

Sense and Avoid Development in Unmanned Aircraft Systems

by

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I would like to dedicate this research to my loving wife Rachel and my wonderful daughter Clare. Your patience and encouragement throughout this process has given me the strength and endurance I needed. To my Mom and Dad, thank you for loving me and raising me in a home that fosters education and a willingness to follow through. Thank you to my friend Chris. Your guidance and advice to me has been invaluable in helping me to do this. Lastly, thank you to my late Aunt Eileen. You always gave great advice, often telling me what I needed to hear instead of what I wanted to hear. It was your gentle admonishment of me over the years that spurred me into action to complete my degree.

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ABSTRACT

Unmanned Aircraft Systems (UAS) represent a new frontier in aviation. The commercial applications are limitless and private industry is continuously creating new and innovative ways to utilize this technology. Package delivery, utilities maintenance, real estate appraisals and remote wireless internet access are just a few of the ways UAS can be used. In fact, it is likely that the most innovative ideas of how best to use this technology have not even been thought up yet. However, before one can have a pizza delivered to their home by UAS, there must be a means of ensuring that a UAS can travel to and from a home in a safe manner.

This thesis focused on the solution for the above mentioned problem, a technology called Sense and Avoid (S&A). This thesis was primarily concerned with finding the current state of S&A's development. This technology is essential to UAS integration, but, due to the wide variety of UAS performance abilities and size, it was discovered that S&A is not a "one size fits all" solution. It was discovered that larger category UAS should minimally affect current NAS users. It is the integration of smaller category UAS where the majority of "outside of the box" thinking will be needed. Smaller category UAS will not fully, if at all, integrate into the NAS. The commercial applications for these small UAS would not put them in traditional air traffic controlled airspace. They will operate much closer to ground level in residential neighborhoods and business parks. S&A solutions for both larger and smaller category UAS will be fundamentally alike, but there will be significant differences in the application of them.

TABLE OF CONTENTS

	Page
LIST OF TABLES	vii
CHAPTER I . INTRODUCTION.....	1
Review of Literature	1
Research Questions	23
CHAPTER II. METHODOLOGY.....	24
Participants.....	25
Instruments Used	27
Data Analysis	29
CHAPTER III. Data Analysis.....	31
Analysis.....	31
Professional Credentials.....	32
Primary Research Questions	35
Secondary Research Questions	41
CHAPTER IV. DISCUSSION AND RECOMMENDATIONS	48
Recommendations.....	51
Limitations	53
Recommendations for Future Research	54
REFERENCES	55

APPENDICES	58
APPENDIX A – IRB APPROVAL	59
APPENDIX B – INTERVIEW QUESTION LIST	60
APPENDIX C – CONTACT REQUEST LETTER	61

LIST OF TABLES

Table	Page
1 Comparisons of interview participants' aviation working experience33	

CHAPTER I: INTRODUCTION

In February of 2012 President Obama signed into law The Federal Aviation Authority (FAA) Modernization and Reform Act of 2012. This new law included \$63.4 billion in federal funding over a four year span, of which \$11 billion was dedicated towards the modernization of the U.S. air traffic control system. This Act was applauded by the National Air Traffic Controllers Association (NATCA), Air Line Pilots Association (ALPA), National Business Aviation Association (NBAA) and the Aircraft Owners Pilots Association (AOPA) for providing a dedicated funding platform for national airspace system modernization programs. Additional parts of the new law included provisions for enhancing runway safety, laws prohibiting laser attacks on aircraft, and flight and duty time limits for maintenance and flight crews. The Act, in entirety, is comprised of 300 pages of detailed rules, regulations and improvements. This thesis concerns what was written under Title III, subtitle B, sections 331 through 336 starting on page 63 of the bill, titled “Unmanned Aircraft Systems.” More specifically, this thesis will focus on the development of sense and avoid systems (S&A) for unmanned aircraft systems (UAS). It will ask what the current state of S&A development is and what the future direction of FAA requirements for S&A will be. Sense and avoid is a critical system needed for the mainstream integration of UAS. Without this system the commercial applications of UAS will be severely limited. This thesis will detail the origin and history of UAS, their development over the last century, how they operate, what sense and avoid is and how it is critical to the safe integration of UAS into the U.S. National Airspace System (NAS).

Review of Literature

To begin with, let us define what a UAS, is. Section 331 of the FAA Modernization Act states that “The term unmanned aircraft system means an unmanned aircraft and associated

elements (including communication links and the components that control the unmanned aircraft) that are required for the pilot in command to operate safely and efficiently in the national airspace system” (FAA Modernization and Reform Act of 2012 p.63).

There are three categories of UAS aircraft, excluding missiles, all of which fly without a pilot physically aboard them. These are unmanned aerial vehicles (UAVs), remotely piloted vehicles (RPVs), and drones. The term UAS is used as a comprehensive, generic title to encompass all of the various types of aircraft that fall under these different categories. In the past, all unmanned aircraft were commonly referred to as drones which, according to Webster’s Dictionary, is defined as a “pilotless airplane controlled by radio signals.” However, this term is inaccurate when it is applied to every type of UAS. Drones, unlike other UAS, have limited flexibility and fly in a monotonous and persistently dull manner. Typically they fly only a predetermined route and cannot deviate from this flight path without being reprogrammed. Yet another term that has been commonly misused for UAS is the acronym UAV (Fahlstrom, 2012). The term UAV has many extensions including unmanned aerial vehicle, unmanned aerospace vehicle, unmanned airborne vehicle and unmanned autonomous vehicle to name a few (Unmanned Aerial Vehicle Systems Association UAV, 2015). These many extensions of the acronym UAV are misrepresentative because they mislead the reader to think that a modern UAS is simply just an aircraft. It is much more than just that, as will be seen. The terms remotely operated aircraft (ROA) and remotely piloted vehicle (RPV) are also two terms that have been commonly misused when describing UAS as well. Today several reputable international organizations including the International Civil Aviation Organization (ICAO), EUROCONTROL, the European Aviation Safety Agency (EASA), the Federal Aviation Administration (FAA) and the U.S. Department of Defense (DOD) have unilaterally adopted the

acronym UAS as the common official term. This acronym was found to be most suitable because it utilizes the word “system”, which is more representative of what the modern UAS is (Angelov, 2012).

The evolution of UAS originated many years ago. In fact, one could argue that a caveman throwing a stone for defensive purposes demonstrated the basic function of a UAS. The throwing of spears and boulders launched from catapults utilized by the armies of the Greeks, Spartans, and Roman Empire could also be argued as early predecessors of today's UAS. However, these are examples of vehicles that demonstrated little to no degree of control and none of these vehicles were capable of aerodynamic lift. The starting point of unmanned aerodynamic flight is believed to have originated in 425 B.C. in South Italy when Archytas the Tarantine built a mechanical bird that could move its own wings and produce enough lift to fly. This bird was powered by a mechanism inside its stomach and it could fly for a reported 200 meters before losing power. Around the same time in China another early version of a UAS was created. This version was a spinning top that gained its propulsion from hand spun sticks attached to it. During the Renaissance period a flying bird, similar to the one Archytas first developed, was redeveloped by an unknown engineer. While it is unclear if this machine was based on the one Archytas created, the designs are very similar. In 1483, Leonardo da Vinci designed and built an aircraft that was capable of hovering. He called it a gyroscope. The aircraft was five meters in diameter and when the shaft was turned with enough force the machine could fly and spin in the air. In addition to being an early prototype of a UAS, some experts today consider this machine of Da Vinci's to be the inspiration for the modern helicopter. Da Vinci also designed and built a mechanical bird, not unlike the flying pigeon of Archytas', in the early 16th century. This bird could flap its wings and stay aloft guided along by a wire via the

propulsion of a double crank mechanism (Angelov, 2012). Douglas Archibald, in 1883, attached an anemometer to a kite in order to measure wind velocity. A few years later Archibald attached a camera to a kite, which could be argued was the first reconnaissance UAS. Around the same time, during the Spanish-American War, William Eddy took several hundred photos from kites for military purposes resulting in the first use of a UAS in combat. In the late twentieth century many steam powered designed aircraft took flight, some of which made major contributions to aircraft design still used today. For nearly 2,300 years unmanned machines of flight have dotted the pages of history. Although appearing infrequently, they have surely been inspiring to future innovators. These early examples of unmanned flight have a commonality and kinship to the modern UAS demonstrated in important themes; they were aerodynamic, unmanned and essentially necessitated a system for them to operate (Fahlstrom, 2012).

The modern day UAS can trace its origin to WWI when in 1917 two U.S. innovators, Elmer Sperry and Peter Hewitt, constructed the radio controlled “Hewitt-Sperry Automatic Airplane” or “flying bomb.” The automatic plane was capable of flying for approximately fifty miles while carrying a 300 pound bomb. The automatic plane was launched by catapult, was unmanned and was stabilized using gyroscopic technology created by Elmer Sperry. Deeming this plane a success the U.S. Army commissioned Charles Kettering, of the Dayton-Wright Airplane Company, for a second such project (Shaw, 2012). In 1918, Kettering developed a rail launched drone called the Kettering Aerial Torpedo Bug. It was developed for the U.S. Army Signal Corps for use in trench warfare. The “Kettering Bug”, or just plain “Bug” as it was also known, was a biplane that would fly for a predetermined amount of time. It was guided to a target via preset controls and upon reaching its target a control device would release the

detachable wings. Once this happened the aircraft would plunge to the earth where 180 pounds of explosives crammed inside it would detonate on impact (Fahlstrom, 2012).

During WWII, the U.S. military created a special air unit, codenamed Project Anvil. Their mission was to use explosive-laden bombers via radio control to destroy hardened Nazi targets inside occupied France. Essentially, one pilot per bomber would takeoff and fly a PB4Y-1 Liberator manually. The Liberator would have regular pilot controls on one side of the cockpit and a mechanism to replicate a pilots inputs on the other side. This device could be radio controlled and once the bomber was in the air the pilot would establish this radio connection with a mothership aircraft flying nearby. Aboard this mothership would be a remote operator who could control the PB4Y-1 via radio. Once full control was established by the mothership the pilot of the Liberator would crawl out the nose gear of the aircraft and parachute to safety (Drone Origins: World War II and Vietnam-era Remotely Piloted Vehicles, 2013). Ultimately, this project was a failure. The life of Joseph Kennedy Jr, older brother to our then future president, was lost, along with his co-pilot when they were unable to parachute to safety before their aircraft exploded. Nevertheless, the U.S. military decided not to give up on this idea of unmanned aircraft. German advancement in V1 and V2 missiles necessitated an accelerated effort by the U.S. towards these projects and a new branch of the U.S. Air Force was soon established (Drone Origins: World War II and Vietnam-era Remotely Piloted Vehicles, 2013).

