COVER PAGE

Title of Design:
Integrating Commercial Unmanned Aircraft Systems into the National Airspace System

Design Challenge Addressed: Airport Management / Planning

University Name: Binghamton University – State University of New York

Team Member(s) Names:

Barer, Solomon	sbarer1@binghamton.edu
Bremer, David	dbremer1@binghamton.edu
Glickman, Justin	jglickm5@binghamton.edu
Jelen, Emily	ejelen1@binghamton.edu
Kaufman, Daniel	dkaufma3@binghamton.edu
Pressimone, Matthew	mpressi1@binghamton.edu
Robinson, Aidan	arobin22@binghamton.edu
Somma, Louis	lsomma1@binghamton.edu

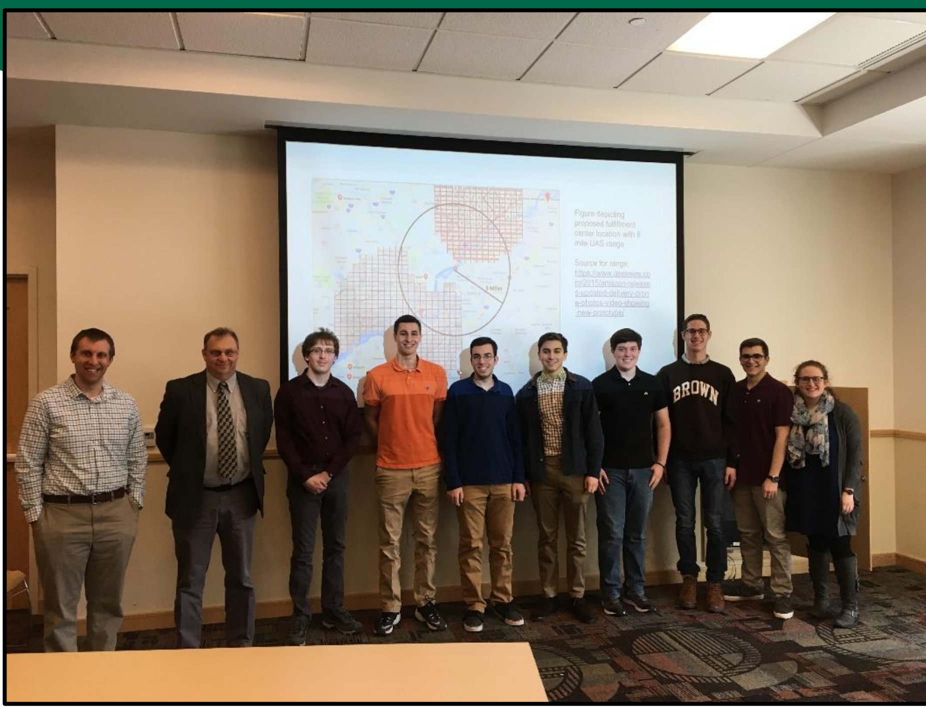
Number of Undergraduates: 8

Number of Graduates: 0

Advisor(s) Names: Professor Chad Nixon, Professor Zachary Staff, Professor William Ziegler

University Design
Competition for
Addressing Airport Needs

Integrating Unmanned Aircraft Systems into the National Airspace System



Faculty Advisors:
Chad Nixon
Adjunct Professor-
Binghamton University
Scholars Program

Zachary Staff
Adjunct Professor-
Binghamton University
Scholars Program

William Ziegler
Executive Director-
Binghamton University
Scholars Program

Team (Undergraduate):
Barer, Solomon
Bremer, David
Glickman, Justin
Jelen, Emily
Kaufman, Daniel
Pressimone, Matthew
Robinson, Aidan
Somma, Louis

BINGHAMTON UNIVERSITY
STATE UNIVERSITY OF NEW YORK

Executive Summary

A major goal of the Federal Aviation Administration (FAA) is to ensure safe and efficient aircraft operations throughout the National Airspace System (NAS). A present concern that risks impeding this goal is the lack of a nationally accepted and standardized system that integrates commercial unmanned aircraft system (UAS) activity into the NAS. Due to the absence of such a system, many inefficiencies in the current operation of UAS exist. Current FAA regulations, for example, require all UAS to remain within the visual line-of-sight (VLOS) of their remote pilot, and remain within 400 feet of the ground. Such regulations greatly inhibit the ability of commercial delivery companies to fully utilize the potential benefits of UAS technology.

Proposed herein is a system for the integration of commercial UAS activity into the NAS, conceptualized by a team of undergraduate students at Binghamton University – State University of New York. The main goal of the system is to adapt the current regulations surrounding commercial UAS operation for the rapidly modernizing commercial UAS industry, moving away from established restrictive policies while improving the overall safety and efficiency of the NAS. The system incorporates a network of "corridors" that serve to designate regions of the NAS through which any UAS may travel freely. A UAS will, upon entering one of these designated corridors, be permitted to fly autonomously toward its destination without concern of unexpected encounters with manned aircraft. In addition, within these designated corridors, all UAS will make use of automatic sense-and-avoid technology to ensure that collisions involving multiple UAS do not occur.

