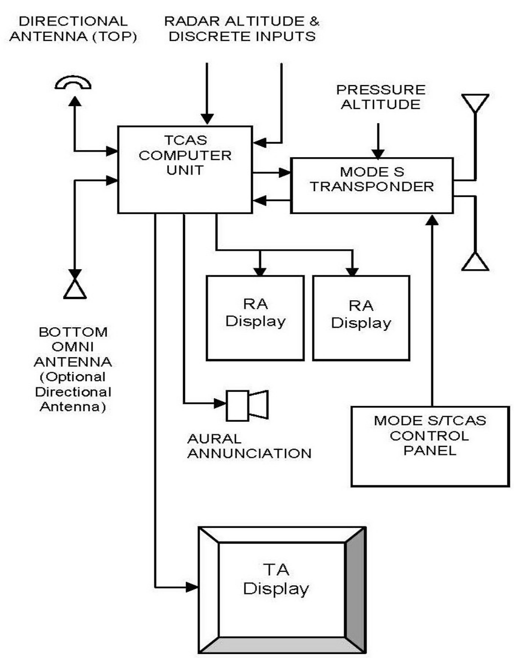

Figure 1 – TCAS II Block Diagram [7] [8]

A follow-on system to TCAS called the Airborne Collision Avoidance System X (ACAS X) has in recent years been the focus of a consortium of organizations formed by the FAA. MIT Lincoln Laboratory has been developing algorithms that specifically address trajectory prediction errors caused by sensors currently available to TCAS systems, and they have shown that significant performance improvements are achievable [5]. The ACAS X systems will be incorporating this type of improved prediction algorithm.

As noted above, ACAS X is being developed in conjunction with the FAAs NextGEN ATC System, described in Section V. A key difference between ACAS X and the TCAS systems that it will replace concerns their flexibility. Neal Suchy, the ACAS X System Program Manager, has stated that TCAS is not flexible enough (for this new purpose,) and something better suited to NextGEN is required [6]. ACAS X is addressing the need for improved flexibility. Whereas TCAS is constrained by the limitations associated with a beacon-type of interrogate/reply surveillance system, ACAS X will accommodate GPS data as well as other sensor types that will vary from platform to platform. ACAS X is being designed to accommodate various sensor arrangements in a "plug-and-play" fashion, enabling ACAS X applications to take advantage of all available sensor information when fusing that data. Further, ACAS X includes dynamic models of the aircraft being tracked and of the sensors in use, and through a state estimation process it "optimally" combines sensor data and the trajectory constraints governed by the dynamic models to produce a superior estimate of the current and future trajectories of the target aircraft being tracked. These trajectories are given to an Action Selection function that selects a conflict Resolution Advisory as needed. Simulation results have indicated the ACAS X can potentially cut conflict alerts that are unnecessary by 1/3, while also reducing collision risk by a factor of 2 [5].

There are currently 4 variants of the ACAS X system under consideration [9]:

- ACAS X_A – The general purpose ACAS X that makes active interrogations to establish the range of intruders.
- ACAS X_P – The version that does not make active interrogations but relies solely on passive ADS-B to track intruders. Intended for general aviation aircraft.
- ACAS X_O – A mode of operation designed for situations that might generate an unacceptable number of nuisance alerts (e.g. closely spaced parallel approaches).
- ACAS X_U – The version designed for Unmanned Aircraft Systems (UAS).

ACAS X variants will extend collision avoidance protection to new user classes and to airspace conditions that are not currently using and benefiting from TCAS I or II.

V. ADS-B HISTORY, CAPABILITY AND DICHOTOMY (ADS-B IN/OUT)

Automatic Dependent Surveillance – Broadcast is automatic because data is transmitted without manual actuation by an operator (pilot), dependent because it requires external geolocation data from an onboard position source (GPS avionics), surveillance in that it allows ATC to build a comprehensive air traffic picture and of the Broadcast variety because transmitters do not require acknowledgment of their periodic transmission of surveillance data. Simply stated, an ADS-B aircraft determines its position via satellite navigation and periodically broadcasts it, enabling it to be tracked [10]. The information can be received by air traffic control ground stations as a replacement for secondary radar. It can also be received by other aircraft to provide situational awareness and allow self-separation. Because these disparate elements were not designed for the specific purpose for which they were being sequestered, each contributor (element) required some enhancement or extension. As stated in the previous section, Mode-S data transmissions are initiated in response to interrogation by an SSR. The original standard includes the provision for an acquisition "squitter" transmission (unsolicited "response") to permit passive acquisition by interrogators with broad antenna beams, where active acquisition may result in significant back and forth communication in a high message traffic environment. These squitters were originally added to improve the efficiency of acquisition during the Mode C ATCRBS listening period (the Mode-S silent period retained to provide continued Mode A/C ATCRBS functionality) [11]