In 1946 a special “Pilotless Aircraft Branch” of the U.S. Air Force was created. The purpose was to develop three types of drones for use as training targets. Of the three drones that were built, one, the airborne-launched Q 2, was the most successful and became the template for a new class of drones which were eventually built by Ryan Aeronautical Company (Drone Origins: World War II and Vietnam-era Remotely Piloted Vehicles, 2013).

Ryan received the first contract to build a drone for the Pilotless Aircraft Branch. They built a jet propelled drone called the Firebee. The Firebee could fly for two hours at a speed of 500 knots at an altitude of up to 60,000 feet. Throughout the 1950s and 1960s the Firebee became the gold standard for use in testing anti-aircraft and missile defense systems worldwide. In 1962 and 1963 these Firebee drones were fitted by Ryan Aeronautical Company to be used for reconnaissance over Cuba, North Vietnam, Laos and the People's Republic of China. They were so successful in their early runs that the U.S. Air Force eventually gave the majority of close-in surveillance during the Vietnam War to the Ryan Drones. By the end of the war the U.S. Air Force approximated that over 3,000 unmanned missions were flown over Southeast Asia including an estimated 85% of the photos taken to assess bomb damage. This success marked the turning point for drones from "targets" to remote "sensor" platforms (Shaw, 2012).

In the early 1970s a high technology sensor and data link system had been developed to the point that drones could be piloted from the ground rather than from an airborne mothership. During simulated dogfights over the Pacific Test Range in 1971 a Ryan Firebee was pitted against an F-4 Phantom fighter aircraft and scored several simulated hits on the F-4. The modified Ryan Firebee had been outfitted with a remote flight control system, essentially making it a genuine UAS rather than a drone or missile. It was controlled by a pilot on the ground. The next year a supersonic Firebee II scored a simulated direct hit on a U.S. Navy destroyer after penetrating its missile defense systems. These successes had a huge impact on the development of UAS and served as a catalyst for further research and funding for these systems (Drone Origins: World War II and Vietnam-era Remotely Piloted Vehicles, 2013).

During the Vietnam era another drone was developed and tested as an electronic listening device. This project used a QU-22 B Beech aircraft to receive and relay signals broadcast from

various sensors that had been dispersed along the Ho Chi Minh Trail. The signal relay tested well, but the project was cancelled due to other equipment reliability issues. Signal development was crucial in the development of UAS. Without an advanced data link system a UAS is unable to effect the maneuverability and information sharing which is fundamentally what separates it from a missile (Drone Origins: World War II and Vietnam-era Remotely Piloted Vehicles, 2013).

A significant program in UAS development was the U.S. Army's Remotely Piloted Aerial Observation/Designation System, also known as Aquila. Conceptualized by Defense Advanced Research Projects Agency (DARPA), this project was eventually awarded to Lockheed Martin. At the time, laser guided smart bombs were successfully being developed and the idea for a small, remotely piloted vehicle for target designation was being considered for use in guiding these smart bombs (Aquila - this early eagle hardly soared, 2011). The system requirements given to Lockheed Martin for the Aquila were real time target acquisition and combat information beyond the limited line-of-sight of ground forces, laser designation for precision guided munitions, target damage assessment, and twenty-four hour capable reconnaissance. Certainly an ambitious project, the Aquila is an example of a system that had all the basic components of a modern day UAS. It also serves as an example of engineering failure, cost overrun, mismanagement, poor reliability and unrealistic expectations (Fahlstrom, 2012).

The Aquila program was essentially conceived in 1971 when the modified Ryan Firebee won a dogfight against the F-4 Phantom fighter jet. Technology used in this dogfight was a breakthrough in detection, communication and data-link capability. The military decided to capitalize on this momentum with an even more ambitious project and in 1978 the Aquila project moved towards formal development. Initially, the production schedule was planned for forty-

three months. Due to technical difficulties with the data link for the Modular Integrated Communication and Navigation System (MICNS) the program was extended for an additional fifty-two months (Fahlstrom, 2012).

The Aquila was designed as a tailless flying wing that was propeller driven with a twenty-six horsepower engine mounted in the rear. The airframe was fabricated using a Kevlar-epoxy material that was metalized for the purpose of minimizing radar return. The gross takeoff weight was approximately 265 pounds, with a ceiling of 12,000 ft. at a top speed of 120mph. The Aquila MPCS contained various display consoles for video and telemetry instrumentation, a computer and signal processing group, communications equipment, ground data terminal control equipment and survivability equipment. The remote ground transmitter (RGT), which is the instrument used to receive and upload datalink information to the air vehicle, had to maintain line-of-sight contact with the air vehicle. This limitation eventually proved to be one of the major reasons the system was abandoned (Fahlstrom, 2012).

The Aquila's launch and recovery system was problematic as well. The launch procedure was linked to the RGT which controlled the entire launch sequence. It utilized a pneumatic/hydraulic catapult system to launch the air vehicle into the air with sufficient airspeed. Recovery was accomplished using a net barrier which was mounted to a five-ton truck. The recovery net consisted of a pair of hydraulic-driven, foldout arms which also contained a guidance control system within them. This system would guide the air vehicle into the net (Fahlstrom, 2012).

The payload of the Aquila consisted of a camera with a bore-sighted laser for target designation. This subsystem actually worked quite well. Reportedly, once the laser locked onto a target, whether it was stationary or in motion, it would seldom lose the target. The camera was

adequate during the day but the initial design requirement called for 24-hour capable surveillance. For operations at night an infrared payload was being developed but was not completed before this project was cancelled (Fahlstrom, 2012).

For undisclosed reasons the U.S. Army shut down the whole project a few years after initial development began. This shutdown was short-lived as the U.S. Congress restarted the program in 1982. However, development momentum was lost and this required an additional extension. In 1985, a quality assurance team was formed to review the system's status. The team's conclusion was that the system's engineering had not fully integrated the data link, control system and payload and that other deficiencies still remained. Two more years were given to fix these problems with another extension after which many of these problems were fixed. Nevertheless, by the time this system actually worked newer capabilities were required and the Aquila was never put into production (Fahlstrom, 2012). One of the leading causes for the demise of this project was that there was no consistent leadership managing the project. Also, over its long period of development this project acquired too many additional mission requirements attached to its original request for design. Ultimately, approximately one billion dollars was spent on this project during its lifetime (Aquila - this early eagle hardly soared, 2011). The most important lessons this failed project taught future UAS developers was that the overall design of one of these systems must consider all the subsystems involved and it must ensure that they interact with each other efficiently (Fahlstrom, 2012).

The failed Aquila project, along with another misfire UAS project called Condor, had convinced the U.S. Congress that money spent on UAS development was money not well spent. As a result, in 1988 the U.S. Congress froze funding for such programs. Here entered Abraham Karem, an Israeli immigrant to the U.S., who saved the future of UAS with his innovating and

cost efficient designs. He is the inventor of what is probably the most commonly known UAS in the world, The Predator (Whittle, 2013).

Abraham Karem is an engineering graduate of the renowned Technion Institute of Technology in Israel. He spent his time in college and the nine years afterwards, while serving in the Israeli Air Force, learning how to design and maintain aircraft. After leaving the military Karem began working for IAI, Israel Aircraft Industries, where he moved up the corporate ladder rapidly. While working for IAI in late 1973, he was tasked with working on an urgent Israeli Air Force request for a drone decoy that could fool radar. Ultimately, nothing came of the project, as the Israeli Air Force eventually decided to buy drones from a U.S. manufacturer. It did, however, plant a seed in Karem's mind. While working on this project Karem had an epiphany concerning the unconquered territory that was unmanned aircraft. Inspiration hit Karem and he shortly thereafter left IAI to start his own company designing and building UAS. He spent the next three years creating and building one UAS system after another and then trying to sell them to the Israeli military. Karem was never able to make a sale in three years and after growing frustrated with the lack of opportunities in Israel he decided to move to the U.S. (Whittle, 2013).

By 1981, Karem had produced a UAS demonstrator that was extraordinarily light and that could carry a payload with a television camera in it. It was called the Albatross. A casual association with a fellow technology entrepreneur, named Ira Kuhn, helped Karem when Kuhn mentioned to then DARPA director, Bob Fossum, that Karem was developing an impressive new UAS system. This led to DARPA's interest and eventual funding for test flights of the Albatross (Whittle, 2013). During testing at Dugway Proving Ground in Utah, Karem's Albatross flew for fifty-six hours straight via remote pilot. Confident given this early display, the Pentagon provided seed money to Karem for further development of the Albatross (Shaw, 2012).

The new contract was for a larger version of the Albatross with greater endurance. DARPA named this project Amber. Amber was designed with a two-blade, rear mounted wooden prop. It had a retractable tricycle landing gear and a downward pointed, v-shaped vertical stabilizer. The downward pointing tail stab was aerodynamic in nature but also practical in that if the aircraft had a rough landing the stabilizers would hit the ground thus reducing the chance of damage to the propeller. The Amber was unique in design in that its recovery method was accomplished by putting the aircraft into a deep stall. This allowed the aircraft's descent profile to mirror a near vertical landing making it attractive for use on military ships with only a small landing pad. Karem was making significant progress on the Amber project when, in 1988, the U.S. Congress became impatient with the continued cost of funding for UAS projects. It was around this time when the Aquila and Condor were both deemed failures which together approximated nearly 1.3 billion dollars in wasted U.S. taxpayer money. As a direct result of these failures the U.S. Congress banned DARPA from supporting UAS development in 1990 (Whittle, 2013). This removed UAS development from the jurisdiction of the Pentagon's JPO (Joint Program Office). Funding for many projects, aside from Amber, stopped. This resulted in the subsequent failure of several start-up companies that were developing UAS and stalled the emerging technologies development nearly altogether (Shaw, 2012). At this time Karem's company, Leading Systems Inc., had a five million dollar bank loan due (Whittle, 2013). Unable to make payment on the loan after losing his contract, Karem sold his company to General Atomics out of bankruptcy and decided to continue development of the Amber project. This essentially made them the only company in the U.S. that continued to actively develop UAS (Shaw, 2012). Design work continued at General Atomics but the UA was renamed the GNAT-

750. This number, 750, refers to the chord of the wing. It is a measurement, in millimeters, of the airfoil from its leading edge to trailing edge (Whittle, 2013).

In 1993, during the Clinton administration, the need was recognized for a way to monitor the Balkans conflict. The CIA Director at that time, James Woolsey, remembered Karem from previous UAS demonstrations and after evaluating the GNAT-750 bought two for his agency (Whittle, 2013). The GNAT-750 was then used successfully for spotting Serbian convoys and artillery, thus proving its tactical use and reinvigorating the U.S. military's interest in UAS (Shaw, 2012).