The proposed system has been designed to minimize interference with the existing regulations for the operation of all manned aircraft, thus ensuring seamless integration in the event of adoption of the system by the FAA. By introducing designated corridors exclusively for UAS operation, the system reduces the risk of collisions while simultaneously increasing the efficiency of all commercial industries that make use of long distance UAS travel as part of their daily operations. Once fully implemented, the system will enable commercial deliveries to be carried out more quickly, and for a wider variety of products, to a far greater number of destinations. The result will be a highly streamlined system that fully integrates commercial UAS activity into the NAS, allowing the rapidly expanding commercial UAS industry to take full advantage of its potential without posing major risks to established manned flight.

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I. Problem Statement and Background

a. FAA Goals

The demand for commercial Unmanned Aircraft System (UAS) technology for delivery of goods continues to grow. As this demand grows and the business case for this type of delivery is further substantiated, the pressure on regulators to develop guidance on the integration of airspace for UAS activity increases exponentially. There are inherent challenges with integration such as safety of flight, privacy concerns, and control over users of the system. It is noted that significant effort has been and continues to be placed on developing an integration model.

Figure 1 – An Amazon delivery drone. [2]

As it relates to airspace, the Federal Aviation Administration (FAA) is focused primarily on internationalizing airspace to modernize it. This project, called NextGen, hopes to promote international collaboration regarding airspace to properly refine and manage the rapidly modernizing air delivery system [1]. Companies like Amazon have already created UAS for product delivery, as shown in Figure 1, and are waiting for the FAA to give them permission to begin offering the service. In the FAA's Comprehensive Plan from 2013, there is a list of the FAA's National Goals for UAS. The six goals contained in the plan are:

1. Routine Public UAS Visual Line-of-Sight (VLOS) use in the National Airspace System (NAS) without a Certificate of Authorization (by 2015)
2. Routine Civil UAS VLOS use in the NAS without special authorization (by 2015)

3. Routine Public UAS NAS Operations (by 2015)
4. Routine Civil UAS NAS Operations (by 2020)
5. Define, Determine, and Establish Acceptable Automation Levels for UAS in the NAS (no target date)
6. Foster United States (US) International Leadership in UAS Capabilities and Standards Development (ongoing) [3]

These efforts by the FAA will help to ultimately integrate UAS into the airspace on a worldwide scale. The goal of this project is to provide a model of UAS corridors to assist the FAA in advancing the implementation of UAS.

b. Current Methods for Meeting FAA Goals

To help with the research and use of UAS, the FAA invested in and set up test sites throughout the United States in 2013. These six test sites are areas that have integrated UAS into the NAS, where they can be under close observation. By utilizing these test sites, the FAA will be able to better develop and form policies that can be enacted in the future [3]. Data and results regarding the test sites have not been released to the public. However, by setting up the test sites, the FAA has shown that there is a foundation for the integration of UAS into the NAS. These current methods have helped guide the project and build a basis for the future synthesis of manned aircraft and UAS.

c. Moving the Industry Forward

In the past few years, UAS technology has improved dramatically, from better navigation capabilities to better see-and-avoid technology. These advancements simplify UAS use and allow for their further commercialization and overall consumer use. This integration of UAS into the NAS will come with its challenges, however. It will require a widespread commitment of different government entities, as well as aviation stakeholders, to unite to integrate UAS into the NAS in a safe and efficient manner [1]. Organizations like the National Aeronautic Space Administration (NASA), Department of Transportation (DOT), Department of Homeland Security (DHS), Department of Defense (DOD), and Department of Commerce (DOC) are collaborating to properly integrate these UAS into the NAS, showing the current broad interest in this rapidly-developing field [3].

From a historic perspective, there were no regulations until the small UAS regulations were released in 2016 for routine, non-hobbyist use [4]. Just recently, a Canadian company, Drone Delivery Canada, completed its first ever test flight in US airspace at Griffiss International Airport in Rome, NY [5]. Currently, UAS use is heavily restricted by the FAA, prohibiting flight near airports or over cities, establishing a maximum altitude the aircraft is permitted to reach, and requiring the operator to constantly have the UAS within VLOS.

Companies like Amazon, Google, and Walmart [6] would greatly benefit from this innovative technology to refine their product delivery system, but to do that there must be FAA regulations and guidelines that permit expanded commercial UAS use without VLOS restrictions. A necessary first step, therefore, is to determine where UAS can fly. The concept presented in this research proposal of using corridors to integrate UAS into the NAS will greatly benefit the FAA in their goals of a safe, integrated airspace. As evidence of the proof of concept, a similar type of system already exists, known as Visual Flight Rule (VFR) corridors. A VFR corridor is defined as a general flight path for pilots to use when planning flights into, out of, through, or near complex terminal airspace to avoid Class B airspace. Air Traffic Control (ATC) clearance is not required to fly these routes [7]. This state-of-the-art corridor system for integration of non-commercial aircraft into the UAS is a primary reference for this project. By basing the project's design on this current system, it will be possible to incorporate a similar system for UAS. This integration will help assist greatly in the modernization of package delivery as well as other UAS uses, both commercial and recreational, helping to accelerate the industry's progress towards the future.