To facilitate the efficient transfer of the greater volume of data required by ADS-B, the squitter size was increased and equipment having this enhancement was labeled Extended Squitter (ES) capable. Original GPS position data was simply not robust enough (vertically) to provide the precision required for reliable extrapolation of track data required by an ATC that relied on ADS-B. In a case of serendipity, the FAA had been experimenting with various GPS augmentation schemes to increase the precision of the geolocation solution available with GPS for the purpose of precision approach capability (without the use of ground based navigation aids). While many proposals were explored, the WAAS (Wide Area Augmentation System) was adopted and is currently capable of providing position accuracy data of 7 meters both vertically and horizontally [12]. Paired with a suitable position source, a Mode-S (Extended Squitter) transponder forms one possible implementation of ADS-B (Out). Because ADS-B is a key part of the FAA's mammoth NextGEN [13] initiative, it is useful to examine first, the airborne components. Airborne Equipment can be divided into subsets (by capability). ADS-B (Out) which provides periodic broadcast of roughly the same elements as EHS above to ground receivers (with or without SSR) and airborne ADS-B platforms equipped with ADS-B (In) equipment. Predictably, ADS-B (In) describes an airborne installation that is capable of receiving ADS-B transmissions from other aircraft and ground stations for the purpose of situational awareness. In North America only, an additional ADS-B standard has been adopted for aircraft that operate below 18,000 ft. Mean Sea Level. ICAO annex 10 details the format and operation of the Universal Access Transceiver (UAT) which the United States adopted to reduce congestion in the 1090 MHz band. In many ways, the UAT is a simpler solution to a continuous broadcast of position, direction and velocity, but since it does not provide any backward compatibility (or any evolutionary equipage process) it remains a US only capability. The functional overview of the ADS-B Out System is shown in Figure 2.

VI. DUE REGARD RADAR SYSTEMS [14]

"General Atomics Aeronautical Systems, Inc. (GA-ASI), the leading manufacturer of Remotely Piloted Aircraft (RPA), tactical reconnaissance radars, and electro-optic surveillance systems, has completed several planned flight tests during 2013-2015 of a Sense and Avoid (SAA) architecture and Self Separation functionality. The system has functioned as a true "system of systems" to detect every class of aircraft equipage and paves the way for a Due Regard radar system capability."

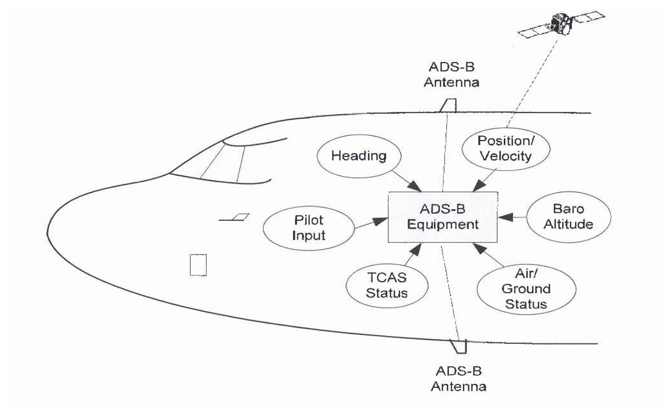

Figure 2 – Functional Overview of the ADS-B Out System [2]

The purpose of the test was to integrate and synchronize BAE Systems' AD/DPX-7 Identification Friend or Foe (IFF) transponder with Automatic Dependent Surveillance Broadcast (ADS-B) IN, GA-ASI's air-to-air radar, called Due Regard Radar (DRR), and Honeywell's Traffic Alert Collision Avoidance System (TCAS) TPA-100 to detect and track cooperative and non-cooperative aircraft. The prototype DRR tracked multiple targets of opportunity, in addition to participating aircraft, throughout 40-plus scripted encounters, including some aircraft not tracked by Air Traffic Control. Sensor data collected by these systems during the flight test will be used by the FAA and industry participants to develop and further refine their algorithms, which will in turn lead to a proof-of-concept SAA system including Collision Avoidance.

