Unmanned Aircraft System Airspace Integration in the National Airspace Using a Ground-Based Sense and Avoid System

Thomas P. Spriesterbach, Kelly A. Bruns, Lauren I. Baron, and Jason E. Sohlke

The concept of integrating unmanned aircraft systems (UASs) into the National Airspace System (NAS) is being developed by multiple governmental and nongovernmental organizations and spans multiple system development efforts. The ability for an unmanned aircraft to "see and avoid" is the primary technical challenge. When UASs were first introduced into the NAS, agreements with the Federal Aviation Administration required either visual ground observers or manned aircraft following the UASs and restricted operations to daytime only. These conditions significantly reduce the quality and quantity of DoD UAS training in the United States. This article covers the DoD Ground-Based Sense and Avoid (GBSAA) technology initiatives to reduce the burden of visual observers, as well as APL's role and contributions to GBSAA. The first initiative described is the Army's initial GBSAA system, which implemented a safe-state concept for the terminal-area operations access profile. The second initiative described is the Army's current follow-on GBSAA system, which allows for greater flexibility in flight operations while providing information for maneuver decisions for terminal-area operations and lateral-transit access profiles. The final initiative discussed is the Marine Corps system, which uses a safe-state concept to support the lateral-transit access profile. In 2013, the Federal Aviation Administration issued a Certificate of Waiver or Authorization for the Marine Corps GBSAA system, a major step toward UAS airspace integration.

INTRODUCTION

One can imagine that in the not-too-distant future, remotely piloted civilian aircraft will be flying everything from cargo to passengers or providing services from traffic spotting to supporting fire and police forces. Dramatic changes to aviation begin with modest starts but have long-lasting impacts. The development of

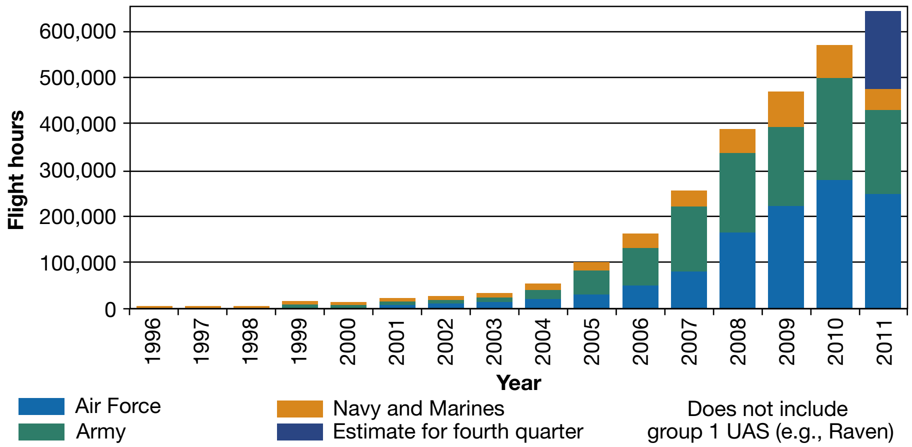

Figure 1. DOD UAS flight hours.[1]

Ground-Based Sense and Avoid (GBSAA), using electronic sensors to provide a safe method for unmanned aircraft (UA) to remain clear of other aircraft while safely flying within the National Airspace System (NAS), is one of these modest beginnings to a historic change in aviation.

The proliferation of unmanned aircraft systems (UASs) in both the civilian and military worlds has necessitated the need for UA to safely integrate with manned aircraft in the United States' NAS. As shown in Fig. 1, the DoD has significantly increased its use of UASs in the past 15 years. As the U.S. military continues to support overseas operations, the contributions of UASs, in terms of hours and expanded roles, continue to increase, and the number and variety of UASs are expected to increase significantly in the next decade.[1] The U.S. military has deployed more than 20 different UASs that are flown and operated overseas by the U.S. Marine Corps, Navy, Air Force, Army, and Army National Guard. The role of the UAS, which once included reconnaissance only, now includes strike, force protection, and signals collection.

The Challenge

A significant challenge that could hinder the growth and further incorporation of UASs into the U.S. military is the ability to operate in the NAS and airspace worldwide. The Federal Aviation Regulation part 91.113 states that "vigilance shall be maintained by each person operating an aircraft so as to see and avoid other aircraft." Because there is no pilot onboard a UA to perform see-and-avoid responsibilities, special provisions must be made to achieve a target level of safety that is consistent with that of onboard piloted aircraft when the UA is operating outside of designated safe states. A safe state refers to an area within the NAS that is fully controlled, such as a restricted area, warning area, and Class A airspace area.

Currently, there is little airspace in the NAS where the military services can develop, test, train, and operate UASs. The continued yearly increase in the number and types of UASs puts a further strain on the limited restricted airspace. Gaining access to civil U.S. airspace, as well as to international airspace, to perform these functions is critical for training and integrating future capabilities.

Today, there are two primary means by which the U.S. military has the capability to fly UASs in the NAS. The first method is to fly only in active restricted or warning area airspace. The U.S. military controls restricted areas, and it assumes responsibility for the safety of any UAS flights within the restricted airspace. The second means allows for flights outside of the restricted areas through the Certificate of Waiver or Authorization (CoA) process with the Federal Aviation Administration (FAA). The CoA process is an agreement for special provisions that the FAA levies on the UAS operator to provide safe operation in the NAS. These provisions in the past have been through the use of visual observers either on the ground (remaining in sight of the UA) or in a chase aircraft. For civil operators, special airworthiness certificates are available for experimental purposes only. Each of these methods comes with its own constraints and limitations. Temporary flight restrictions are another short-term means to fly UAS in the U.S. airspace but are mainly limited to emergency response or national security considerations.

In 2006, APL began working with the DoD to develop methods to ease access to the NAS for UASs. The DoD established a tri-service joint integrated product team (IPT) in which each service provided leadership and resources to solve the "see and avoid" problem. The joint IPT was superseded by the Office of the Secretary of Defense (OSD) Airspace Integration (AI) IPT in order to more closely coordinate the DoD efforts for UAS access to the NAS. This new tri-service AI IPT has a specific subgroup to deal with GBSAA issues and challenges.