II. Summary of Literature Review

a. FAA Goals

The future of transportation, surveillance, and goods delivery will undoubtedly involve UAS. Consequently, in its Portfolio of Goals, the FAA has indicated its goal to assimilate UAS into the NAS [8]. While companies such as Amazon have already begun planning for this, there are significant boundaries and limitations to the integration of UAS into the airspace infrastructure [9]. FAA Small UAS Part 107 of Title 14 Code of Federal Regulations covers all major FAA regulations on UAS [10]. It lists, among other rulings, that unmanned aircrafts must: remain within the VLOS of a remote pilot, fly at a maximum speed of 100 miles per hour, fly no higher than 400 feet, weigh less than 25 kilograms, and yield right-of-way to other aircraft [10]. Although FAA regulations stipulate that UAS must be within the VLOS of the pilot, collaboration projects between the FAA and the National Aeronautics and Space Administration (NASA) are already underway to test the possibilities of automation and see-and-avoid technology regarding UAS integration [11]. UAS Traffic Management, or UTM, is NASA's umbrella venture to provide services such as UAS corridors, dynamic geofencing, severe weather avoidance, congestion management, and terrain avoidance [11].

The FAA estimates that the commercial UAS fleet will grow from about 42,000 at the end of 2016 to any number between 442,000 and 1.6 million by the end of 2021. The dramatic discrepancy in this estimation is a result of the dynamic regulatory environment surrounding UAS use for commercial purposes [12].

In “Destination 2025,” the FAA explains its goals for the future, along with some strategies and challenges. One major goal, “Delivering Aviation Access through Innovation,” describes the FAA’s aim to allow for more activity for “the traveling public and other users” [1]. The FAA also plans to achieve safe flight for UAS by 2025 [1]. By having UAS move around the airspace on specific paths, there is a lessened risk of traffic problems or collision risks as the UAS would not interfere with airspace currently used for other aircrafts.

b. Commercial Benefits and Development

Commercial UAS would be able to carry packages of up to five pounds, and currently, approximately 86% of Amazon’s shipments weigh under that amount [13]. UAS delivery would cost Amazon only $0.88 per shipment [14], as opposed to the $2.00-$8.00 it costs Amazon to deliver using ground transportation, resulting in a cheaper shipping cost of $1.00 for consumers [15]. Even at $1.00 per package, “Amazon’s rate of return on its UAS investments should exceed 50%,” according to Ark Invest [14].

Another issue that must be addressed in the coming years for UAS technology to be integrated into delivery system, is how and where to drop the package. Prime Air will include autonomous flight for UAS carrying packages five pounds or less. The UAS will fly about 400 feet in the air and will deliver in 30 minutes or less. The UAS may even scan the ground for a proper landing site [9].

c. Risks and Safety

The FAA’s Safety Risk Management process determines the risk of a situation by its likelihood and the severity of its worst possible outcome [16]. According to a study performed by the Alliance for System Safety of UAS through Research Excellence (ASSURE), collisions between airplanes and UAS were found to cause more damage than ones involving airplanes and birds of the same mass and velocity as UAS tend to be more stiff and rigid [17]. The damages were found to range from "small deformations" to "penetration of UAS into airframe" and "failure of primary structure," but even deformations could have serious financial implications [17].

Since the severity of a collision between a UAS and a manned aircraft is considered "catastrophic" according to the FAA Safety Management System Manual [18], the best way to lower the risk from "high" to "medium" would involve managing UAS in such a way that a collision is as unlikely as possible. For example, UAS should stay out of controlled airspace to avoid airplanes that are undergoing departures or arrivals. FAA policies also promote UAS and aircraft safety by requiring UAS weighing over 250 grams to undergo a registration process [19]. Another method for lowering the chance of a collision and the subject of this research proposal involves the creation of UAS corridors, or specific airspace "roads" on which UAS must remain.

III. Problem Solving Approach

The project team consisted of eight members, divided into four subgroups. The subgroups included the project leader; the design team subgroup; the risk assessment, strategies, and approach team subgroup; and the engineering and graphics team subgroup. The project leader oversaw the proposal and ensured all aspects were completed on time and in accordance with the project guidelines; furthermore, the project leader completed the ACRP Notice of Intent to Compete Form, the ACRP Cover Page Form, the Executive Summary, the Table of Contents, and Appendices D and F. The design team was responsible for examining the finer details of how the corridor system would work, for describing the financial effects of implementing the system, and for addressing how the system aligns with the FAA's goals; in addition, the team

Figure 2 – The teams working on their assignments.

completed the Projected Impacts and Technical Aspects Addressed sections. The risk assessment, strategies, and approach team reviewed the potential risk and safety concerns and completed the Summary of Literature Review, the Safety/Risk Assessment, the Problem Solving Approach, and the Interaction with Airport Operators sections, and Appendices A, B, C, and E. The engineering and graphics team were responsible for all graphics and produced the cover page, the Problem Statement and Background, the Summary and Conclusion, a photo gallery of the project's progression, and all graphics used for the project. Several members of the team are pictured in Figure 2.

As no member of the team had any background in aviation, Professor Staff provided an overview of aviation issues deemed Airports 101. All subgroups also composed a detailed literature review for areas of the project that their team would cover. All literature reviews were then combined to form the final literature review for the project proposal. Furthermore, all teams researched airspace demarcation, the different classes of airspace, and the implications they would have on the design and safety of the proposal. In addition to studying airspace safety and restrictions, the teams developed research and collaboration skills.