The radar itself is an active electronically scanned array system, such as is carried by modern fighter aircraft. It weighs about 120 pounds and has two AESA panels -- two separate antennas that operate as one. The system is big enough to require a new radome on the front, which gives the Predator a more bulbous front end. The larger radome was also needed to support X-band transmission. "The field of view is ±110 (degrees) horizontally, or a little bit behind the wings, and ±15 in elevation, although we can track targets up to 45 degrees," says Brandon Suarez, GA-ASI Lead Engineer. "And so those requirements basically replicate the windshield requirements on larger aircraft." The radar can track any airborne vehicle, but isn't intended to focus on those that aren't already tracked by another system, such as air traffic control. Instead, it looks for "non-cooperative" aircraft or those that aren't broadcasting their location. "The radar requirements were built around this idea that the radar could detect everything but should focus on the aircraft that are not being tracked by another sensor, which we call non-cooperative".

The detector maximum range R_{MAX} can be calculated when the radar power and antenna gain are known (ERP -- effective radiated power). Using the values shown below, the Radar Range R_{MAX} = 17788 meters = 9.6 Nautical Miles [15].

$$R_{MAX} = \frac{P_t \times G \times S \times A_e}{(4\pi)^2 \times P_{MIN}}$$

R_{MAX} = Radar Range meters
P_t = Transmitted Pulse Peak Power 105 dBi
G = Maximum Power Gain of Antenna 500W
A_e = Antenna Aperture 1 (m^2)
S = Radar Cross Section Area 1 (m^2)
P_{MIN} = Minimum Detectable Signal of Receiver, 1 μW

As noted in [8], "The flight test occurred November 18-20, 2013 at GA-ASI's Gray Butte Flight Operations Facility in Palmdale, Calif. During the test, a company-owned Predator® B leveraged its SAA system to detect two participating intruder aircraft with all three sensors. The Honeywell sensor fusion algorithm excelled in combining the multiple sensors' outputs and fusing them into a single track picture to send to the ground. Tracks were displayed in the ground control station using GA-ASI's Conflict Prediction and Display System (CPDS), which is designed to aid pilots in making maneuvers to remain well clear of other traffic."

The results of this flight test follow GA-ASI's successful demonstration and follow-on integration of ADS-B aboard a Department of Homeland Security (DHS)/Customs and Border Protection's (CBP's) Guardian RPA (the maritime variant of Predator B) and the successful test of DRR on the company's Predator B. GA-ASI is working with FAA to develop a technical standard that would demonstrate how the sense and avoid system like the Due Regard-equipped Predator may fly safely in the U.S. National Airspace System as well as in international airspace. See Figures 4 and 5.

Figure 4 – MQ 1 Predator/ MQ-9 Reaper UAS[21]

Figure 5 – US Customs Border Protection Predator B UAS Guardian [21]

VII. Regulatory Issues (FAA-NEXTGEN and EUROCONTROL)

NextGEN is composed of programs to facilitate a safer, faster, cheaper, more efficient air traffic management system in the FAA area of responsibility. These programs include Automatic Dependent Surveillance–Broadcast, Data Communications, Enroute Automation Modernization, Terminal Automation Modernization and Replacement, NAS Voice System and System Wide Information Management, however, this discussion will be restricted to the air situational awareness enhancements proposed for ATC and airborne users. To reduce the costs inherent in ground based radar systems and improve aircraft tracking accuracy, an air traffic system based entirely on self-reporting traffic is proposed. The cornerstone of this program is ADS-B. When all users are capable of determining their three dimensional position and vector and then transmitting that to the appropriate ATC facility, the requirement for ground based radar acquisition becomes obsolete. Because the system must remain safe and robust during transition and because the cost of the mandated new equipment is an issue, there are many additional elements to the program to smooth transition. Because the cost of equipage for primarily low altitude piston engine aircraft amounts to as significant fraction of the overall worth of the airframe, the FAA provided an incentive for users to upgrade to ADS-B before the Jan 1, 2020 mandate. This incentive came in the form of Broadcast Weather information termed Flight Information Service – Broadcast (FIS-B). To provide an effective traffic picture, each ADS-B (In) receiver must see all the traffic in the vicinity. With some users transmitting ADS-B on UAT and others on 1090ES, it was necessary to provide a translating repeater, thus, ADS-R (Rebroadcast) was born, ATC received UAT transmissions are rebroadcast on 1090ES and vice versa. Because mandatory compliance is still 5 years away, there are targets that will be identified by ATCRBS that are not reporting position on either 1090ES or UAT. In an endeavor to provide a comprehensive traffic picture, ATC provides a Traffic Information Service – Broadcast (TIS-B) with these additional targets to all ADS-B (Out) equipped traffic [17].