As the need for surveillance grew in the skies over Bosnia and other parts of the world, so did demand for UAS, but the industry was slow to rebound from the early 1990s when the U.S. Congress ceased funding development. In fact, little to no development, other than by General Atomics, was being conducted in the field of unmanned flight at this time. Also, while the GNAT-750 was far superior to the Vietnam era Ryan drones, it was vulnerable to weather and its data communications range was limited to only 150 nautical miles. This communications range was considered a major limitation since it meant all the support equipment and personnel also had to be within 150 miles of where the UAS was going (Shaw, 2012).

Limitations aside, the Central Intelligence Agency realized the potential of such technology and sought out more advanced UAS. The CIA assumed they would be able to circumvent the Congressional block on development of UAS because they operated outside of military jurisdiction. In 1993, CIA Director James Woolsey contacted Karem at General Atomics and requested a new and improved UAS, one that could provide a persistent aerial presence and real time surveillance. General Atomics responded with the "Predator" (Shaw, 2012).

The Predator was a massive upgrade to the GNAT-750. By using satellite communications for the Predator, operators did not have to be in the same region, continent or even hemisphere, as the drone. The Predator's range, payload and flight capabilities were far superior as well. Additionally, they could fire missiles, paint targets for other aircraft with a laser, and use various types of sensors per mission needs. In use since 1995, the Predator has seen combat in Bosnia, Pakistan, Serbia, Yemen, Libya, Syria, Iraq and Afghanistan. They have become an essential tool of the military and intelligence agencies and their development has spawned the birth of a commercial industry that we are now in the dawn of realizing. However, the UAS of present day are much different than their predecessors. So let us examine the modern day UAS (Shaw, 2012).

First, UAS classification must be discussed. UAS capabilities vary largely depending upon the size, performance and intended function of the UA. The variability of UA designs leads to varying ranges in size, speed, wingspan and operating ceilings as well. The FAA has yet to release an official UAS classification table, but the U.S. Department of Defense has been using an unofficial classification table for its own purposes for a number of years. These classifications have become a de facto point of reference for research and periodicals pertaining to UAS. This classification table is divided into five groups.

Group one categorizes the smallest of UAS. These are typically hand-launched, self-contained portable systems the likes of which can commonly be found in a toy store, mall kiosk or hobby store across the U.S. Group one would have a typical weight of less than twenty pounds with a normal operating altitude below 1,200 actual ground level (AGL). Group two categorizes small to medium sized UAS which are typically launched via catapult. This group would include UA between 21 to 55 pounds with a normal operating altitude below 3,500 AGL.

Group three encompasses UA weighing less than 1,320 pounds which operate at or below an altitude of 18,000 feet with medium to long range and endurance. Group four are relative large UA. This group would encompass UA weighing more than 1,320 pounds which operate above 18,000 feet and have extended range and endurance. The UA in group four also typically require dedicated, improved areas for launch and recovery. Group five comprises the largest of systems. These UA share the same weight and altitude characteristics as group four but have greater range, endurance and airspeed capabilities (U.S. Department of Defense, 2011).

The term system is now commonly used when describing a UAS. This is because they are not just an unmanned aircraft, or UA, but rather a distributed and integrated system of several parts (Angelov, 2012). The equipment and infrastructure that comprise a UAS includes an unmanned aircraft, a ground control station (GCS) or a mission planning and control station (MPCS), a payload and the data link. There are also various subsystems used in support such as the launch and retrieval systems and the ground handling and maintenance equipment which transport and power the entire system in addition to life support for the crew operating a UAS (Fahlstrom, 2012). The systems and subsystems that comprise a UAS can be categorized into three major segments. These are defined as an air segment, ground segment and communications segment (Angelov, 2012).

The air segment includes the unmanned aircraft as well as their payload. A UA is fundamentally made up of an airframe, a propulsion unit, flight controls, and a power system. A UA can either be a fixed-wing aircraft, rotary wing aircraft or a ducted fan aircraft. Mounted on the inside of the UA is the airborne portion of the communications data link which is called the air data terminal. The air data terminal includes a transmitter and antenna for transmitting video and UA status information. There is also a receiver for receiving commands from the ground

based portion of the data terminal (Fahlstrom, 2012). The payload is an independent subsystem and is easily interchangeable to suit various UA models and also to meet specific mission requirements. Examples of commonly used payloads are cameras, radar, altimeter, inertial measurement units (IMU), global positioning system (GPS), antennas, and eventually sense and avoid systems (Angelov, 2012).

The ground segment refers to the MPCS, also called a GCS. This segment is the operational control center of a UAS system. All video, command, and telemetry data from the UA are processed and displayed in these stations. Data is typically relayed through a ground terminal, which is the ground portion of the data link system. The MPCS station can include a mission planning facility, control and display consoles for the UA pilot, video and telemetry instrumentation, a computer and signaling processing group, communications equipment, environmental controls and lodging facilities for personnel. Ground support equipment (GSE) is categorized in this segment as well. GSE may include test and maintenance equipment, fuel supply and refueling equipment, handling equipment to move the UA and generators for all ground equipment. Depending on the UAS system a MPCS can be as small as a suitcase or permanently located (Fahlstrom, 2012).

The communications segment is divided into the command and control data link, the payload data link and external communications (Angelov, 2012). The data link for a UAS system is responsible for providing two-way communications. This can be effected either on a continuous basis or upon demand (Fahlstrom, 2012). An uplink to the UA provides the control commands to the UA and also sends commands to the sensors in the payload. The downlink provides acknowledgement of the commands and also provides status information regarding the UA and data such as radar or video. Position information regarding the UA can be determined

by azimuth and range from the MPCS antenna. This information is for navigation of the UA. The term link can vary in its meaning based on the distance the UAS is operating from the ground segment. A UAS can operate through visual line of sight (VLOS), line of sight (LOS) or beyond line of sight (BLOS) (Angelov, 2012).

The launch and recovery of a UAS can be accomplished by a number of techniques. The techniques can range from a conventional takeoff and landing to a rotary wing controlled vertical descent. Catapults can be used by either pyrotechnic, pneumatic, or hydraulic means. Some UAS are simply launched by hand and thrown into the air. Recovery can be accomplished through nets, arresting gear, parachutes or parafoils (Fahlstrom, 2012).

The major advantages that UAS have over conventional manned aircraft are aerial surveillance, reconnaissance and inspection missions in complex and dangerous environments. Currently, several hundred companies are developing UAS. The size and scope of these companies are as varied as the types of UAS they design. There are small firms working out of their garages, as Karem Abraham once did, and major defense firms like Boeing, BAE Systems, Lockheed Martin and L3 Communications. The future challenge for UAS will be to keep pace with the increasingly complex and nuanced mission demands that are being made of them. Full integration of UAS into the NAS is also extremely critical to this technology's future and this depends on several key attributes improving. Increased autonomy level, all weather performance, human interface, speed and maneuverability, durability and longevity and interchangeable payloads are a few of these attributes that must improve. One more attribute, the one of utmost concern to this paper, is situational awareness (Angelov, 2012).

In February 2015, the FAA proposed regulations for the operation of small UAS. This proposal would allow UAS weighing up to fifty-five pounds to be used for commercial purposes,

with some restrictions. The UAS must remain within sight of their operator without the aid of binoculars during daylight hours only. Also, the UAS must stay below 500 feet actual ground level and cannot exceed 100 mph (Phelps, 2015). While this step by the FAA marks progress in the evolution of UAS it falls short of the expectations of U.S. corporate interest such as Amazon. Amazon foresees a business model that utilizes a veritable fleet of UAS for specialized package delivery of items in thirty minutes or less (Crovitz, 2015). However, the FAA cites two main safety concerns it has which led them not to currently propose rules for UAS with beyond-line-of-sight operational capabilities. These two concerns are collision avoidance and loss of positive control by the UAS operators. For these concerns to be overcome, and for full UAS integration to occur in the U.S., a sense and avoid system must be developed (Pomerleau, 2015).

To begin, S&A must be described, along with why it is of such critical concern. “The purpose of a sense and avoid function is to act in the place of a human pilot to detect and resolve certain hazards to safe flight. These hazards consist of other traffic or objects presenting a risk of collision. Air traffic encompasses aircraft, gliders, balloons and even other unmanned aircraft systems. Other hazards include terrain and obstacles.” (Angelov, 2012, p.35). There is an inherent risk in unmanned aircraft that is greater than manned aircraft. This is due to the physical separation of the pilot from the cockpit of the UAS. The most significant barrier of UAS integration has been the restrictions put on their operation and their segregation from most classes of airspace. These restrictions are due to the risk UAS present to other aircraft in the NAS. What is needed before these barriers can be crossed is for a collision avoidance system to be put into place with an algorithm that ensures the separation of UAS from other traffic in high density traffic environments. The system must also function to prevent UAS from colliding with

ground traffic and have fail-safes for the event of an emergency or diversionary event. Without a sense and avoid system, the future of UAS is bleak (Angelov, 2012).

Manned aircraft have a pilot who can “see and avoid” other traffic. One of a pilot’s primary duties is to continuously scan for other aircraft and terrain. If in the event the pilot sees traffic they must calculate whether that traffic or terrain presents a risk. Certain conditions such as weather, poor visibility at night, confusing backgrounds and high workload can present challenges to this task, but it is the system used today by manned aircraft. In S&A development there is a guiding premise that it cannot be only as good as human capability; it must surpass these limitations (Angelov, 2012).

Currently, there are numerous variations to sense and avoid configurations. There are, however, common components among the systems being tested and developed. These components are the aircraft and system onboard, the off-board control station and the communications link between these two components. Distinctions between these configurations exist and affects how the system works. These distinctions are predicated upon whether the sense and avoid sensors are placed onboard the UA, off-board the UA, or both and where the traffic avoidance decision making is made, onboard or off-board (Angelov, 2012).

There are two primary services that sense and avoid must provide. These services were defined by the FAA and a panel of defense agency experts. The first service is self-separation. A UAS must be able to act in a manner so as to anticipate a collision avoidance maneuver before it is even needed. A UA making a rapid descent, climb or steep banking turn to avoid traffic in a last chance maneuver is not preferable, if avoidable. An earlier and gentler maneuver is preferred when applicable. Further requirements for ATC compliance must be defined in the future for self-separation. The flight performance of the numerous UAS designs currently

available are varied. As a result there are inconsistencies in performance characteristics like rate-of-turn, speed and climb/descent rates. These performance variations will require that more clearly defined response parameters for ATC instruction be incorporated into sense and avoid. This will undoubtedly be tied into future performance regulatory requirements of UAS as well. The second service required of sense and avoid is collision avoidance. The panel determined that a collision zone must be defined for this system. This zone will encompass the conditions upon which an aggressive evasive maneuver be executed to avoid a collision. The guiding example used was the Traffic Alert and Collision Avoidance System II (TCAS II) utilized currently in the U.S. by manned aircraft (Angelov, 2012).