Three faculty members oversaw the team: Professor William Ziegler, Professor Chad Nixon, and Professor Zachary Staff. Professor Ziegler is the Executive Director of the Binghamton University Scholars Program and Associate Professor of the T.J. Watson School of

Engineering and Applied Science. Professor Nixon and Professor Staff are actively involved in the aviation industry as consultants and are also adjunct professors in the Binghamton University Scholars Program.

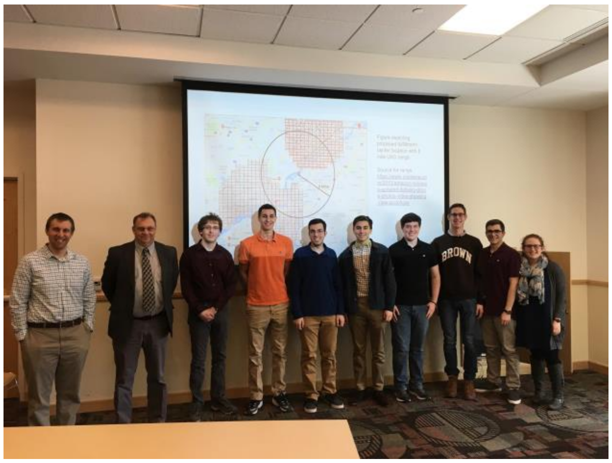


Figure 3 – David Hickling visiting the class.

The team also met with David Hickling, the Commissioner of Aviation at the Greater Binghamton Airport, on March 22, 2018 to discuss how the project would affect the airport environment and any unexpected consequences of implementation. Mr. Hickling is considered an expert in the UAS field given his experience as not only an airport commissioner but also as the co-chair of the New York Aviation Management Association’s UAS Committee and through his collateral duties as the regional spokesperson for UAS in the Southern Tier of New York State. Mr. Hickling’s visit to the class is seen in Figure 3. Hickling stated during the interactive class session that he found the project to be feasible and advantageous. He recommended incorporating geofencing into the design and noted the correlation between the UAS corridors and existing VFR corridors.

While developing the initial concept for the design competition, the class initially considered several ideas, including boarding bridge automation, fleet emissions analysis, and UAS corridors as potential project ideas. After some exploratory research, a team member found that an automated boarding bridge already existed [20]. After discussing the two remaining topics, the team decided to conduct its research on UAS corridors, as there was more interest in the growing relevance of UAS. The idea fell under the category of Airport Management and

Planning. Preliminary research led to the discovery of a patent from global security company Northrop Grumman, outlining a system that allows UAS to fly safely in and out of airports. As Northrop Grumman's proposal of risk-mitigating UAS pathways gave credence to the overall project design, it led the team to continue towards the corridor concept and to narrow the focus to integration of commercial UAS into the NAS.

As part of the project, the class examined airspace considerations, FAA requirements, and how each relates to the project. The design team assessed how to allow seamless UAS flight far from aircraft and restricted airspace, as seen in Figure 4. The group considered the possibility of UAS corridors entering and exiting Class B, C, and D airspace, but settled on the idea of circumnavigating airport airspace altogether.

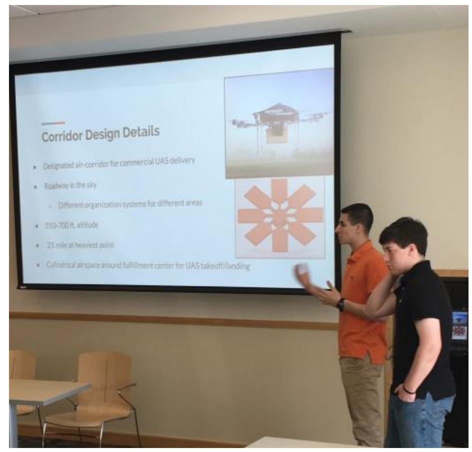


Figure 4 – The design team assesses how to allow seamless UAS flight far from aircraft and restricted airspace.

Part 107 of the Federal Aviation Regulations outlines rules for non-hobbyist small UAS [10]. The proposed design will comply with most of the Part 107 regulations while assuming other aspects — VLOS, 400-foot altitude restriction, and inability to fly directly over people — will be altered to support increased commercial UAS activity [10]. The design suggests maintaining the daylight/twilight-flight-only stipulation.

The corridors can be implemented into the NAS relatively quickly — within one to two years — presuming that FAA regulations will change to accommodate commercial UAS. While the corridors are not tangible objects, they may require long-term maintenance. For example, their dimensions or positions may need to be altered over time. The corridor system would only improve with advancements in global positioning, sense-and-avoid, and geofencing technologies.

By implementing the UAS corridors, UAS and aircraft would be able to fly safely and efficiently.

IV. Technical Aspects Addressed

In the age of technology, society has an increased consumer demand and decreased patience for delivery time. Technology has penetrated nearly every aspect of society as innovations are made to expedite all walks of life. On the horizon is a revolutionary design for the delivery of goods. As mankind was once restricted to the ground, so too was its mode of delivery. Man will soon experience delivery directly by air. This, however, will not be bulk loads, but individual customer delivery via an unmanned aerial system (UAS). With the vision of the future, and the technology to do so now, UAS will scatter the skies bringing goods to doorsteps in a miniscule amount of time.