GBSAA OVERVIEW

GBSAA is a ground-based means of detecting airborne traffic and providing the necessary intelligence to the UAS to mitigate or provide an alternative means of complying with the FAA see-and-avoid regulations. The GBSAA system includes all available sensors, correlation, fusion, communications, networks, logic, pro-

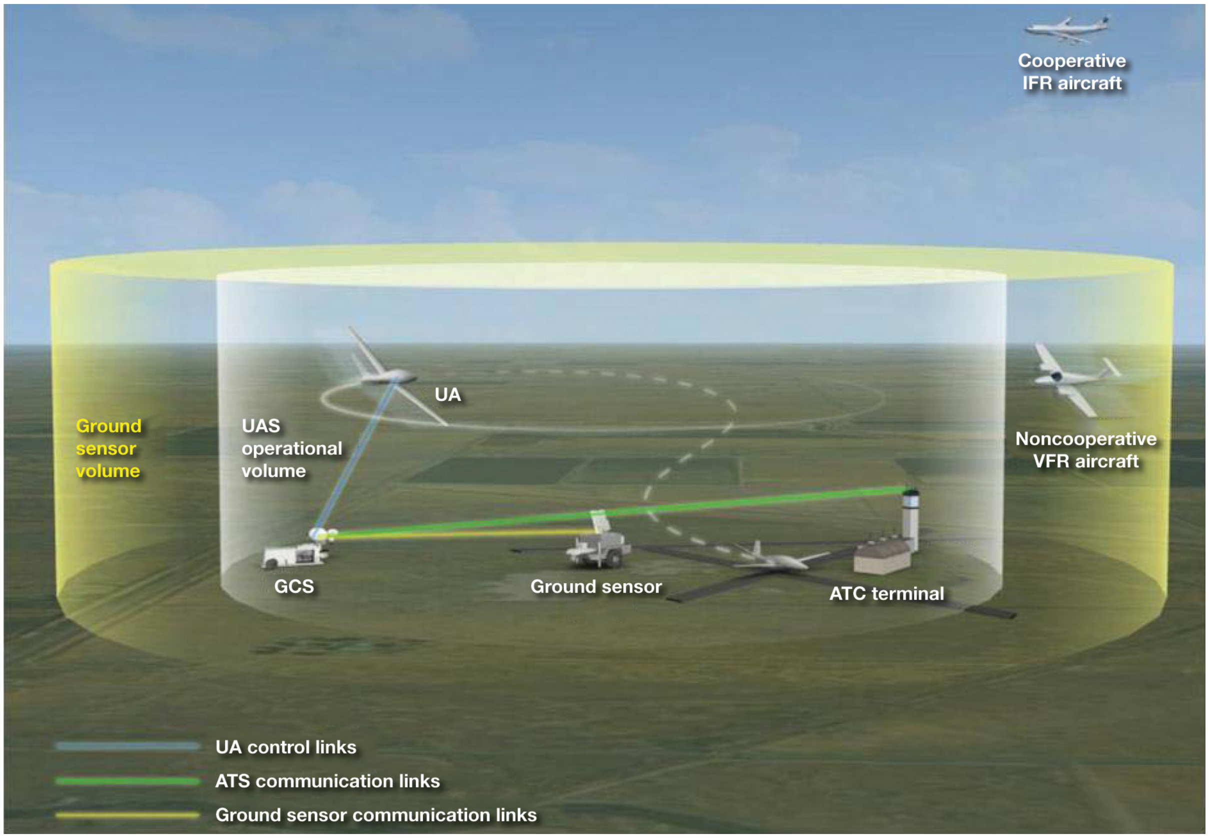

Figure 2. Terminal-area operations access profile.[2] ATS, air traffic services; GCS, ground control station; IFR, instrument flight rules; VFR, visual flight rules.

cedures, and user interfaces ("Ground Based Sense and Avoid (GBSAA)," presented at Small UAS Symposium, APL, Laurel, Maryland, 24 June 2010). Ground sensors, primarily radars, detect air traffic in a fixed volume of airspace called the surveillance volume. The GBSAA system develops a track picture based on detections from the ground sensors. The GBSAA system uses a scoring algorithm to evaluate the risk of the UA's position, heading, and velocity relative to the other aircraft in the surveillance volume. A GBSAA operator (GO) monitors the GBSAA system and alerts the UAS operator if action is required to avoid loss of separation. The GBSAA system also has health- and integrity-monitoring capabilities. If the system detects any problems within the system or possible traffic conflicts, the system notifies the GO that an action is required. During GBSAA operations, the UA flies in a volume of airspace referred to as the operational volume. The operational volume's size and location are site specific and dependent on the surveillance volume, such that an aircraft can be detected and tracked with enough time to notify the GO and the UAS operator if an action is required and the action can be performed.

The OSD AI IPT developed an *Unmanned Aircraft System Airspace Integration Plan*,[2] which describes six access profiles to enable UAS access to nonsegregated airspace. The access profiles include visual line of sight operations, terminal-area operations, operating area operations, lateral-transit operations, vertical-transit operations, and dynamic operations. The near-term focus of GBSAA is on enabling terminal-area operations, lateral-transit operations, and vertical-transit operations with a desired end state of dynamic operations.

Terminal-area operations are focused on a fixed volume of airspace, typically near a small airport or Class D airspace. This access profile enables UAS operators to practice takeoffs and landings and to fly in a region of airspace that is generally clear of surrounding aircraft. Figure 2 shows how a UA will fly in an operational volume that is within the ground sensor coverage area (i.e., surveillance volume).

Lateral-transit operations are focused on enabling UASs to transit from one region of airspace to an adjacent region of airspace through a lateral corridor. For example, as shown in Fig. 3, lateral-transit operations enable a UA to transit from a Class D airspace to an adjacent restricted area. Once in the restricted area, and assuming the restricted area was reserved for UA operations, the UAS operator can fly the UA within the designated portions of the restricted area to conduct testing or training. This profile can be used by all classes of UAs.