These primary functions are achieved through the services of the following sub-functions. These are detect, track, evaluate, prioritize, declare, determine, command, and execute. A UAS must be able to detect the various types of hazards it will encounter such as traffic, weather and terrain. This step is the first indication that one of these hazards exists. The UAS must then track the motion of this identified hazard and determine its position and trajectory relative to its own position. The system must then evaluate each object tracked. First it must validate if the track it generated is sufficiently predictive enough. Then it must determine if a sense and avoid maneuver is warranted. If multiple hazards are identified the system must prioritize these hazards based upon their track parameters and evaluation step conclusions. The system then must declare when the track(s) of the hazard(s) and itself have reached a decision point for maneuvering to begin. Separate declaration points will be needed for both self-separation and collision avoidance. Then the UAS must determine the best specific maneuver for separation or avoidance. For instance, can separation maneuvers from one hazard elevate or diminish the traffic situation overall? Finally, it must execute the determined maneuver. If any aspects of the

evaluate or determine sub-functions are to be performed at an off-board control station then a reliable air-to-ground communication system is of critical importance. Due to this safety consideration various weight and balance factors need to be considered in regard to S&A system configuration placement. Also, data link latency and bandwidth will be of important consideration to sense and avoid system configuration as well (Angelov, 2012).

Sensor capabilities for use in a sense and avoid system are available in various forms. Some of these technologies can be carried onboard the UAS, some off-board. Another option is to utilize existing surveillance systems such as radar, or in the future Automatic Dependent Surveillance Broadcast (ADS-B) if it becomes available. Each of these options offer different capabilities ranging from their coverage volume, measurement types, accuracies, update rates and probabilities of false detection (Angelov, 2012).

In spite of the engineering challenges that lie ahead the future for sense and avoid and its system requirements are not technology dependent. It is dependent upon the regulatory requirements of the FAA which, as of this writing, have not been defined. Still, the technology and algorithms required for this system to operate are available. In January of 2015, the FAA, General Atomics Aeronautical Systems and Honeywell International, Inc. announced that they had successfully demonstrated a proof-of-concept sense and avoid system (Merlin, 2015).

This test was conducted between a civilian version of the Predator B, two remotely piloted aircraft and various manned aircraft over the course of five weeks. Nine separate flights were conducted during which 170 air-encounters were performed. These tests did not use an artificial horizontal and vertical offset applied to the algorithm used. Instead actual conflict conditions were created for testing. These tests marked the first time that a coordinated automatic response was employed by a UAS to resolve collision avoidance conflicts. It was also

the first time that testing involved air-to-air collision avoidance encounters between two UAS. The FAA's Airborne Collision Avoidance System for Unmanned Aircraft (ACASxu) was also evaluated during testing. The ACASxu system has its own collision avoidance algorithms and they work in conjunction with legacy software like TCAS II and ADSB. Researchers tested three different self-separation displays and algorithms during these flights. The algorithms' ability to effectively inform the pilot of nearby traffic and to resolve conflicts in a timely manner was deemed successful. The data provided by these tests will significantly contribute to the ongoing effort of the FAA to develop a technical standard for sense and avoid systems (Merlin, 2015).

The commercial applications of UAS are unlimited, once full integration is attained. In the U.S. alone, total sales of civilian UAS are expected to reach \$15 billion dollars by the year 2020. According to IGI Consulting this growth is expected to be driven by both commercial and consumer markets. Hui Pan, chief economist of IGI consulting, predicts that the major commercial applications of UAS will be in agriculture, real estate, motion pictures, the oil and pipeline field, electric utilities and specialized package delivery (Seitz, 2014). Flavius Killebrew, president of Texas A&M University in Corpus Christi, TX, envisions a world where UAS deliver anything from DVDs to double-cheese stuffed crust pizzas (Roberts, 2014). Public Safety Agencies (PSA) are already using UAS for everything from geological surveys to search and rescue. Some private businesses have received special waivers to operate UAS ahead of FAA regulation. In June of 2014 an Aero Vironments Puma AE drone became the first UAS to provide commercial services over U.S. land. They received permission from the FAA to survey BP's land operations in Prudhoe Bay, Alaska (Seitz, 2014). In April of 2015 the FAA approved USAA, the San Antonio based financial firm, to conduct tests with UAS in an effort to improve

processing insurance claims (Thompson, 2014). President Killebrew, when asked about the future of UAS, was quoted as saying “I believe they’re going to be a big part of our future. Maybe not in the way you see on some of the ads, but in ways that we haven’t even conceived of yet.” (Roberts, 2014).

UAS have been in development in one form or another since the beginning of the twentieth century. They have been operationally used in many capacities which has allowed many of the technical challenges inherent to new technology to be corrected and further developed. U.S. Air Traffic Control has had nearly 100 years of practice, innovation, and continued improvement. Since Archie League first started waving his checkered flags in the 1920s, to the first radar control system, to the present day NexGen modernization efforts the U.S. ATC system has gone through numerous growing pains. Today, it is the busiest and safest ATC system in the world. The greatest aviation challenge of the early 21st century will be the blending of these two industries, UAS and ATC, and the myriad challenges that stand in the way. The research presented in this paper is focused on finding the current state of development for S&A. Additionally, this paper seeks to find the developmental challenges of S&A and what the future requirements for this system are likely to be.

While UAS and ATC have existed and operated for many years the FAA was only given three years to create a plan to integrate UAS into the NAS. The FAA is tasked with accomplishing this feat while also keeping the NAS operating and the flying public safe. The Modernization and Reform Act of 2012 outlines how this is to be accomplished. However, for these plans to take effect the regulatory requirements for sense and avoid must be defined. Once defined, the technology to implement these new safety standards will follow shortly. What is

critical to full UAS integration is that the FAA make a decision on what it wants sense and avoid to do. No further major progress can occur until this decision is made.

The purpose of this study is to discover what the current state of Sense and Avoid development is. There are many factors in play before full UAS integration into the NAS can become a reality. Regulation, policy, technological standards, and a myriad of other challenges lay ahead. The questions this study seeks to answer are included below.

Research Questions

1. What is the current state of Sense and Avoid development?
2. What will be the future requirements for Sense and Avoid by the FAA?
3. What are the challenges for Sense and Avoid development and integration?

CHAPTER II: METHODOLOGY

Qualitative research involves a deep probe into the research material in order to obtain a deep understanding about the way things are, why they are that way, and how the participants in the context perceive them. The types of data that are commonly collected include records of formal and informal conversations, observations, documents, audio and videotapes, and interviews. Achieving the detailed understanding of the research material requires the researcher to undertake sustained, in-depth, in-context research. This is so the researcher can glean the more subtle and personal understandings of the participant. Also, data analysis is an ongoing process in qualitative research. As information is collected and recorded the researcher refines his prior analyses and understandings. As a result, data analysis is conducted throughout the entire research study in contrast to quantitative research which is done at the end (Airasian, Gay & Mills, 2006).

Several aspects of qualitative research led to the determination that this study be conducted from a qualitative approach. Interviews were determined to be the best data collection tool to do this research. Also, recordings of the interviews were determined to be necessary, which is explained why later in this chapter. As the data collection process began it was discovered that perceptions of the research material became more refined and led to more focused follow up questions during participant interviews.

An interview is a purposeful interaction between two, or more, people focused on one person trying to gain information from another person. This type of data collection technique allows researchers to obtain important data that is not attainable from observation. For example, the observation technique cannot provide information concerning past events. The how's and why's of the past cannot be observed, they can only be realized by the words of the research

participant. UAS are a constantly evolving technology rooted in past advances while simultaneously being vetted by multiple safety and regulatory agencies for integration into the U.S. National Airspace System. Due to the nature of this research subject there are many questions from the past that must be asked to gain a clear idea of what the future may hold. Another benefit of interviews is that they can gather more in-depth data from participants about their experiences and feelings concerning the research matter (Airasian, Gay & Mills, 2006).

Interviews can be conducted in a variety of ways. The method that was determined best suited for this research was the semi-structured interview. A semi-structured interview combines the techniques of both structured and unstructured interviews. This research utilized the structured interview technique via a list of eleven interview questions that were asked to each participant in this study. As the interview flowed, participant answers to the interview questions resulted in additional and spontaneous questions being asked of them. The subsequent conversations and additional new questions that were prompted during these interviews are an example of the unstructured interview technique being utilized (Airasian, Gay & Mills, 2006). Interviews were conducted only one time per participant and the participants were interviewed individually. Additionally, the interviews were formal and planned with each interview scheduled at least two weeks in advance. All interviews were conducted at the participants' places of work, so as to minimize any inconvenience to the participant. This study design was approved by the MTSU Institutional Review Board. Appendix A contains all pertinent documentation regarding IRB approval.

Participants

The participants in this study included employees of both the Federal Aviation Administration and MITRE Corporation. In order to be considered for this study the participants

had to work in either a dedicated UAS office or for a program that directly supports UAS integration. These qualifications allowed the researcher to identify departments within the FAA and MITRE Corporation with which to initiate contact with. An appointment was made to tour the FAA UAS integration office at FAA Headquarters at L'Enfant Plaza in Washington D.C. A FAA UAS integration manager who works there was consulted regarding the purpose of this study. He made several recommendations of persons who would fit the required participant profile. Two of the recommended participants work for the FAA. The other two participants work for MITRE Corporation, Inc.

The FAA is the governing aviation authority of the United States. It is an agency that falls under the United States Department of Transportation which has authority to regulate and oversee all aspects of American civil aviation. The agency was created through the Federal Aviation Act of 1958. Its current name was adopted in 1966 when it was enveloped into the Department of Transportation. The FAA website states the following:

Our continuing missions is to provide the safest, most efficient aerospace system in the world.

According to the MITRE Corporation website it is a not-for-profit company that's purpose is to operate and coordinate multiple federal funded research and development centers (FFRDCs). To put it another way, MITRE Corporation is essentially a U.S. chartered entity that facilitates research and development in the U.S. public's interest. United States agencies that MITRE supports in this manner include the U.S. Department of Defense, the FAA, the Internal Revenue Service, the Department of Veteran Affairs, the Department of Homeland Security, the Administrative Office of the U.S. Courts, the Centers for Medicare and Medicaid Services, and the National Institute of Standards and Technology. Since 1999, the MITRE Corporation has

functioned as the primary Certification and Accreditation (CAN) organization as well as the primary editing functionary for Common Vulnerabilities and Exposures (CVE). As a CAN for several organizations MITRE Corp. institutes systematic procedures for evaluating, describing, testing and authorizing systems prior to a system being put into operation. As a CVE provider MITRE Corp. maintains a reference method for publicly known information security vulnerabilities and exposures and quantifies these risks for the U.S.