To combat mass confusion and optimize delivery routes, this project proposes the implementation of "corridors" specifically for commercial UAS. These commercial UAS would be smaller vehicles initially owned by large companies, such as Amazon, Walmart, Domino's, etc., to individually deliver goods to the consumer's doorstep. The proposed air corridors would be controlled airspace and a "highway in the sky" that would allow the delivery of goods via UAS in a significantly shorter period than currently established distribution systems. By creating specified corridors for this purpose, conflict with other aircraft would be drastically decreased. These proposed corridors will be very similar to VFR corridors that are already in place. These act as "holes" through class B airspace designated for a separate purpose. The same will be the case for the proposed UAS corridors, which will prevent aircraft interference and increase the safety of the corridors. While present FAA regulations have numerous restrictions on recreational UAS, which are aircraft purchased and/or piloted by civilians, this proposal assumes a portion of these would be lifted or altered in favor of technological advances in addition to the fact that it applies to commercial, rather than recreational, UAS. This mass enterprise of UAS delivery is quickly approaching to satisfy the public's demands. This proposal is designed to minimize conflict from the outset, rather than to implement a reactionary solution.

a. Unmanned Aircraft Systems

The integration of UAS into society has leapt forward during recent years. As technology continues to improve at a rapid rate, UAS are becoming more capable of prolonged, automated flight. UAS have moved beyond national defense and into the recreational market, while currently transitioning into the commercial market as well. With this move, the FAA has implemented regulations for their usage. UAS are becoming capable of higher, faster, and smoother flight. However, certain FAA rules restrict flight to the line-of-sight of the pilot, an altitude of 400 feet, and daylight hours. Additionally, unless pre-approved by an airport and control tower, flight within five miles of an airport is prohibited for recreational use [21].

i. Sense-and-Avoid Technology

Sense-and-avoid technology allows UAS to maneuver around obstacles in their flight path to avoid collision. This allows them to fly autonomously from one location to another without crashing. This technology works nonstop in three steps, as pictured in Figure 5. Sensors on the UAS are constantly scanning the area around it to make sure obstacles are not in its path. If an obstacle is detected, the sensors evaluate as much information about it as possible. Finally, the drone moves around

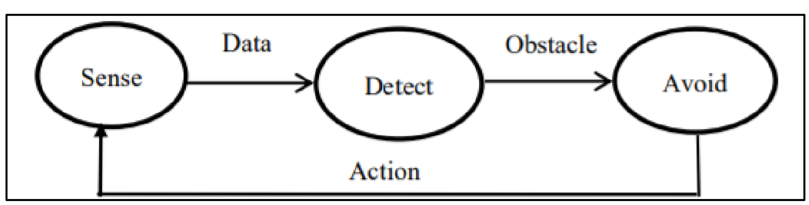


Figure 5 – Schematic view of the sense-and-avoid technology process.

the obstacle and continues its path, all autonomously [22]. This technology is continually improving and allowing UAS to become more independent during planned flights.

Even as technology continues to improve, there are shortcomings that still need to be worked out before it can be implemented onto commercial drones. One of these problems is the carrying capacity of UAS. The sense-and-avoid technology can become heavy due to its large quantity of sensors. This poses a problem since a UAS cannot carry both the sensory equipment and a heavy package as the load will be past the maximum lifting strength of the UAS. A solution being researched, however, is the combination of sensors to decrease the weight of the sense-and-avoid technology. Another problem with the sensors' implementation is that the light sensors of the technology are unable to detect obstacles in the dark with substantial consistency [22]. Until the design of the sensors improves, or a different method is used, commercial drones using this technology will be unable to make night deliveries. A final issue current technology has is the inability to communicate with other aviation vehicles. In planes, there is Automatic Dependent Surveillance-Broadcast (ADS-B) technology that allows pilots to know where other planes are in relation to their own, but in UAS, this technology does not yet exist. As the technology used by UAS continues to improve, so too does their ability to maintain autonomous flight over an extended range.

ii. Global Positioning Systems

This mode of delivery would require the use of global positioning systems (GPS). GPS has become one of the world's most critical inventions, and the past several years has seen it drastically expand into commonplace use. GPS can be found on any smart phone and countless additional apps. Presently, there are nearly two thousand satellites orbiting Earth, about 30 of which are designated for GPS [23]. While the precision of GPS is still increasing, it is currently accurate to within one meter [24]. The exactness with which GPS tracks a location increases as more satellites are above the horizon and can "see" said location. GPS uses trilateration to locate a receiver. A series of satellites, usually three, evaluates the distance between itself and the receiver. This provides the GPS satellite with a spherical zone of the receiver's possible locations. As the second and third satellites do this as well, the receiver's location becomes revealed where the three spheres meet, shown as circles in Figure 6 [25]. The more satellites that track the receiver at a time, the more well-calculated the receiver's location would be. For this UAS delivery system, each drone would be fitted with a GPS receiver, and customers would insert their address as they typically would. Depending on the scale of this endeavor and the current satellite technology, there is the possibility additional GPS satellites would have to be added to increase real time data and information flow; these additional satellites may be designated specifically for this purpose as well. Just as roads are programmed into today's GPS systems, pre-programmed air corridor routes will be available for the UAS to access.