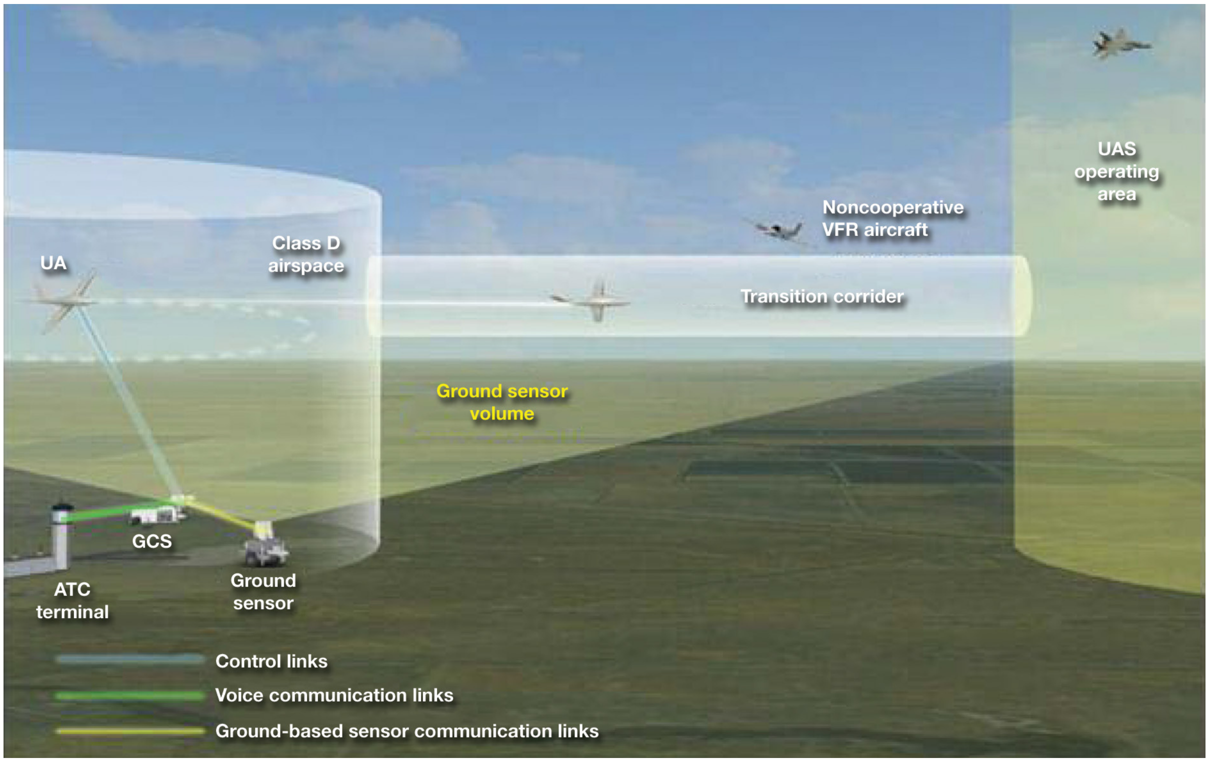

Figure 3. Lateral-transit operations access profile.[2]

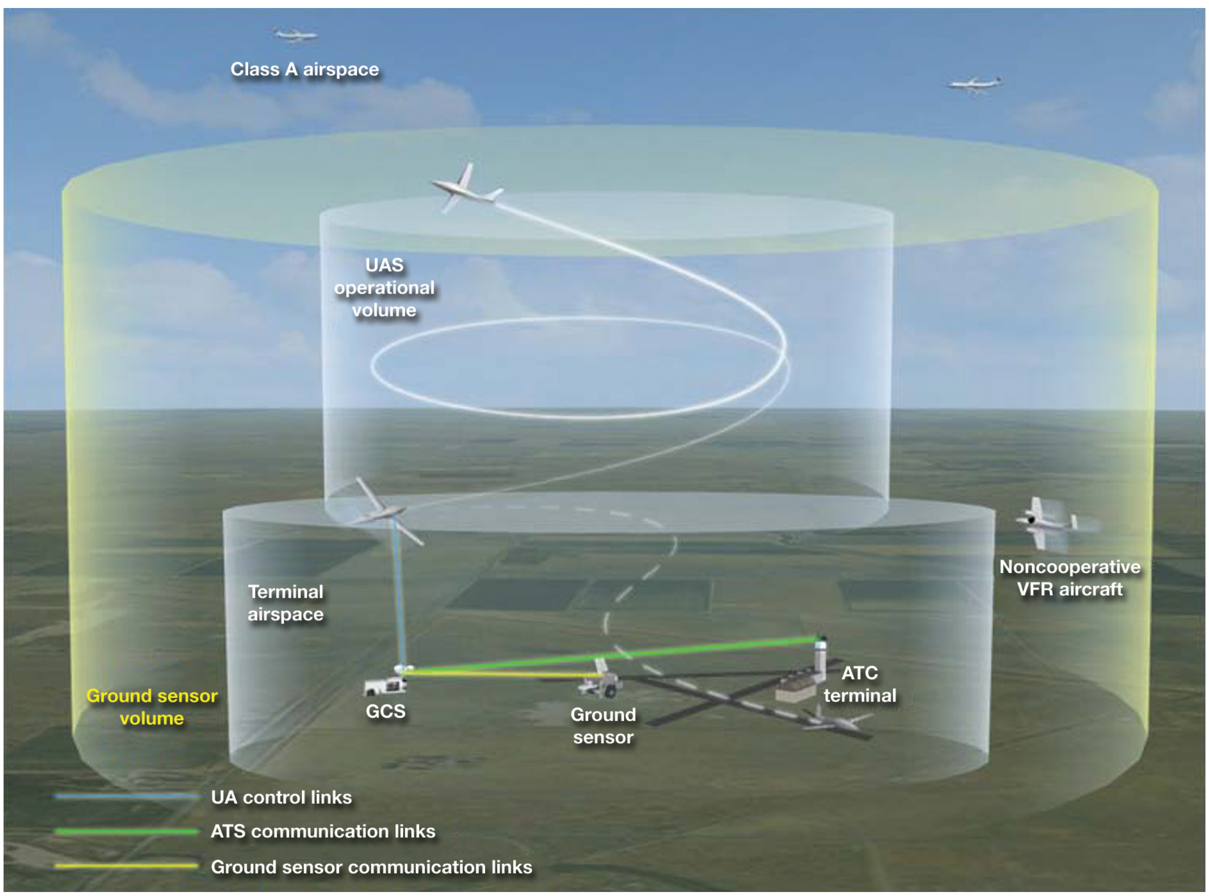

Figure 4. Vertical-transit operations access profile.[2]