Instruments Used

The instruments used in this research were relatively few and simple. Data was collected via use of a computer with internet connectivity, an audio recording device, a cell phone, an IRB consent form, a legal writing pad, and an interview question list. Initial data collection began via the participant selection process. This was, as previously stated, facilitated through a tour of the UAS Integration Office at FAA headquarters in Washington D.C. After participant selection was completed individual emails were sent to selected participants soliciting their help for this research. In these emails the purpose of this research study was explained.

Four participants were sent emails, however, only three responded, all of whom agreed to participate. Appointments were made to meet each participant. Before the interviews were conducted, each of the participants was provided with an IRB consent form to read. Prior to beginning the interviews each participant was afforded an opportunity to ask questions regarding the interview or to make known any concerns. Additionally, verbal consent was obtained from each of the participants to record the interviews with an audio recording device. The audio recordings of the interviews were then stored on a personal computer for cross reference with notes from the interviews.

The interview questions were designed to gain a general sense of where the current state of Sense and Avoid development presently is. The interview questions were developed after doing a comprehensive literature review. At that point a clear idea had formed of what needed to be asked of participants to answer the primary questions posed by this research. Several interview questions were then developed and through consultation with a thesis committee the list was narrowed to eleven. The list of these questions can be found in Appendix B. There are eleven interview questions that were asked to each of the participants. The questions were grouped into three categories. Questions one through five were developed in order to gain a comprehensive professional pedigree of each participant. Questions six and seven were designed to answer the first two primary research questions. Questions eight through eleven were designed to answer the third primary question of this research and to gain supplementary data. The answers to these questions and the subsequent discussions that resulted from these research questions varied greatly per the differing expertise of the selected participants.

The interviews were conducted in person at each of the participant's professional office. During the interviews notes were taken with a legal pad and, as previously stated, the use of an audio recording device was employed. After the interviews notes taken from the interviews were reviewed and the audio recordings were downloaded onto a personal computer. The advantage of using an audio recording device for the interviews was that attention could be focused solely on performing the interviews. No interruptions of the participants to repeat something were needed. Furthermore, answers gleaned from these interviews are not paraphrased, partial captions of data on a piece of paper. This is because the audio recording device allowed a thorough review of each the participant's answers, in their entirety, as they were originally spoken.

Data Analysis

Qualitative data analysis requires that the researcher systematically comb through the data collected in order to categorize, integrate and interpret the data for final analysis. In the case of this study there was superfluous data that had to be filtered. As the researcher reviewed his notes and the audio recordings of the interviews he had to interpret what the participants responses meant. Some new terms, acronyms, studies and lines of thought were discovered in this process. The researcher noted that a detailed review of the different classification levels of UAS was necessary before further analysis could be accomplished. The FAA has not formalized a classification list for UAS but the DOD has, and this is the working list most UAS research. Also, a more thorough review of the Automatic Dependent Surveillance Broadcast (ADSB) and the Airborne Collision Avoidance System for unmanned aircraft (ACAS Xu) was required to understand the answers two participants gave.

Through use of a personal computer the audio recordings of the interviews were replayed. The recorded answers from these interviews were then transcribed. The software used to accomplish transcription is called Sound Organizer and is the proprietary software offered by Sony Corporation with purchase of their IC Recorder audio device.

The audio recordings allowed the interviews to be replayed as necessary. As a result of this research tool, each participant's interview were slowly and methodically reviewed and cross referenced with the hand written notes taken during the interviews. After filtering, interpreting and recording this data a written analysis was performed by lining up the participants answers to each question. This allowed a trend analysis to be performed on each of the interview questions. A personal computer and Microsoft Word were used for this process.

Trends observed were written down and then were analyzed on a deeper basis. A trend was determined if at least two of the three participants provided a similar response to the same research question. Some question responses were outliers that did not fit the determined trends, however, they still provided significant data and thus were included in the final analysis.

CHAPTER III: DATA ANALYSIS

This research study collected data through interviews with three participants. Originally, four participants were selected to participate, but only three responded to the email solicitation. These participants were selected for their expertise in UAS integration and more specifically for their experience and knowledge with the UAS sensor system Sense and Avoid. Each participant was asked eleven interview questions. A copy of the interview questions can be found in Appendix B.

Analysis

The analysis of such a large amount of qualitative data required that the process be streamlined. This was accomplished by grouping the interview questions and answers into three different categories. The categories are: professional credentials, primary research questions, and secondary research questions.

The interviews were designed to be semi-structured, and, as a result, there are miscellaneous answers from each of the interviews interwoven with the specific research question answers. It was the intent to leave the interviews open-ended as the nature of the research material is highly complex and quickly evolving. Data collected from these miscellaneous answers is specifically drawn upon in the recommendations section of the fourth chapter.

The questions and answers about each of the participants' professional credentials are important. The professional experience and specific UAS involvement of the participants lend significant weight to the research data collected, as well as the conclusions drawn from this data. The primary research questions and the secondary research questions were the most important

part of the analysis. This data was used to find commonalities and trends in order to make the most accurate assessment of the current state of S&A development.

Professional Credentials

The first question asked to each of the participants was to describe their job title. Participant one is an Unmanned & Autonomous Systems Research Strategist and Senior Principal Systems Engineer for MITRE Corp. Participant two is a Terminal Collision Avoidance System (TCAS) Program Manager for the FAA in the Program Management Organization. Participant three is a UAS Research & Development Section Manager for the FAA.

The second research question asked that the participant describe their job function. Participant one described his job as being a thought leader in the area of manned and unmanned systems. As a systems engineer, participant one described his expertise in looking at the big picture and figuring out how all the pieces fit and worked together. Participant one also stated that he is involved in defining the research used to integrate UAS. Specific areas that participant one has directed research in the past has included integration issues, data management, risk analysis, traffic management analysis, air traffic control and aviation procedures.

Participant two described his primary job function as the monitoring and sustainment of TCAS functionality within the NAS. This includes continuously looking for interoperability issues between different TCAS systems and at specific equipment issues. Additionally, participant two investigates new means of collision avoidance for introduction into the NAS. These means could potentially include new algorithms, equipment, and procedures.

Participant three described his primary job function as coordinating research concerning UAS between the FAA and their partnering organizations. This participant also stated that part of his responsibilities include reviewing UAS research among the FAA community. These

efforts are twofold in purpose. One is to prevent duplicate research and the other is to foster the continued collaborative research efforts between the FAA and their partners.

The third interview question asked the participants how long they have worked in the aviation field. All the participants had at least twenty years of experience. Table 1 indicates the number of years of experience each participant has with a mean average.

Table 1

Comparisons of interview participants' aviation working experience

Interview Question 3		
Aviation Working Experience in Years		
Participant 1	Participant 2	Participant 3
24 yrs.	22 yrs.	35 yrs.

Mean Average	27 yrs.
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In addition to acquiring the data specific to this interview question, other information from each participant was attained consistently during this portion of the interview. As each participant's field of expertise are different the calculating of each participants work experience to answer this interview question required adding sums from various parts of their professional work history. Two of the participant's had prior military experience. One is a former pilot. One is a trained engineer. All three participants have at least a Bachelor's degree. One has a Master's degree. One commonality, and that of utmost importance to this research, all three participants have experience working either directly with, or, in direct support of UAS integration.

Interview question four specifically asked each of the participants how long they have worked with UAS. Participant one has over fourteen years of experience working specifically with UAS. Participant two has six years of experience. Lastly, participant three has five years of working with UAS on a full-time basis.

Again, when the participants answered question four there was a discussion of what parts of their work experience should be added together to attain a numeric figure in years. Participant one had the easiest time answering this question. This participant has direct, full-time experience in many facets of UAS development and integration totaling fourteen years. In summary, participant one has participated in Radio Technical Commission for Aeronautics (RTCA) committees, science and research panels, and in directing research all specifically involved with UAS. RTCA, to briefly explain, is a private, not-for-profit association. It is a public-private partnership venue involved in the development of critical aviation modernization issues across competing interests.

Participant two has six years of direct experience with UAS dating back to the year 2009. TCAS and collision avoidance programs were consulted for S&A development purposes and this is how participant two gained UAS experience. Participant two was introduced to UAS development issues prior to 2009, but determined that six years was an accurate value quantifying his direct involvement.

Participant three had the hardest time answering this question. This participant's work experience includes military, contract and governmental roles. Participant three decided upon five years as the best answer to this question. This value accounts for his present five years as an FAA employee, however, this participant had additional time during his military service working on special flights standards projects for UAS. This additional time was not included in

participant three's answer to interview question four as his experience in this capacity was intermittent and brief.

Interview question five was the last question asked in this category. This question asked the participants what their working knowledge of Sense and Avoid is. Again, this question involved some difficulty in answering as S&A development has crossed a wide spectrum of programs and research in its development.

Participant one has a working knowledge of S&A requirements, sensor solutions, algorithms, standards, proposed operating policy and initial proposals for regulation. Participant two's working knowledge of S&A is specific to the developing self-separation requirements and collision avoidance interoperability requirements for the system. Participant three's knowledge stems from standards development in RTCA committees on TCAS and ADSB sensors, through focused research and through national forums on proposed S&A standards held by International Civil Aviation Authority (ICAO) and with Joint Authorities for Rulemaking on Unmanned Systems (JARUS). ICAO is a specialized agency within the United Nations that works with member states in order to develop international standards and recommended practices for aviation. JARUS is a group of experts from the National Aviation Authorities (NAAs) and assorted regional aviation safety organizations that make certification standards recommendations on UAS.

Primary Research Questions

Interview question six asked the participants to describe the current state of S&A regulatory requirements. Participant one explained that currently there is no regulation that would allow a user to operate a Sense and Avoid system with one exception, the U.S. Military. The U.S. Military has received waivers for S&A operations, but the rest of the aviation

community is waiting for the rules to be written. In June of 2011 the U.S. Department of Transportation chartered an Aviation Rulemaking Committee (ARC) specifically for UAS called Unmanned Aircraft Systems Aviation Rulemaking Committee (UASARC). This committee invited subject matter experts from industry and government for the purpose of advising the FAA on rules and regulations necessary for the safe integration of UAS into the NAS. Since UASARC was formed it has made recommendations on modifying 14 Code of Federal Aviation Regulations (CFR) Part 91. Specifically sections 111 and 113 of 14 CFR Part 91 which, respectively, deal with rules for operating near other aircraft and right of way rules. Participant one specified that UASARC has made suggestions to the FAA on how to amend 14 CFR to account for an electronic means of See and Avoid. Essentially, the newly modified regulations would make an exception for UAS by allowing them to use Sense and Avoid as an acceptable substitute for See and Avoid. Participant one specified that these modifications to 14 CFR are a crucial first step for S&A regulation. Once these rules are adapted it will create a technical standard to use in certifying S&A systems for use.