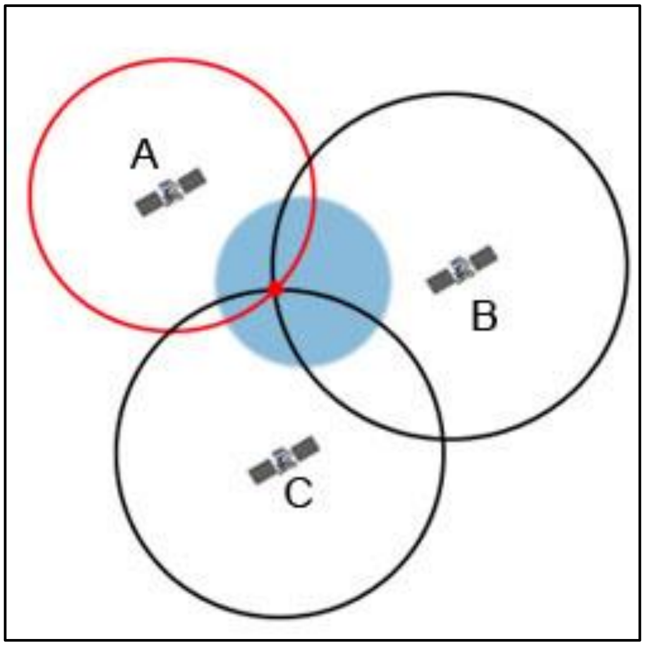


Figure 6 – Triangulation of location via three satellites.

iii. Battery Life and UAS Range

For UAS, battery life severely limits their ability to sustain long-distance flight. Flight time is further limited with additional payload, meaning adding more batteries to the UAS does not prolong its flight. Current technology allows for a flight range of about 15 miles without a payload, based on Amazon's recently released delivery UAS design [26]. For deliveries, this means UAS will be able to deliver a package with negligible weight seven and a half miles from the distribution center, with enough battery left for the return trip. This distance decreases with the addition of more weight to the payload, up to Amazon's limit of five pounds [27]. This range also does not consider weather conditions that may cause the UAS to have to expend more energy during its flight. Range of the UAS will be increased, however, based on speed, consumption efficiency, and improved battery technology, which are all being researched by various firms.

Currently, most UAS have either Lithium Polymer (Li-Po) or Lithium Ion (Li-Ion) batteries. These two types of battery are easily charged, relatively inexpensive, and have a high energy density, meaning they provide a great deal of power while remaining lightweight [26]. Li-Po and Li-Ion batteries are soon to be overtaken as the best commercially used power sources, however. Research in battery technology has led to the development of two new batteries that promise at least twice as much energy density as Li-Po batteries. The first is the Lithium Thionyl Chloride (Li-$SOCl_2$) battery. These batteries are much more expensive than Li-Po batteries, but offer twice the energy density per kilogram over Li-Po batteries [26]. The second is a battery that is still in the research and experimental stage of its development, the Lithium Air (Li-Air) battery. The developers of Li-Air batteries promise seven times the energy density of Li-Po batteries [26]. Using Li-Air batteries on delivery UAS would allow for a much longer flight range with a similarly-sized battery, or the ability to carry a larger payload the same distance. Even though the technology is not yet fully developed, the promise of better battery life and an enlarged flight radius is the basis for the mass employment of a new UAS delivery system.

Along with development of new batteries, research has been done on other types of fuel for UAS, although the results have been largely disappointing. A first alternate fuel source is fossil fuels such as kerosene and gasoline. Although these do offer their advantages, such as a much higher energy density than batteries, and the fact that the UAS would become lighter as it ran for longer (as it would consume fuel), the environmental concerns outweigh the positives [26]. In addition, fossil fuels are a one-use energy source, meaning over time they would become more expensive than rechargeable batteries. Hybrids of fossil fuels and electric energy have also been researched, however these systems add a lot of weight to the UAS and greatly decrease possible payload [26]. Solar power is yet another type of energy being currently researched. With a similar weight to batteries and the ability to charge mid-flight, solar power is an enticing option. However, solar power is very inefficient, as only approximately 50% of possible energy is stored and used [26]. Super Capacitors have also been researched, but with current technology they are unrealistic, based on size and weight, and have a very low energy density [26]. Another new technology that utilizes lasers on the ground that shoot up to power a drone mid-flight is being developed and researched to extend UAS continuous flight time [26]. This technology is also in its early stages, but it offers an alluring way to extend delivery UAS flight range. Finally, hydrogen fuel cells are a viable replacement to batteries soon. They have no pollution, no noise, and have 148 times the energy density of a Li-Po battery [26]. These cells could be prevalent on the UAS of the future, but batteries are the best option in the current climate.

b. Corridor Implementation

i. Introduction

When designing the different aspects of the proposed corridors, the team took many variables into account to maximize both safety and efficiency. The corridors will be designed to travel different routes based on the population density in the area below it. These designs were chosen to promote both efficiency and safety. The team also made significant design adjustments around airports, due to the nature of takeoffs and landings and to promote runway safety. The proposed system optimizes delivery routes for the UAS based on the area they are in. For example, the path of travel in a city is much different than a path of travel in a rural setting. The proposed system also assumes the modification of the VLOS rule by the FAA, as the range of the UAS will initially be up to eight miles away from the distribution center.