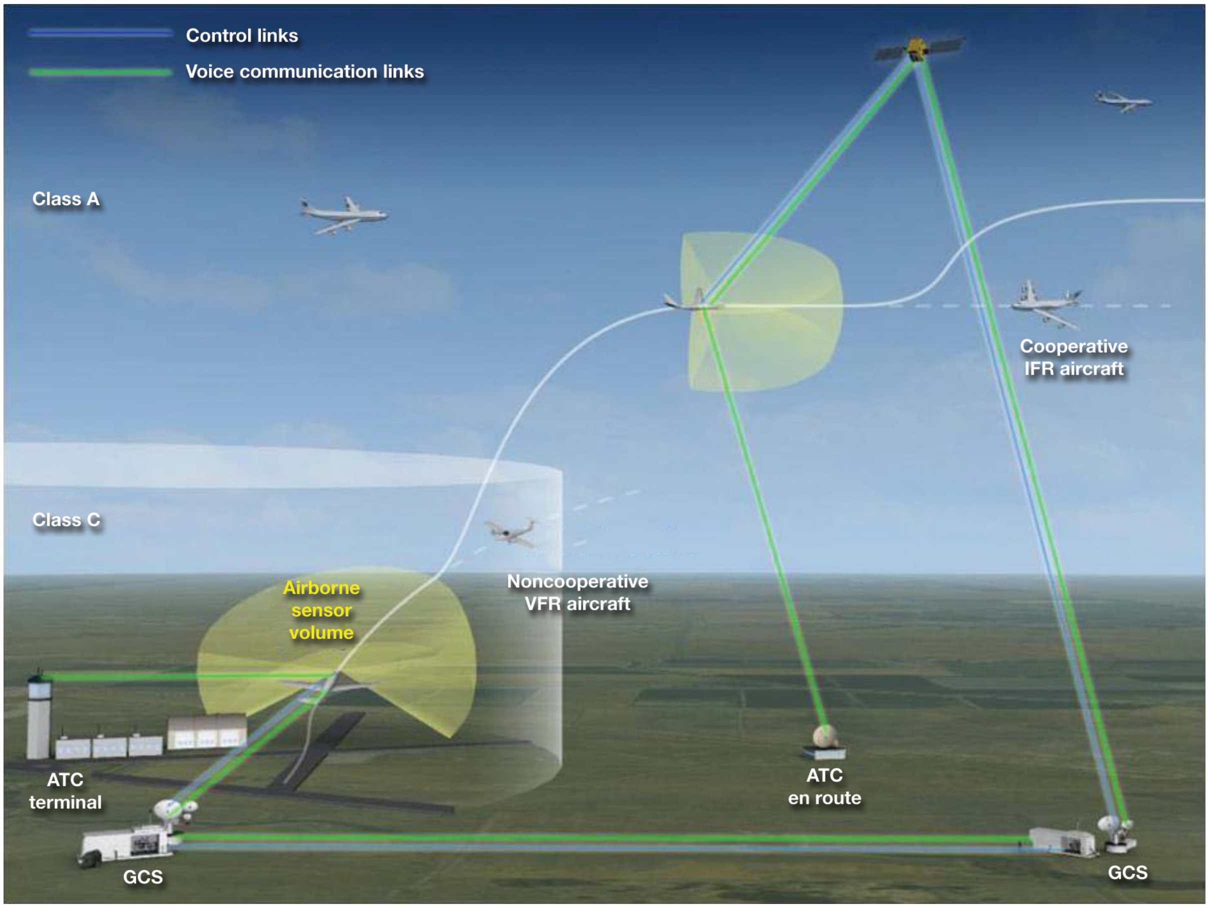

Figure 5. Dynamic operations access profile.[2]

Vertical-transit operations are similar to lateral-transit operations but enable UAs to vertically transit through a corridor to airspace above the airfield. Figure 4 shows how the UA could fly from a terminal area through a vertical corridor to Class A airspace. This profile is most commonly used by larger UAs that are approved for flight in IFR airspace and that are able to operate at higher altitudes.

Finally, the dynamic operations access profile enables UA access to the airspace, just like any other manned aircraft. Unlike terminal-area operations in which the operational volume is generally clear of other aircraft, the dynamic operations access profile allows a UA to fly among other aircraft using a GBSAA solution. Figure 5 shows how the UA would interact in the airspace under dynamic operations.

PATHWAY TO AUTHORIZATION

As previously stated, currently there are limited ways UAs can gain access to nonsegregated airspace within the United States. UAs cannot comply with Federal Aviation Regulation part 91.113, the need for the pilot onboard an aircraft to see and avoid other aircraft. Potential regulatory changes may someday provide an alternative means of complying with this regulation, but for now the DoD has been using the CoA process to gain access to the nonsegregated NAS for military UAS operations. Under the CoA process, the FAA conducts a comprehensive operational and technical review for the applied method of UAS access. The FAA levies limitations on the UAS operations to ensure the safety of others within the NAS. Until GBSAA, these strict limitations have limited the areas of operation and the time of day for operations and have required the use of visual observers or chase aircraft. Although these restrictions have provided the DoD with limited access to airspace, it has proven logistically difficult, expensive, and cumbersome to conduct testing and training. For example, for an operator to fly a UAS within the nonsegregated NAS, the FAA would require a manned chase aircraft with a visual observer onboard to fly within 1 mile of the UA at all times, while maintaining voice communications back to the ground control station for the UA, effectively doubling the costs and significantly increasing the manpower for one UA flight.

GBSAA was identified not as the “golden key” to unlock all airspace within the NAS for UA activity but as a first step to lessen the impact of FAA limitations placed on UA operations because of the UAS's inability to see and avoid other aircraft. Each implementation of a GBSAA system requires a rigorous review by the particular military service's safety organization, followed by additional scrutiny by the FAA. The FAA reviews all aspects of the proposed solution, including, but not limited to, software implementation, the engineering design of the methodology, implementation of the logic algorithms, and the operations and procedures to be followed by the UA and its crew. Additionally, the FAA requires a comparative safety assessment to ensure that this "new" system can be considered as safe, if not safer, than previously approved CoAs that use visual observers.

The following sections describe GBSAA methods used by the Army and the Navy/Marine Corps to gain limited access to nonsegregated airspace for UASs. Each GBSAA system handles the mitigations differently through the use of effectively used electronic means and operations and procedures to remove the need for visual observers and chase aircraft to be used during UA flights in the NAS.