Participant two discussed how TCAS could affect S&A regulatory requirements. Within the RTCA committees and ARC committees working on S&A there is a prevailing thought that it might not be necessary for UAS to be equipped with collision avoidance systems in Class A airspace. This is due to the requirement that UAS operating in Class A airspace would be required to be equipped with a transponder. As transponders offer mode C altitude information, other aircraft in Class A could see these UAS with their TCAS systems for collision avoidance. In this instance UAS would still use the self-separation aspects of S&A but the collision avoidance aspect would potentially be relegated optional. Participant two also stated that TCAS interoperability between larger manned aircraft and smaller category UAS would not work.

Participant two further expanded on his answer to interview question six by discussing stakeholder opinions on collision avoidance requirements for UAS. ALPA has expressed a desire for all UAS operating in Class A airspace to be equipped with collision avoidance systems. Also EUROCONTROL, European Aviation Safety Agency (EASA), European Organization for Civil Aviation Equipment (EUROCAE) and various other European stakeholders have expressed a strong interest in making collision avoidance systems mandatory on UAS.

Participant three answered interview question six with a discussion about RTCA standards currently being written. He said that standards are being designed so that subtle maneuvers would be required of UAS so as not to induce a resolution advisory from manned aircraft. A resolution advisory is the suggested avoidance maneuver TCAS makes to pilots when a conflict is detected. He also discussed the RTCA committees' dilemma in defining response maneuvers that do not cause a third party conflict. Third party being an aircraft or UAS that was not initially part of the conflict scenario. It was also suggested that these maneuvers could have different responses per traffic density and per air traffic control limitations. Participant three also stated that while well clear has been defined a definition for self-separation for UAS has not.

Interview question seven asked the participants to describe the potential challenges for Sense and Avoid development and integration. Participant one defined four challenges for S&A development and integration. He explained these to be sensor technology, algorithms, standards and policy.

Sensor technology is a complex problem. The question that must be answered before major progress can be made is what is appropriate technology? Must sensors be designed to sense cooperative traffic or non-cooperative traffic or both? Cooperative traffic is known traffic.

In other words, traffic that has a transponder that is reporting altitude. Non-cooperative traffic is traffic that does not have a transponder and thus no electronic altitude reporting is provided. In Class A airspace all aircraft must be transponder equipped which presents a more manageable solution to this problem, but there are several other classes of airspace where transponders are not required. For smaller category UAS the added cost and weight of a transponder would be prohibitive. ADSB is a possible all-encompassing solution. If all UAS and manned aircraft were mandated to be equipped with ADSB then sensors could be designed to use this surveillance technology as a means of employing Sense and Avoid. However, non-cooperative traffic for smaller UAS operating near the ground could potentially include buildings, cars, power lines, humans, animals, etc. These types of non-cooperative traffic would present surveillance problems of an entirely different dimension. Also, the future of ADSB is unclear and there are no short to mid-term plans for this system to be turned on.

Participant one also discussed the problems surrounding algorithms used for S&A. Several algorithms have been written and employed in test scenarios successfully, but there are complicating factors delaying the decision of which one(s) to use. For example, in order to ensure well clear standards of separation what would be the right maneuver choice needed from an algorithm? TCAS gives vertical guidance, where potential S&A solutions could provide both vertical and lateral separation maneuvers. How would these different systems interact? Also, who is making the decision regarding separation maneuvers? Is it a human pilot disseminating conflict information from the ground control station or would an algorithm calculate these maneuvers? If it is the algorithm, then how is it certified?

Standards have yet to be determined. Currently RTCA Special Committee 228 (SC-228) are developing standards for S&A technology. The committee has defined Well Clear as 35

second Tau with a Horizontal Miss Distance (HMD) of 4,000 feet and a Vertical Miss Distance (VMD) of 700 feet. However, these standards are being developed for larger classes of UAS. Smaller UAS would require a different standard of separation according to participant one. Separating two fifty pound UAS by 700 feet laterally and by 4,000 feet vertically is excessive and would grossly underutilize available airspace.

The last contention participant one made answering interview question seven focused on policy. He presented several different challenges facing policy moving forward. How is the FAA to certify Sense and Avoid? Who would write the operational requirements for UAS? The FAA regulates airspace through rulemaking and air traffic control. Would this translate to oversight of a pizza delivery company using a small UAS for deliveries in Class G uncontrolled airspace where air traffic services are not provided? Will there be different criteria for the different categories of UAS?

Participant two discussed three major challenges for S&A development while answering interview questions seven. These challenges are the technical aspect, communications, and operations. The technical challenge is deciding upon what type of surveillance technology to use. For S&A to function properly it must be decided what surveillance equipment will be used and whether this will vary upon category of UAS and airspace. Participant two then discussed communications as a major hurdle for S&A development but said this area was out of his expertise. Participant three then discussed operational problems that could arise between Sense and Avoid and ATC. How does a UAS pilot, if sense and avoid is not autonomous, notify ATC? If there are multiple calls per UA throughout a flight this could become burdensome on the air traffic controller. The flip side to that is what if the UAS pilot does not call and an S&A maneuver becomes a conflict with an air traffic control maneuver? Also, participant three stated

that the U.S. air traffic system is not equipped or staffed sufficiently to oversee small UAS operations.

Answering question seven participant three illustrated multiple challenges to S&A development and integration. He began his answer by stating that the integration of UAS into air traffic controlled airspace has many challenges ahead. UAS, either through a human pilot or automation, which execute small deviations from their filed flight plan could cause considerable discomfort to air traffic controllers. Additionally, while well clear has been defined there are nuances of that definition which require further examination. Well clear is a metric which will prompt an S&A system to make a slight deviation to avoid traffic, but there will be a need for a more progressive algorithm(s). For instance, a situation could arise where a conflict situation begins within the threshold of well clear but before the threshold for collision avoidance begins. In this instance, what participant three labeled as “near well clear”, expedited maneuvers by one or more aircraft would be required. Definitions, algorithms, operational requirements, and regulations are all need for these incremental points of conflict which, presently, represent a grey area.

Participant three also discussed the need to decide which sensors are to be used and then the technical challenges of designing them, validating them and certifying them as large barriers that needs to be overcome. Additionally, he mentioned that while there are several algorithms that have been used successfully in tests by various agencies working on UAS, there has not been a firm decision upon which to use. This indecision is due to many other interrelated issues, such as a lack of agreed upon surveillance system, lack of 14 CFR guidance, and many other policy and regulation unknowns. Furthermore, he said that once these decisions are made there is still the challenge of ensuring interoperability with TCAS and ATC systems.

The political challenge of developing and integrating S&A was also mentioned by participant three. Stakeholders in the NAS are still debating on when and where airspace is dense enough to merit an S&A requirement for UAS. He spoke of the National Business Aviation Association (NBAA) and the Air Line Pilots Association (ALPA) as strong proponents of all UAS being required to have S&A. Contrary to this stance he said that many other private entities, who are hoping to utilize UAS for commercial purposes, have argued against this. The idea of creating a separate airspace for smaller, more autonomous UAS has been debated in meetings participant three has attended. If this were to come to fruition and this airspace was designated solely for smaller category UAS who would oversee it? Would this require a new and specialized form of oversight, similar to ATC, specific to UAS? Who would be financially responsible for this airspace? It is of participant three's opinion that a "one size fits all" solution to the problems of UAS integration cannot be found. It is likely that UAS operations will be segmented by category with appropriate solutions tailored accordingly.

Secondary Research Questions

Interview question eight asked participants to discuss the current state of air traffic control requirements for Sense and Avoid. Participant one first discussed how UAS will interoperate with ATC in general. He discussed that the problem with unmanned aircraft is that they vary. They have different propulsion methods, speeds, turn rates, size and weight. He went on to discuss that initially the FAA was focused on creating policies and procedures for larger category aircraft operating in controlled airspace. This was driven largely by the U.S. Department of Defense who wanted guidance for their UAS to operate in the NAS. However, in the past few years the FAA has pivoted from concentrating on larger category UAS to the smaller ones. In 2005 the FAA created the Pathfinder Program. This is a public-private

partnership to study how to operate small UAS in a variety of commercial ways. This program is specifically looking to help shape the Small Unmanned Aircraft Systems Rule, or more commonly referred to in the UAS community, the rule. The Pathfinder Program is testing small UAS operations in three capacities: flight over people, extended visual range and beyond visual range. Participant one believes that the data generated from this program will allow for a more comprehensive ruling on small UAS policies and procedures. However, this will not necessarily mean that they will be operating in controlled airspace. In summary, participant one said that larger category UAS will simply require procedural changes by ATC to accommodate their slower than typical manned aircraft speeds. Smaller UAS will need to be compartmentalized in this regard. Those that could affect the safe operation of manned aircraft will require a solution that allows them to operate safely in controlled airspace, while those operating outside of controlled airspace will require a completely new form of flight safety management which is yet to be determined. Specifically regarding S&A requirements, participant one believed that S&A avoidance maneuvers will largely mirror TCAS policies and procedures. Slight deviations from filed flight paths will require that UAS operators inform ATC. Typically with TCAS maneuvers the pilot is required to inform ATC that they are responding to a resolution advisory, but this can be after that pilot has already begun the maneuver. With S&A maneuvers this will likely be the same.

Participant two was not directly aware of any information on current ATC standards being developed for S&A but offered his thoughts on the process of creating them. He suggested that since Sense and Avoid is an atypical piece of avionics it has to be designed to work not just with new technology, but with old legacy systems as well. He asserted that S&A would not be as challenging to make work with new aircraft, but that it would require “dumbing down” before

it could work properly with thirty year old aircraft. He then went on to say that the challenge for S&A use in controlled airspace is not writing the algorithm, but how to write it, or them, in a way that it will effectively interoperate with a variety of aircraft with different avionics systems and performance metrics.

Participant three believed that ATC standards for UAS will have to be tailored to three factors: traffic density, ATC service limitations and S&A response maneuver parameters. For small UAS, operating at low altitude, participant three maintained that different requirements per UAS operational capabilities would have to be created. Regarding smaller category UAS, participant three believes that potential operators are more worried about objects such as power lines, trees, cars, and persons. He then discussed a Chinese system being developed that uses a fairly simple radar to avoid objects moving towards it and suggests that this could be a solution for smaller category UAS operating near the ground. The possibility of small UAS operating near airports was discussed as well. In the U.K., participant three said, there is a fail-safe system for UAS performing low altitude operations that when there is a system failure the UA lands immediately. He said that this system is in its early stages of development but suggested that this also could be integrated into the Small UAS Rule at some point in the future.

Interview question nine asked the participants to discuss whether UAS will have to meet standardized performance requirements in the future. Participant one believed that the varying type and performance of UAS will prevent a one-rule solution, but believed instead that the degree of regulation will be directly proportional to the degree of risk. Further explaining, if a larger category UAS, comparative in size, weight and speed to Boeing 747 heavy cargo jet, were to begin operating out of a large commercial airport that serves manned aircraft then the performance requirements of this UAS would have to approximate the Boeing 747. Participant

one then mentioned that arguments might be made by UAS operators regarding redundancy systems. Aircraft that are commercially used to carry human passengers are required to have redundancy for major systems on the plane. This safety protocol could potentially be argued unnecessary for UAS that are not carrying human passengers.