ii. Network Structure

The proposed system involves multiple corridors connecting distribution centers to houses within range of the UAS. The corridors will avoid or have modified guidelines around no-fly zones and airports to maximize safety and comply with FAA restrictions. Each corridor will be rectangular, 150 feet tall, a quarter mile wide, and be between 550 and 700 feet above the ground at all points, adjusting with the terrain beneath it. The corridor will utilize geofencing technology to prevent UAS from leaving the designated corridor area. This will enhance the integrity of the network structure. When the UAS leave the distribution station, they will travel straight up until they reach the 550-foot mark, then head in the direction of their destination. From above, the structure looks like a snowflake, with the corridors gradually getting larger as they move away from the distribution center, until they reach their maximum quarter mile width as seen in Figure 7. The UAS will travel to their destination, which is a maximum of eight

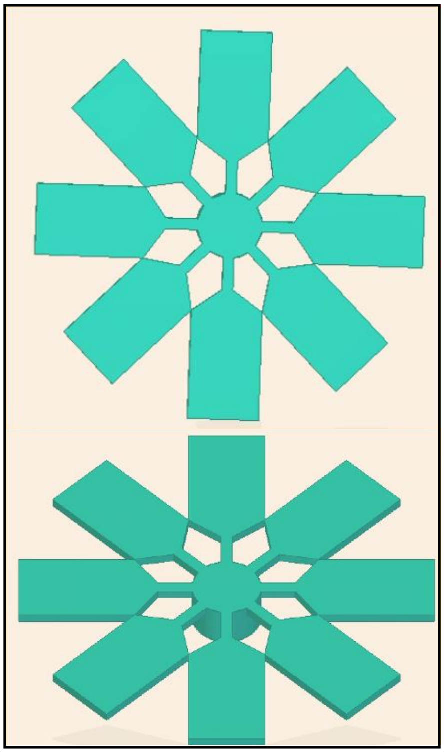


Figure 7 – Computer drafts of top (above) and front-angle (below) views of corridor entrance.

miles away (with present technology), drop off the package, then return to the distribution center to recharge. Above the delivery location, the UAS will descend straight down based on the GPS location of the destination.

The process of entering the corridor, exiting the corridor, and delivering the packages to each individual house is more complicated. For entering and exiting the corridor, UAS will occupy the bottom 50 feet of the corridor. For UAS traveling a further distance, akin to the left lane of a highway, they will be able to cruise at a higher altitude to avoid interference with other UAS that are entering or exiting the corridor. For different places, different network structures are needed to optimize distance and order. This team's current designs are a grid system, where the UAS follows a grid pattern to its destination, a "Lollipop Method," where the main corridor separates into concentric circles of decreasing radius and the UAS travels along the circle that its delivery point is on, and a roadway system, where the UAS travels directly from the main corridor to its destination. These three structures are shown in Figure 8. The roadway system will most likely be used in more rural areas to decrease the distance that the UAS must travel. In an urban area, however, the residences are tightly-packed, and a grid or circle is more manageable. The network structure of the entire system would continue to change and improve over time as certain techniques are shown to be better than others through experimentation and field data.

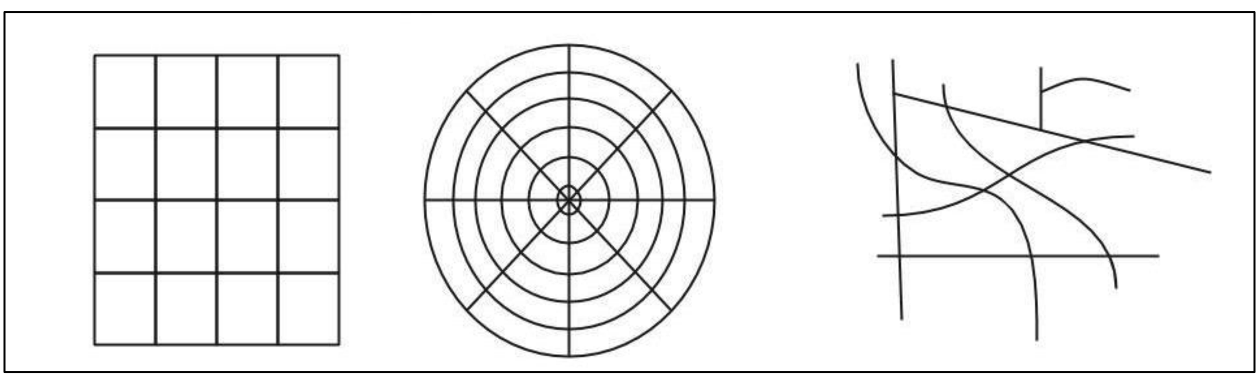


Figure 8 – The grid (left), lollipop (center), and roadway (right) corridor configurations.