GBSAA ARMY ACTIVITIES

Background

As the GBSAA lead designated by the OSD AI IPT, the Army's Program Manager for Unmanned Aircraft Systems Unmanned Systems Airspace Integration Concepts Product Directorate has led the way on a variety of GBSAA activities, including an initial GBSAA system at El Mirage; a follow-on GBSAA system currently under development at Dugway Proving Grounds (Utah), which will ultimately be used at multiple sites; and other process improvement and standardization activities.

One of the restrictions of using visual observers is that UA operations can take place only during the day. However, to train under conditions similar to those of actual operations, there was a need to also perform night operations. To enable 24-h-a-day Gray Eagle operations at El Mirage, California, the Army developed an initial GBSAA system. This system allowed UA to use the terminal-area operations access profile so that the USA operators could practice takeoffs, landings, and terminal-area operations. The system was designed such that a GO works in close coordination with the UAS operator. The GO is stationed at a GBSAA system that uses a simple red light and green light display. If the light is green, then it is safe for the UA to conduct operations within the operational volume. If the light is red, then the UA must land as soon as possible. After completing a safety case review with the FAA, the Army was granted a CoA for Gray Eagle operations at El Mirage using the GBSAA system. On 27 April 2011, it conducted the first flight of a UA in the NAS using a GBSAA system.

The Army is currently developing a follow-on GBSAA system to enable airspace access for additional locations to support both the terminal-area operations access profile and the lateral-transit access profile. A version of this software is currently being tested at Dugway Proving Grounds.

GBSAA Architecture and Description

The initial system installed at El Mirage, California, used ground-based radars along with a stand-alone GBSAA system to monitor the local airspace. This system implemented a concept referred to as safe states. A safe state is a volume of airspace in which the UA is safe from an intruder aircraft. Examples of safe-state operations include landing at the airfield or operating in a restricted area. For the initial El Mirage system, the only safe-state operation was landing the UA at the El Mirage airfield because the concept implemented the terminal-area operations access profile. For this system, the GBSAA algorithm assesses whether an aircraft, under the worst-case assumptions, can reach the operational volume before the UA can land back at the airfield. This included the assumptions that the surrounding aircraft was traveling at 250 knots, co-altitude with the UA, and was headed directly for the UA. On the basis of the radar locations and associated sensor coverage, a surveillance volume was defined that provided enough time for the UA to land before the intruder aircraft could reach the operational volume on the basis of worst-case assumptions. Within the surveillance volume, an operational volume was also defined in which the UA could operate. If the GBSAA system determines that there are no detected intruders or system issues, then a green light is displayed. If there is a detected aircraft in the surveillance volume or there is a system issue, then a red light is displayed along with an audio alert. This system is composed of three subsystems, one for sensing and tracking, one for alerting, and one for health and integrity monitoring.

The system currently under development also uses ground-based radars to monitor the local airspace; however, this system uses complex algorithms to fuse the data from the ground-based radars, assess which aircraft may pose a threat to the UA, and provide airspace information to the GO. This system is composed of multiple subsystems to perform the sensing, fusing, classifying, assessing, informing, and monitoring functions. This concept is designed to be robust enough to enable different types of operations and access profiles at different sites, including terminal-area operations and lateral-transit operations. The current system under development also uses the concept of a surveillance volume and operational volume. However, the operational volume is significantly larger than the previous system's operational volume, on the basis of different underlying assumptions. The current system not only uses the aircraft's current position, but it also takes into account the altitudes, headings, and speeds of the UA and the intruder aircraft. There are still assumptions about aircraft maneuverability and acceleration; however, using fewer assumptions about the intruder aircraft and taking into consideration information on the UA results in more operational time in the NAS. The other major difference is that this system does not require the UA to return to a safe state once an intruder aircraft has been detected. Rather, the GO provides information to the UAS operator so that the latter can make an informed decision on what action to take.

Airspace Architecture

The most common airspace architecture is a military airfield adjacent to a restricted area. For UA to transit to the adjacent restricted area, they must transit through a segment of nonsegregated airspace. These transits are on the order of minutes and are critical to support UAS operator training. GBSAA operations are well suited for these types of operations because of the short transits and the availability of existing ground-based radars. The current GBSAA system plans to incorporate existing sensors as well as GBSAA-specific sensors. Existing sensors, referred to as inorganic sensors, are typically owned by the FAA and support only range and azimuth detections and tracking. GBSAA-specific sensors, referred to as organic sensors, support range, azimuth, and altitude detections and tracking.

To test airspace integration concepts, the Army has installed a test bed at Dugway Proving Ground in Utah that allows UA operations entirely within a restricted area. The GBSAA system installed at Dugway enables the exploration of different algorithms and geometries to test the robustness of the sense-and-avoid algorithms.

Roles and Responsibilities

The GBSAA system is monitored by a dedicated person, referred to as the GO. The GO works closely with the UAS operator to ensure safe operation of the UA in nonsegregated airspace. For both the initial El Mirage system and the current system under development, the GO monitors the GBSAA system and alerts the UAS operator when an action is required. One of the major underlying assumptions for both systems is that the GBSAA operations will not have an impact on current air traffic control (ATC) operations. That is, the GO interacts only with the UAS operator, and the UAS operator interacts with ATC with or without GBSAA.

APL's Role

APL provided critical contributions to the Army's initial system at El Mirage and continues to provide major systems engineering contributions to the system currently under development. Initially, APL led the development of architectures for both current and future operations for El Mirage. This was important to understanding how future operations using GBSAA would affect the current operations with visual observers. APL also developed and maintained the system-level requirements associated with the initial GBSAA system.

For the current system development, APL continues to play a critical role in the systems engineering activities. This includes documenting the concept of operations, developing the system-level requirements, maintaining traceability to detailed requirements developed by other contractors, developing operational and system architectures, and leading the planning and execution of system-level integration and verification. Thorough systems engineering and traceability are imperative for this safety-critical system to convince the certifying organizations of both the Army and the FAA that the system is sufficient as an alternative means of complying with see-and-avoid regulations.

Because the Army is the GBSAA lead, it also oversees other cross-service activities, to which APL is the prime contributor. One major initiative is the development of a common set of GBSAA requirements across the services to aid in future development and procurement activities. To develop a standardized set of requirements, APL has led a requirements workshop with cross-service representation and several follow-on meetings. Another initiative is to standardize certification activities. The Army and APL co-led a safety workshop to share lessons learned from the El Mirage safety case development and a software certification workshop to discuss methodologies, standards, and criteria.