VIII. Alternative Sensor Technologies

Technology advances have occurred by integrating technologies to provide more flexibility and performance. These integration trends are expected to continue. Avionic companies such as Garman and Honeywell have provided aircraft integration of GPS/Autopilot/transponders to reduce pilot overload and provide improved situational awareness for greater flight safety.

LIDAR—Light Detection and Ranging is a remote sensing method used to examine the surface of the earth. LIDAR technology may be used for aircraft detection but presents hazards for manned aircraft due to laser emissions and this should not be considered for collision avoidance.

Although military aircraft systems are more expensive than can be afforded on commercial aircraft or UASs, there are fielded systems on the F-35 Joint Strike Fighter that show how 360 degree situational awareness could be applied to collusion avoidance.

Northrop Grumman has developed a 360 degree, spherical situational awareness system in the electro-optical (EO) distributed aperture system (DAS). The DAS surrounds the aircraft with a protective sphere of situational awareness. It warns the pilot of incoming aircraft and missile threats as well as providing day/night vision, fire control capability and precision tracking of wingmen/friendly aircraft for tactical maneuvering. Designated the AN/AAQ-37 and comprising six electro-optical sensors, the full EO DAS will enhance the F-35's survivability and operational effectiveness by warning the pilot of incoming aircraft and missile threats, providing day/night vision and supporting the navigation function of the F-35 Lightning II's forward-looking infrared sensor for pilot Situational awareness employing advanced Infrared Search and Track technology and Day/Night navigation. [18]

Bistatic Radar systems with radio detection (electromagnetic waves) and ranging were developed in the 20th century with terrestrial, space and airborne applications. Passive Bistatic radar systems have various configurations of spatially separated receivers and utilize electromagnetic signals such as television, cellular, microwave, etc. in place of typical radar transmitters [19]. There may be an application for bistatic radar systems to provide collision avoidance equipment for aircraft recognizing the limitation of receiver spatial placement onboard aircraft and intermittent reliability of commercially broadcast transmitter signals.

Miniature transponders, telemetry to provide “First Person View (FPV) and Global Positioning System (GPS) with enhanced autopilot systems such as Pixhawk ®, using open source control, may lead to a solution providing small UASs with minimal collision avoidance capabilities.

IX. Conclusions and Recommendations

Future safety equipment for manned and unmanned aircraft must meet two requirements – compatibility with the FAA NextGEN ATC System, and operational performance exceeding the existing collision avoidance systems. This paper has described the current ATC System and how its operation is procedurally based, with human operators (pilots) executing those procedures, where unsupervised automatic pilotage not permitted. The integration of the UAS into the NAS is expected to build upon that tenant, with human operators engaged in the application of procedures for maintaining separation with all other air traffic. Notably, UASs are subject to limitations (and special considerations) that differ from their manned counterparts. First, UASs are usually smaller (but not always) than aircraft designed to carry passengers and cargo; these smaller aircraft are more sensitive to weight limitations than their manned counterparts. For Group 1 aircraft, the addition of new equipment to facilitate ATC control may exceed the payload and volume available. Further, smaller aircraft are notoriously difficult for ground based radar to acquire. While the “cockpit window – see and avoid” concept is not readily achievable with an “unmanned” platform, current FAA rulemaking requires that UASs operate in such a way that their flight path is observable and controllable by an operator. Based on the above constraints, the ADS-B Out solution provides the best cost benefit picture of any of the proposed solutions. Exclusive of antennas and cabling ADS-B (Out) solutions exist weighing only 4 lbs with a volume of 0.2 cubic feet enabling inclusion in the ATC “picture” without dependence on ground radar [20]. The additional capabilities and safety enhancement that could be provided by the adoption of ACAS-X and/or the addition of the various alternative sensor systems are promising, but the regulatory environment is far behind the technology. Once the UAS is integrated unto the NAS, procedural enhancements and new technologies that improve sense and avoid and air traffic safety should be the next step.

Acknowledgment and Decication

This paper is dedicated to the FAA Air Traffic Controllers (14,000) and Aviation Safety (8,000) personnel who keep American skies safe and regulate aircraft in United States airspace to promote economic growth to benefit, industry, academics and government employees.

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