Participant two believes that performance requirements will be segmented by UAS category and that the focus will be on the smaller category UA. He contends that the larger category UAS are so near in overall performance and size to their manned counterparts that little work will be needed regarding them. The smaller category UAS will require an outside-the-box solution due to their uniqueness. With small UAS performance largely vary, but the largest difference from their larger counterparts are their pilots. The regulations, participant two says, will be very unlike what we have today.

Participant three, while answering interview question nine, suggested that the market will address performance requirements. He contends that UA manufactures will assess the likely airspace usage of UA they design and factor the performance characteristics of other aircraft in that airspace so as to make their UA compatible. Participant three believes that one caveat to UAS performance standardization will be wake turbulence and that a greater separation rule for UAS will be required. He also contends that due to the market drivers in commercial design of UAS there will be no need to create a separate airspace category for them. He believes that UAS will be designed so as to accommodate current airspace requirements rather than requiring excessive special rules and procedures.

Interview question ten asked participants to discuss how ADSB development will affect Sense and Avoid development. Participant one believed that ADSB will greatly help S&A as a surveillance means, but does not believe that this is a single solution. He believes that a low cost

solution will be necessary before ADSB can have a significant impact with smaller category UAS. Then he discussed the company Google and its efforts to produce a low cost ADSB alternative. This, participant one contends, could be of significant help in S&A for the types of UAS that will be operating close to the ground.

Participant two contends that ADSB development will not affect S&A development. He continues to say that according to RTCA phase 1 Minimum Operating Standards (MOPS) all that will be required of UAS operating in the NAS will be an active transponder. Because of this S&A will be dependent on ADSB. However, if and when ADSB surveillance becomes available then participant two says that S&A development would be receptive to its use. However, he contends that self-separation standards will be different than TCAS standards. Participant two then continues to say that regardless of what surveillance system is used for S&A that the collision avoidance system on board the UA will operated independently of it as TCAS does for manned aircraft.

Participant three ascertained that some NAS users, such as the NBAA and the AOPA, are resistant to ADSB due to the prohibitive cost their members would have to incur in order to use this system. The Navy and Amazon are both developing a low cost alternative to ADSB he said and this could be a more cost acceptable surveillance solution for many NAS users. However, participant three pointed out two potential major problems for using ADSB as a large scale solution for S&A. One, will near universal use of ADSB saturate ATC avionics frequencies? Two, there will be some NAS users flying Visual Flight Rules (VFR) who will deliberately not want to be tracked by a surveillance system. These users would represent a category of non-cooperative traffic that would require some alternate means for S&A to interrogate conflicts.

Interview question eleven asked participants to discuss whether Sense and Avoid component configuration will be regulated. Participant one contended that it will have to be. Then he maintained that the question to ask is how much responsibility is regulated. The tradeoff with S&A component configuration is directly proportional to the robustness of the data link system. A secure data link system can allow component configuration that would incorporate more human decision making. An automated system would require a less robust data link system but then there is an added problem with software. The software would then become the most crucial aspect of the S&A system and this, participant one, would be hard to design certification standards for.

The self-separation logic function of S&A was not discussed by participant two but he had much to say on ACAS development. Participant two asserted that the collision avoidance aspect of S&A will have to be configured on the aircraft independent of communication via the data link system. ACASx is the NexGen TCAS system being developed for manned aircraft. ACASxu is the NexGen collision avoidance system being developed for UAS. ACASx is already far along in its developments and, as a result, UAS are directly benefiting from this. ACASxu will essentially tailor the logic from ACASx for non-cooperative traffic. Participant two was unsure of whether this technology would be usable on smaller category UAS but suggested that the larger UAS would benefit greatly from it.

Participant three said that the RTCA is looking at Minimum Operating Standards for both higher and lower level performance UAS. He contended that the range and response times of UAS inputs will have to be standardized for certification purposes. Since S&A is being designed as a substitute for See and Avoid on UAS it was suggested by participant three that regulations for S&A will mirror those of manned aircraft for See and Avoid. Any changes to response

requirements will have to be justified. He also discussed maintenance standards for S&A equipment. There will be need to be regulation for sensor inspections and replacement intervals. Participant three further stated that regardless of component configuration S&A must be able to discern any and all collision hazards without limitation and that in the event of a system failure there are recovery contingencies in place. Regarding collision avoidance participant three suggested that the “heavy lifting” of development of a system has been done by ACASx. The FAA will be able to simplify and cheapen the certification requirements for UAS thanks to the development of ACASxu.

CHAPTER IV: DISCUSSION AND RECOMMENDATIONS

The primary purpose of this study was to determine what the current state of Sense and Avoid development is. The interview questions listed in Appendix B were designed to define where S&A development presently is, how it will work eventually, and what challenges lay ahead for its operational use. The participant answers to these interview questions provided the data necessary to answer the primary research questions. These answers are included below.

The first research question asked what the current state of Sense and Avoid development is and the answer to this question is broad and expansive. There are no regulations for the use of S&A currently, with the exception of the U.S. Military. Presently, RTCA and ARC committees are making recommendations for S&A development in a variety of ways. Recommendations are being made on how to adapt the Part 49 Code of Federal Regulation so that S&A electronic technologies are an acceptable substitute for the See and Avoid requirements. The standards of Well Clear have been defined, but self-separation has not. Maneuver standards for UAS that would comply with Well Clear are still being written by an RTCA committee. Yet, even if these maneuver standards were agreed upon and written tomorrow there is still a debate among these various committees as to how much automation is given to these maneuvers. Two of the participants in this study pointed out the following two questions. Would the logic functions for these maneuvers be programmed into a system that is physically on the UA? Or, would a human make these decisions, which would then rely on a relay of electronic signals via the UAS pilot at the ground control station through the data link to the UA? These questions have not been answered and they need to be before a comprehensive S&A algorithm can be written. The answer to these questions could have a large impact on U.S. ATC operations and procedures regardless of what the decision is. Automated responses would require that ATC create

additional safe distances, both laterally and vertically, around UAS. This would diminish usable airspace in the NAS and put an extra burden on ATC. A human pilot advising ATC of an S&A maneuver would likely require less ATC procedural changes, but could flood ATC communications and severely increase controller workload. Additionally, it has still not been determined what collision avoidance system will be utilized by UAS. RTCA and ARC committees are presently trying to determine if UAS will only be required to carry a transponder and not a collision avoidance system, instead, relying on manned aircraft's TCAS systems to provide this safety measure. However, this requirement would only effect categories of UAS that would operate in ATC controlled airspace. See and Avoid development for smaller category UAS, operating outside of ATC controlled airspace, are still in early stages of development and presently RTCA committees are not looking at self-separation standards for non-cooperative aircraft. Furthermore, the FAA has yet to create a Technical Standard Order (TSO) for S&A systems, which will be necessary for manufacturers of these systems before they can get even initial design approval before manufacture.

The second research question asked what will be the future requirements for Sense and Avoid by the FAA. This question made assumptions that data collection would find S&A development farther along than it was found to be. Michael Whitaker, the Deputy Administrator of the FAA, said before the U.S. Congress in June of 2015 that the RTCA Special Committee 228 (SC-228) is expected to release the operating standards for S&A technology sometime in 2016. As was made clear in the answer to the first research question, much is still undecided about S&A requirements and regulation. However, much information was gained through participant interviews that should shed light on what are likely to be the requirements made by SC-228 in 2016. All three participants agreed that larger category UAS interaction with ATC

will be the main driver of S&A development in the near future. With this being said, two of the three participants said that sensor technology standardization will be of critical importance and all three participants agreed that a common algorithm(s) will be as well. SC-228 will likely require that larger category UAS operating in ATC controlled airspace be equipped with a transponder and not a collision avoidance system, at least in the near to mid future. A transponder is a typical piece of avionics equipment with a long track record of reliable use. For a new technology, operating in a highly safety sensitive capacity, this will be a safe play and will act as a default collision avoidance system for UAS through its interrogation by manned aircraft's TCAS systems. The algorithm(s) will have to be standardized across the spectrum of UAS operating in ATC controlled airspace. The major problem with the algorithm(s) will be certification. All three participants expressed their concern for this process. It is very hard to one, create a standard to certify software against and two, create the necessary safety protocols required for a failure in this system. If an S&A system were to fail the requirements will likely mirror those of manned aircraft requirements when they lose Reduced Visual Separation Minimums (RVSM) and TCAS operational abilities. In the event these systems were lost, and radio communications with a UAS were lost, safety protocols for the UAS to safely descend through controlled airspace and land will have to be established and this will be extremely challenging to regulate as well. For these reasons, this research concludes that SC-228 will not meet its goal of releasing operating standards for S&A technology by 2016.

The third research question asked what the challenges of S&A development and integration are. All three participants agreed that the surveillance system utilized for UAS oversight in the NAS will be a major hurdle for integration to overcome. In the immediate future ADSB is not available. The system is not expected to come online until the year 2020. While

the existing surveillance systems currently used by ATC can most likely accommodate larger category integration, a system like ADSB is deemed, at this time, a crucial development towards the integration of smaller category UAS operating outside of controlled airspace. Also, ATC interoperability was agreed upon as a major challenge by all three participants. This problem is twofold. The first is the most immediate challenge of deciding upon how ATC accommodates S&A self-separation maneuvers in controlled airspace. The second is how to effect oversight of smaller category UAS that operate close to the ground outside of controlled airspace. Two of the participants questioned whether this oversight would be best served by ATC or some other entity that would be created for this sole purpose. Two of the participants stated that developing the S&A algorithm(s) will be the most difficult challenge in the immediate future. SC-228 is currently developing S&A avoidance standards to comply with Well Clear, however, this will likely be an evolving process. Situations will arise that were not factored into the algorithm(s) original design and, like any new technology, there will be growing pains.

Recommendations

The integration of larger category UAS into the NAS is a major concern expressed by the aviation community during this research. This concern could potentially be a “red herring” though. UAS that transit ATC controlled airspace are similar in performance to manned aircraft using that same airspace. ATC rules and procedures will be written for UAS integration but they will be written so as best to facilitate UAS accommodating to the current system and not vice versa. UAS manufactures will consider the airspace their UA will be operating in and will make designs compatible to this airspace. In summary, larger category UAS will be of minimal disruption to ATC controlled airspace and its current users. The greatest challenge ahead lay with small category UAS.