GBSAA NAVY ACTIVITIES

Background

The Navy's implementation of GBSAA, led by PMA-262, is for Marine Unmanned Aerial Vehicle Squadron 2 (VMU-2) at Marine Corps Air Station (MCAS) Cherry Point in North Carolina. VMU-2 operates the RQ-7B Shadow and provides aerial surveillance for the II Marine Expeditionary Force.

VMU-2 continues to be deployed overseas to Afghanistan, and use of the Shadow UAS is a daily occurrence. In the past, the Marines have been forced to gain most of their training flight hours overseas because of logistical struggles to train in the NAS before being deployed. This lack of state-side training and preparation often results in inexperienced flight crews learning on the job in often high-stress and time-critical environments. There are two main ways that VMU-2 conducts UAS training flights in the United States: (*i*) launch and recovery from an airfield embedded in the restricted area and (*ii*) through the use of visual observers, which observe the UA and surrounding air traffic. Each of these approaches has logistical issues.

Near Cherry Point, there is a large restricted area, R-5306A, that resides over a small airfield, Atlantic Field Marine Corps Outlying Field. Because R-5306A is continuously in effect from the surface to, but not including, flight level 180, VMU-2 is able to launch its Shadow UAS from Atlantic Field and conduct training missions completely within the restricted airspace, without having to enter nonsegregated airspace. This approach involves VMU-2 packing up all equipment (including multiple cargo trucks) and "deploying" to Atlantic Field for multiple days at a time; the drive to Atlantic Field is longer than 2 h. For squadron members, this mini-deployment means additional time away from their families, increased burden of planning and packing, potential for delayed and/or canceled flight time if the weather does not cooperate, and significant costs for the Marine Corps to deploy near their home base. Because of these logistical burdens, VMU-2 is not able to gain sufficient training flight hours using this method.

Alternative methods for the UAS to gain access to the restricted areas around MCAS Cherry Point include using either ground-based observers or an observer in a chase aircraft to monitor the UAS flight and provide information to separate the UA from other aircraft with which it may be in conflict. MCAS Cherry Point currently uses ground observers. The primary duties of the ground-based observer are to report observed segment status; report UAS observation, weather, and traffic updates; and acknowledge when transit is complete. At Cherry Point, ground-based visual observers covering the Class E airspace are employed in teams of two Marines. One individual visually scans and acquires the UAS, maintaining constant visual contact with the air vehicle at all times. The second observer communicates with the UA commander (UAC)/pilot in command and assists the first member in acquiring the UAS and scanning for traffic. Visual observer teams need to be deployed at 1-nautical-mile intervals along the entire planned flight path of the UAS and must remain in constant visual contact with the UAS at all times. This solution requires extensive planning and manpower. The Marines typically use a team of 12 Marines to provide enough visual observers for the Shadow to make a typical transit from Cherry Point to the restricted area.

Neither of the two previously described solutions increase training flight hours, nor would they be considered optimal. To maximize training opportunities and minimize cost, Shadow UAS operations at MCAS Cherry Point dictate that the UA must transit between the Cherry Point Class D surface area (CDSA) and the restricted areas R-5306A and R-5306C through the NAS. A GBSAA solution was chosen as risk mitigation to the see-and-avoid requirement while flying within the NAS.

GBSAA Architecture and Description

In lieu of ground observers or chase aircraft, the GBSAA system at Cherry Point provides the necessary see-and-avoid capability through the use of technology and procedures. The GBSAA system analyzes track data from the MCAS Cherry Point surveillance radar, the ASR-11, and displays noncooperative air hazards, in addition to cooperative air traffic, within the local operating area.

An underpinning of the GBSAA concept classifies aircraft into two categories: cooperative aircraft and noncooperative aircraft. Cooperative aircraft are defined as those that are squawking a discrete Mode 3/C beacon code. These aircraft are assumed to be under the control of ATC and are therefore not considered a safety risk to the UA because ATC personnel are required to separate controlled aircraft from all other aircraft. Noncooperative aircraft are defined as those transmitting a Mode 3 code ending in "00" or not transmitting any electronic identification. It is assumed that these aircraft are not under the control of ATC, and they are therefore monitored and scored by the GBSAA system. Both types of aircraft are displayed to the GO, but they are displayed and handled differently because of their varying levels of risk potential.

The GBSAA system operates as a stand-alone console with nominal initial employment in an ATC facility radar room; the console is referred to as the GBSAA operator console (GOCon). The console's primary indicator, referred to as the alerting system, is a three-color operational decision ("stoplight") display that will show red, yellow, or green lights depending on the noncooperative intruder's ability to interfere with the UA's transit.

The GOCon software supports the reception and tracking of data from the ASR-11 and displays the resultant tracks. The software is built on a government off-the-shelf system currently used by Navy range facilities, the Stand Alone Radar Console (STARCON) system. The primary function of the GOCon's display is to alert the GO to the highest threat level determined by GBSAA system. The GO uses the alerting system, which consists of a three-color (red, yellow, and green) stoplight display, to continually monitor the overall threat level. Additional display functionality provides the GO with operational awareness of the UA's state (i.e., location, speed, and orientation), as well as noncooperative intruders' and cooperative traffic's geographical positions, speeds, and headings. This display allows the operator to provide information on individual intruders. The GOCon will alert the GO when a system or subsystem failure is detected. When failures are detected, the system will display a red overall threat level, and a failure description will be displayed to the GO.

The GOCon will display the following: a unique indicator for the UA, all aircraft within the surveillance volume (i.e., all cooperative and noncooperative

Figure 6. GBSAA display.

aircraft, including the respective threat levels of noncooperatives); an overall threat-level status indicating either a red, yellow, or green alert status; the surveillance volume; the active operational transit volume (OTV); the CDSA and restricted areas; and any preset exclusion zones.

Each noncooperative intruder is scored on the basis of its ability to interfere with the UA's transit through the active OTV. This scoring yields an intruder's individual threat level. Noncooperative intruders are displayed on the GOCon display as either a red, yellow, or green target on the basis of that individual intruder's scored threat level. All cooperative aircraft are displayed as blue targets and are not scored or assigned a threat level because they are under the control of ATC.

The overall threat level, displayed as a three-color stoplight on the GOCon display, as shown in Fig. 6, reflects the highest threat level for a noncooperative intruder currently being tracked by the system; this highest threat level is also referred to as the rolled-up threat level. A rolled-up threat level status of red indicates that one or more noncooperative aircraft being tracked could reach the active OTV at their current speeds. A rolled-up threat level status of red can also indicate that there is a critical subsystem failure or that connectivity to the radar is lost. A rolled-up threat level status of yellow indicates that one or more noncooperative aircraft being tracked could reach the active OTV if the aircraft accelerate to 250 knots at an assumed maximum rate of 2 knots per second. A rolled-up threat level status of green indicates that there are no noncooperative aircraft being tracked that can reach the active OTV, even if an intruder aircraft were to accelerate to 250 knots at an assumed maximum acceleration of 2 knots per second.

The GO reports the rolled-up threat level status to the UAC in order for the UAC to make an informed decision on whether to begin transit through the OTV. The UA can begin transit through the OTV only if the rolled-up threat level is green. If the UAC determines that additional airspace information would be important for his or her decision, he or she can ask the GO to provide that information.

Airspace Architecture

The GBSAA concept at MCAS Cherry Point uses the lateral-transit access profile. Shadow UAS training flights depart from and arrive at MCAS Cherry Point CDSA and fly training missions in either of two adjacent restricted areas, namely R-5306A to the northeast

Figure 7. Cherry Point areas of interest.

and R-5306C/D to the southwest, as shown in Fig. 7. The UAS travels approximately 6 nautical miles (NM) to either of the restricted areas. The CDSA and restricted areas are considered safe states because they are heavily controlled airspaces and air traffic will not be entering those areas without being cleared and in contact with the appropriate controlling agencies. The 6-NM transit from the CDSA to the restricted areas occurs through a lateral tunnel of airspace known as the north and south OTVs. These volumes are fixed in space and have a proven history of safety when used during past UA operation exercises under previous agreements. The route of the Shadow UA through the transit volume is nominally down the middle of the defined area.

For the designated path through the OTV, and assuming wind is not a significant factor, the UA would require 4 min to transit the 6 NM of the south OTV at 90 knots. However, the nominal procedures require that the UA climb to the appropriate transit altitude. Also, it is likely that the UA will encounter winds during its transit, which could adversely affect the UA's possible speed. Accounting for the distance, winds, and climb, a time buffer was added to the nominal transit time, yielding a maximum time of flight for the UA of 5.2 min within the OTV.

In addition to the CDSA, OTV, and restricted areas, there are two other airspace regions that are important to understand for the Cherry Point GBSAA concept: the surveillance volume and exclusion zones.

The surveillance volume is defined as a volume of airspace in which aircraft are detected and tracked by the surveillance radar and in which the GBSAA system will monitor and display the tracked aircraft. Within the surveillance volume, all noncooperative aircraft are scored using the GBSAA algorithm. Any cooperative or noncooperative aircraft detected within the surveillance volume are defined as intruder aircraft. The GBSAA system monitors traffic within the surveillance volume by displaying data from the surveillance radar system (ASR-11 at MCAS Cherry Point). This volume extends out to 40 NM from the Cherry Point radar, with upper and lower limits that correspond to the typical radar envelope provided by the ASR-11.

An exclusion zone is defined as any area where detected aircraft are not evaluated for threat level. Exclusion zones are identified so as to limit false-positive radar detections within airspace regions that are known to be of no consequence. For Cherry Point, the exclusion zones are not configurable by the GO and include R-5306A, R-5306D, and an area within a 2-NM radius from the center of the Cherry Point CDSA.

Roles and Responsibilities

The GO is a suitably qualified staff member of the ATC facility or VMU-2 and serves as an integral member of the UAS crew. The GO directly reports to the UAC for the duration of the mission. The GO operates the

GOCon any time the UA is preparing for flight or is in flight; the GO's main duties include monitoring aircraft (mainly noncooperative aircraft, which may pose a threat to the UA while it is in the NAS and using the GOCon), ensuring the proper coordination and communications with approach control, and ensuring timely and accurate airspace updates to the UAC. Figure 8 illustrates the organization and communications necessary for the GBSAA system.

The UAC is the lead member of the VMU-2 aircrew. The UAC operates or manages the operator of the UA and is in constant communication with the GO in order to fully understand the airspace. The UAC's main duties include overall responsibility for the operation and safety of the UAS mission, sole authority and responsibility for transit decisions, and ensuring the proper coordination and communications with the GO, tower, approach control, and range control.

ATC handles several functions within the Cherry Point airspace. Approach control provides separation services for the aircraft within the Cherry Point area; it is also located in close proximity to the GO in the radar room. The close proximity of approach control to the GO aids in their coordination during UA operations. The approach controller is aware of the UA operations within his or her airspace but assumes no additional responsibility for the GBSAA and UA activity; the UA is treated the same as any manned aircraft. Approach control's main duties are unchanged from everyday operations and include maintaining situational awareness of UA operations within the assigned airspace, providing radar monitoring of the UA, and providing advisories and safety alerts regarding UA operations to other manned aircraft as prescribed per FAA Order JO 7110.65.

GBSAA Concept at Cherry Point

When UA operations are scheduled at Cherry Point, the GO is required to perform preflight checks of the GOCon and prepare for UA operations at least 1 h before launch. When the mission time approaches, the UAC contacts the GO and relays any pertinent launch information. The UAC also contacts the necessary entities within ATC to ensure that they are aware of the UA operations.

Once the UA is launched within the CDSA, the UA proceeds to a holding point and loiters in a pattern until the GO relays a green rolled-up threat level indicating a sanitized airspace. If the rolled-up threat level is red or yellow, there is an aircraft in the area that could reach the UA during its transit through the OTV or there is a system malfunction, and the UA should not transit. The GO will continue to update the UAC on the threat level status until a green status is gained and the airspace is clear of all imposing traffic.