During the participant interviews, extemporaneous questions were made throughout the interview. This led to information gained from two participants about the current efforts by private industry to create a low cost ADSB surveillance system specifically for small UAS use. Google is one such private company, but there are several others. Additionally, low-cost and low-weight ADSB receivers, some weighing only a few ounces, are being developed for use on small UAS. If these technologies came to fruition they could facilitate the widespread growth of small UAS commercial use envisioned by so many in the private industry. Sense and Avoid would have to be adapted much differently for small category UAS and the algorithm used for the larger category UAS would not be effective for the smaller classes so that would have to be adapted but these are manageable obstacles. To separate small category UAS with the same vertical and lateral separation requirements of manned aircraft would be grossly inefficient. Self-separation standards will need to be adapted for the smaller category UAS as well. TCAS and the Airborne Collision Avoidance System for Unmanned Aircraft would not work with smaller category UAS according to participant two, so a collision avoidance system, if necessary, would have to be adapted for these UA as well.

The technology is there, potentially. What is not is a flight management system to provide oversight and regulation for these small UAS. The Pathfinder Program is a good first step towards the data collection required to build a flight management system, but, more programs like this, with a public-private partnership, are needed. Different facets of commercial applications of UAS need to be explored and data collected. Then, a flight management system needs to be given federal authority to oversee the safe and efficient operation of UAS. A major concern that was expressed throughout this research process was that potential operators of these smaller category UAS are going to be persons who have no working knowledge of the NAS or

prior flying experience. While these smaller category UAS will not likely use ATC controlled airspace in their operation, they will need to circumvent it. A potentially good solution to this problem is to create a new tier of ATC, one that does not use three or five miles lateral separation and 1,000ft vertical separation like the current system. This new ATC flight management system would not control small UAS traffic in the fashion it does manned aircraft now. It would be fundamentally different. The benefit though, would be that while the operators of these smaller category UAS might not have significant knowledge of the NAS or much, if any, flight experience, the oversight of them would be effected by an organization that has a long history of safeguarding U.S. airspace.

Limitations

Although this research was carefully prepared and reached its aim there are still limitations and shortcomings. Three limitations were identified. One was the accuracy of the participant's answers to the interview questions. This is a current state research paper, but it also sought to answer questions about future projected regulation and development. The answers to these questions by the participants were speculative. This speculation was mitigated by selecting the best qualified participants available, but the limitation remains nonetheless. The second limitation was the population size of participants. There were only three participants utilized for data collection. This small sample size might not accurately represent the majority view of the answers to the questions posed by this research. The third limitation was the competency of the research participants. Each of the participants were highly recommended by work peers and their professional credentials attest to their legitimacy, which mitigates this limitation. However, S&A technology is highly complex with a lot of interoperable pieces. It would be quite possible

for assumptions or oversights to be made by professionals in regards to areas outside of their expertise.

Recommendations for Future Research

Future research in the area of UAS integration should include a larger sample pool of interview participants. A larger sample size of participants would generalize interview question answers thus qualifying the data to a higher degree. Additionally, input from both UAS operators and air traffic controllers would benefit future research as their practical experience could provide additional insight.

REFERENCES

- Angelov, P. (2012). *Sense and avoid in UAS research and applications*. Hoboken, N.J.: Wiley.
- Aquila - this early eagle hardly soared. (2011, November 4). Retrieved April 7, 2015, Retrieved from <https://travelforaircraft.wordpress.com/2011/11/04/aquila--this-eagle-hardly-soared-draft/>
- Crovitz, L. (2015, April 5). Amazon's drones exiled to Canada. Retrieved April 7, 2015, Retrieved from <http://www.wsj.com/articles/l-gordon-crovitz-amazons-drones-exiled-to-canada-1428270643>
- Drone Origins: World War II and Vietnam-era remotely piloted vehicles. (2013, December 2). Retrieved April 7, 2015, Retrieved from <https://understandingempire.wordpress.com/2013/12/02/drone-origins-world-war-ii-and-vietnam-era-remotely-piloted-vehicles/>
- FAA Modernization and Reform Act of 2012. 49 U.S.C. §§ 331-336 (2012)
- Fahlstrom, P., & Gleason, T. (2012). *Introduction to UAV systems* (4th ed.). Hoboken, N.J.: Wiley.
- Gay, L., & Airasian, P. (2003). *Educational research: Competencies for analysis and applications*. (7th ed.). Upper Saddle River, N.J.: Merrill/Prentice Hall.
- Merlin, P. (2015, January 26). NASA, FAA, industry conduct initial sense-and-avoid test. Retrieved April 7, 2015, Retrieved from http://www.nasa.gov/centers/armstrong/Features/acas_xu_paves_the_way.html

- Phelps, N. (2015, March 28). Experts expect drone use to surge. Retrieved April 7, 2015, Retrieved from <http://www.greenbaypressgazette.com/story/money/2015/03/28/drones-faa-regulations-business-applications/70559566/>
- Pomerleau, M. (2015, February 18). What's keeping drones from taking off - GCN. Retrieved April 7, 2015, Retrieved from <http://gcn.com/articles/2015/02/18/sense-and-avoid-drone.aspx>
- Roberts, J. (2014, April 22). The drones are coming: FAA-approved labs test UAVs for use in US skies. Retrieved April 7, 2015, Retrieved from <http://www.foxnews.com/politics/2014/04/22/drones-are-coming-faa-approved-labs-test-uavs/>
- Seitz, P. (2014, October 6). Commercial uses seen fueling unmanned aerial vehicles. Retrieved April 7, 2015, Retrieved from <http://news.investors.com/technology/100614-720465-uav-sales-set-to-triple-by-2020-igi-consulting-says.html>
- Shaw, I. (2012, May 21). History of U.S. drones. Retrieved April 7, 2015, Retrieved from <https://understandingempire.wordpress.com/2-0-a-brief-history-of-u-s-drones/>
- Thompson, C. (2014, October 6). Why one insurance firm wants to start using drones. Retrieved July 14, 2015, Retrieved from <http://www.cnbc.com/2014/10/06/why-one-insurance-firm-wants-to-start-using-drones.html>
- U.S. Department of Defense. (2011). Unmanned Aircraft System Airspace Integration Plan (Report No. 1-7ABA52E). Retrieved from [http://www.acq.osd.mil/sts/docs/DoD_2011_UAS_Airspace_Integration_Plan_\(signed\).pdf](http://www.acq.osd.mil/sts/docs/DoD_2011_UAS_Airspace_Integration_Plan_(signed).pdf)

Unmanned Aerial Vehicle Systems Association UAV or UAS? (n.d.). Retrieved April 7, 2015,
Retrieved from <https://www.uavs.org/index.php>

USAA the latest to test drones for commercial use - Tampa Bay Business Journal. (2015, April
7). Retrieved April 7, 2015, Retrieved from
<http://www.bizjournals.com/tampabay/blog/morning-edition/2015/04/usaa-the-latest-to-test-drones-for-commercial-use.html>

Whittle, R. (2013, April 1). The man who invented the Predator. Retrieved April 7, 2015,
Retrieved from <http://www.airspacemag.com/flight-today/the-man-who-invented-the-predator-3970502/>

APPENDICES

APPENDIX A

IRB Approval

IRB
INSTITUTIONAL REVIEW BOARD
 Office of Research Compliance,
 010A Sam Ingram Building,
 2269 Middle Tennessee Blvd
 Murfreesboro, TN 37129



EXEMPT APPROVAL NOTICE

8/27/2015

Investigator(s): Sean Kavanagh
 Department: Aerospace
 Investigator(s) Email: smk2g@mtmail.mtsu.edu
 Protocol Title: "Sense and Avoid System Development in Unmanned Aircraft Systems"
 Protocol ID: 15-357

Dear Investigator(s),

The MTSU Institutional Review Board, or a representative of the IRB, has reviewed the research proposal identified above and this study has been designated to be EXEMPT.. The exemption is pursuant to 45 CFR 46.101(b) (2) **Educational Tests, Surveys, Interviews, or Observations**

The following changes to this protocol must be reported prior to implementation:

- Addition of new subject population or exclusion of currently approved demographics
- Addition/removal of investigators
- Addition of new procedures
- Other changes that may make this study to be no longer be considered exempt

The following changes do not have to be reported:

- Editorial/administrative revisions to the consent of other study documents
- Changes to the number of subjects from the original proposal

All research materials must be retained by the PI or the faculty advisor (if the PI is a student) for at least three (3) years after study completion. Subsequently, the researcher may destroy the data in a manner that maintains confidentiality and anonymity. IRB reserves the right to modify, change or cancel the terms of this letter without prior notice. Be advised that IRB also reserves the right to inspect or audit your records if needed.

Sincerely,

Institutional Review Board
 Middle Tennessee State University

NOTE: All necessary forms can be obtained from www.mtsu.edu/irb.

APPENDIX B

Interview Question List

1. What is your job title?
2. What is your job function?
3. How long have you worked in Aviation?
4. How long have you worked with UAS?
5. What is your working knowledge of Sense and Avoid?
6. What is the current state of Sense and Avoid regulatory requirements?
7. What are the potential challenges for Sense and Avoid development and integration?
8. What is the current state of Air Traffic Control compliance requirements for Sense and Avoid?
9. Will Unmanned Aircraft have to meet standardized performance requirements in the future?
10. How will ADSB development affect Sense and Avoid development?
11. Will Sense and Avoid component configuration be regulated?

APPENDIX C

Contact Request Letter

Dear Sir or Ma'am,

My name is Sean Kavanagh. I am an air traffic controller at Washington EnRoute Center and I am also completing my Masters of Science in Aviation Safety and Security Management. Currently, I'm writing my thesis on UAS integration into the NAS. More specifically my research is focused on the current state of development for Sense and Avoid and further examines the future challenges facing the development of this system.

I'm looking to conduct interviews this July with persons knowledgeable about any of the following: Sense and Avoid (the current state and future development of), regulations pertaining to UAS operations in the NAS, and/or air traffic control procedures being developed for UAS.

The interview would take about one hour and would be at the participant's convenience. Also, I might ask to email with follow up questions as well.

With the interviewees permission I would like to record our conversation for later reference. All participants would be presented with a consent form provided through the IRB at my university (Middle Tennessee State University). Participants would be required to sign before I could interview them. Confidentiality will be maintained for all who participate.

The interview would be semi-structured meaning I would ask from a list of questions I've developed and then, hopefully, a more detailed discussion would evolve from the participants answers to these questions. Below is the list of questions I would begin the interview with:

1. What is your job title?
2. What is your job function?
3. How long have you worked in Aviation?
4. How long have you worked with UAS?
5. What is your working knowledge of Sense and Avoid?
6. What is the current state of Sense and Avoid regulatory requirements?
7. What are the potential challenges for Sense and Avoid development and integration?
8. What is the current state of Air Traffic Control compliance requirements for Sense and Avoid?
9. Will Unmanned Aircraft have to meet standardized performance requirements in the future?
10. How will ADSB development affect Sense and Avoid development?
11. Will Sense and Avoid component configuration be regulated?

Sincerely,

Sean Kavanagh