After receiving a green rolled-up threat level status, the UAC makes the decision to begin transiting through the OTV. The UAC has sole authority for the decision to transit and will use all available information and resources to aid in the decision-making process to ensure that the airspace is sufficiently sanitized and that the UA will be able to cross the OTV safely. Once the UA exits the CDSA and enters the OTV, procedures dictate that it should continue on to the restricted area; the UA should not turn around within the OTV. In the event of the rolled-up threat level changing to yellow or red or the system malfunctioning, the UA should still have sufficient time to cross the OTV safely on the basis of the concept's time and buffer allocations. Once the UA exits the CDSA on the rolled-up threat level status of green, the airspace is sufficiently sanitized for 5.2 min. Once it reaches the restricted area, the UA performs its training mission without the aid of the GBSAA system. When the UA is ready to transit back to the CDSA, the GBSAA system is used in the same manner as it was used to get to the restricted area.

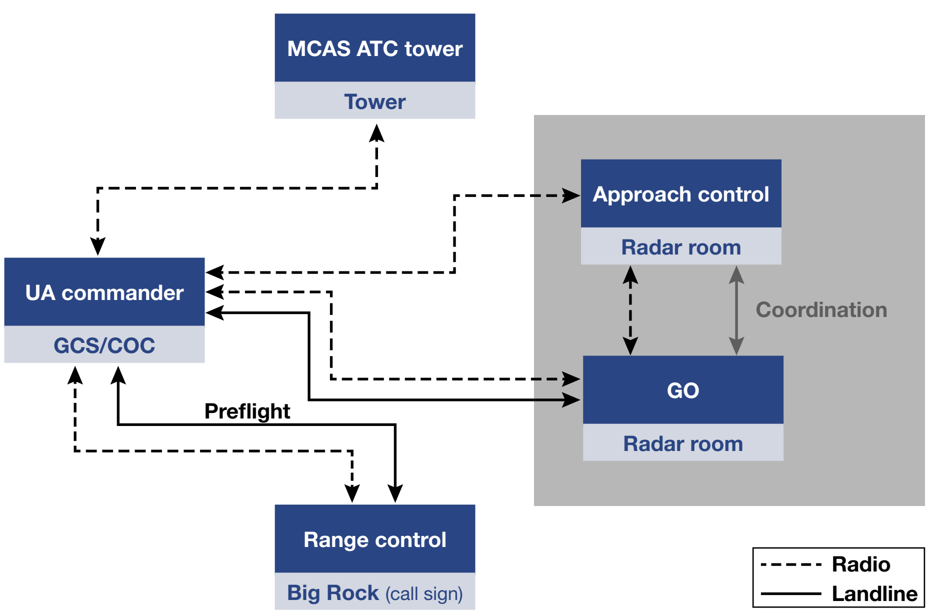

Figure 8. Organization and communications for GBSAA. COC, combat operations center.

APL's Role

APL was involved with the Navy/Marine Corps' GBSAA effort from the beginning, before the MCAS Cherry Point was selected as the first GBSAA site. The Navy/

Marine Corps GBSAA team remained relatively small throughout the development phases, and APL played a significant role in systems engineering and analysis. Involvement included initial system design, continued system conceptual design, timeline analysis studies, airspace characterization studies, requirements development and management, architecture development and management, concept of employment development, operations and procedures manual development, full Marine Corps training package development, the conduct of two weeklong training sessions, assistance with safety case development (functional hazard analysis, fault trees, etc.), assistance with drafting the CoA application documentation, defense of the GBSAA system at multiple FAA/OSD forums, and data analysis metrics reports development (initial and continued after the system became operational).

CONCLUSION

As the service lead for GBSAA, Program Manager for Unmanned Aircraft Systems Unmanned Systems Airspace Integration Concepts has led GBSAA activities through the development of an initial system installed at El Mirage, California; the development of a follow-on system for multiple locations and access profiles; and collaboration activities on safety case development, requirements, and software certification methodologies. Their GBSAA development methodology uses an incremental approach for UA access to nonsegregated airspace. The initial system used safe states to ensure that a UA could get out of the airspace before a potential conflict, and the current system is exploring more complex algorithms that would allow a UA to operate in the same airspace as manned aircraft. This incremental approach is not only important for enabling data collection to support the safety case but also for the general acceptance of manned and UA operations in a common airspace.

Currently, the Army activity is progressing with the implementation of a dynamic access profile at Dugway Proving Grounds. The Army is preparing for a test in 2014 to investigate the proposed concept, algorithms, and technology implementation for UASs to dynamically avoid other aircraft by using ground-based sensors.

The Navy's current system involves the operational implementation of an incremental GBSAA approach for lateral-transit operations. This system is currently in place at MCAS Cherry Point and was awarded a CoA in June 2013 to authorize UAS flights from the airfield to the local restricted areas, transiting through the surrounding Class E airspace.

Unfettered airspace access for UASs is a difficult problem, both technically and politically. Concerns for the safety of manned aircraft have to be balanced with the needs for UAS operations, and the collaboration of all stakeholders is required to come to an acceptable solution. GBSAA is seen as only one step in UASs gaining access to nonsegregated airspace and more general airspace integration. It is envisioned that GBSAA will play a major role in the final airspace integration solution, which will also implement airborne sense-and-avoid technologies.

REFERENCES

[1]Joint Planning and Development Office, *NextGen UAS Research, Development and Demonstration Roadmap*, Version 1.0, p. 20 (15 Mar 2012).

[2]UAS Task Force Airspace Integration Integrated Product Team, *Department of Defense Unmanned Aircraft System Airspace Integration Plan*, Version 2.0 (Mar 2011).

The Authors

Thomas P. Spriesterbach is an engineer and the Group Supervisor for the Special Concepts and Engineering Development Group in APL's Force Projection Sector (FPS). He has been working with both the Army and Navy supporting UA airspace integration. **Kelly A. Bruns** is an aerospace engineer in FPS. In support of the airspace integration effort, she is responsible for providing systems engineering guidance and technical leadership to the GBSAA tasks. **Lauren I. Baron** is a systems engineer and the Assistant Group Supervisor for FPS's Operational System Analysis Group. Previously, she served as a project manager of the UAS airspace integration project and contributed to the development of the requirements and architecture for the Army and Navy GBSAA systems. She also served on the OSD Sense and Avoid Science and Research Board. **Jason E. Sohlke** is a systems engineer in FPS. He has served as a system architect and as a project manager of the UAS airspace integration project. For further information on the work reported here, contact Thomas Spriesterbach. His e-mail address is thomas.spriesterbach@jhuapl.edu.

The *Johns Hopkins APL Technical Digest* can be accessed electronically at **www.jhuapl.edu/techdigest**.