iii. Airport Modifications

There are numerous regulations regarding UAS flight within certain proximities of airports. For recreational use, a pilot must contact the airport and control tower before flying within five miles of an airport [21]. However, if, as in the case of this corridor, there was a limited path by an airport for these commercial UAS to use, the main fear of collisions or interference would be minimized while maintaining the system's efficiency. Typical aircraft have a take-off angle of seven degrees, with an additional seven-degree climb as it crosses the end of the runway [28]. Incoming aircraft approach with an angle of ten degrees until they are above the end of the runway, at which point they quickly level out and maneuver into a three-degree touchdown angle [29]. For safety purposes, the UAS should be kept at least 500 feet from all manned aircraft. Based on these calculations, the corridor will have modified specifications of altitude and width. The UAS will be restricted to an altitude of 40 to 70 feet at 0.7 to 0.8 miles (3,696 to 4,224 feet) beyond the end of the runway. This keeps the UAS a safe distance away from aircraft while accounting for both take-off and landing approach angles. Like how a highway may have increased traffic during merging, this section of the corridor may become slightly busier due to its restricted size. The altered spacing would only take place at either end of a runway. When flying parallel to a runway, the corridor can be held at an altitude of 200 to 350 feet at 0.25 to 0.40 miles (1,320 to 2,112 feet) away from the runway. This is lower than its standard height to limit conflict with planes but can still be highly trafficked without a problem. Overall, very little UAS traffic is expected to be near airports given the ability to design the new corridors from scratch. By designating this airspace for commercial UAS, they can be integrated into airport activity with a coordinated system to prevent interference.

c. Example of Implementation

The team has chosen an area near Philadelphia to show a proof of concept. After an order is made, the first step for the UAS is a vertical takeoff from the warehouse to the specified corridor level, as shown in the left portion of Figure 9. This is followed by the UAS choosing one of the eight paths away from the center, based on the direction of the delivery site. The UAS continues its path until it nears the site of its delivery, as shown in the center portion of Figure 9. In this specific example, a suburb of Philadelphia, the UAS will choose to follow the "Lollipop Method" design to the house, as there is no need for a grid system in this suburban area, but more structure is needed than in a rural area. After it is directly above the house, the UAS will then vertically descend onto the delivery site as shown in the right portion of Figure 9. Finally, the UAS will drop the package and take the same route back to the distribution center.

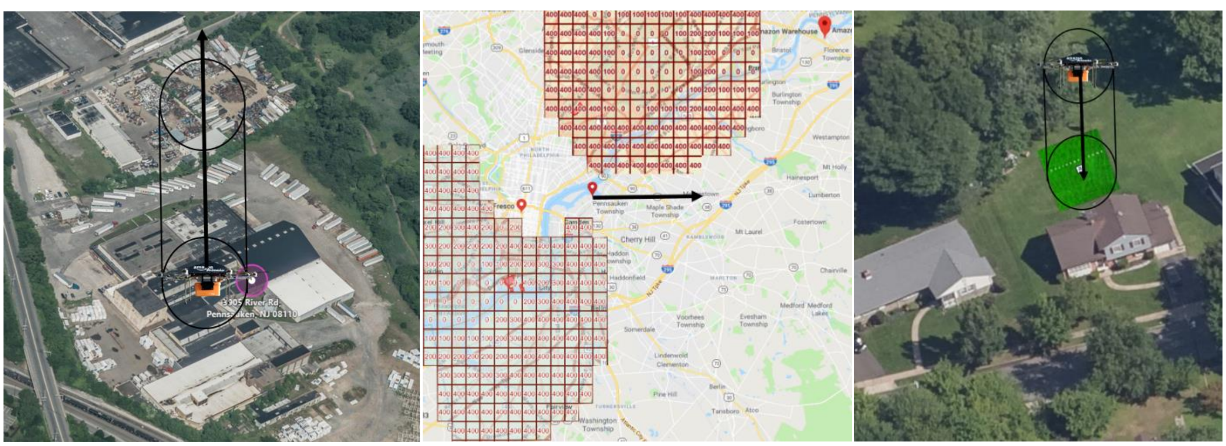


Figure 9 – The takeoff (left), travel (center), and descent (right) of a delivery UAS.

V. Safety and Risk Assessment

Maintaining the safety of airports and aircraft is one of the FAA's main concerns, as outlined in their portfolio of goals [8]. To manage UAS safety, the FAA has presently "prohibited all UAS flights within the airspace defined under UAS NOTAM [Notice to Airmen] FDC7/7282", up to 400 feet above ground level [30].

Security is another crucial component to FAA regulation. In order to maintain national security, the FAA currently prohibits UAS flight in all airspace defined under UAS NOTAM FDC7/7282, classified as “National Defense Airspace” [31]. The proposed corridors will fully bypass all restricted airspaces to maintain, to the utmost stringency, the security of the National Defense Airspace. Therefore, the corridors will also circumnavigate Washington, D.C., as it has been named a “No Drone Zone” due to the security risks UAS pose to the nation’s capital [30].

As highlighted by the FAA, UAS pose a potential risk to aircraft flying around airports, most notably within class B airspace [30]. Therefore, UAS are currently not allowed within five miles of an airport without notifying the airport operator and control tower, or within class B airspace without ATC permission [30]. Class B airspace is defined as the “airspace from the surface to 10,000 feet above Mean Sea Level (MSL) surrounding the nation's busiest airports” [32]. UAS are also not allowed within class C, D, or E airspace without “an airspace authorization or airspace waiver” [33]. The proposed corridors will avoid all airports; however, operators may have to apply for authorization for flight in class E airspace, which occupies a “large amount of the airspace over the United States” [34].

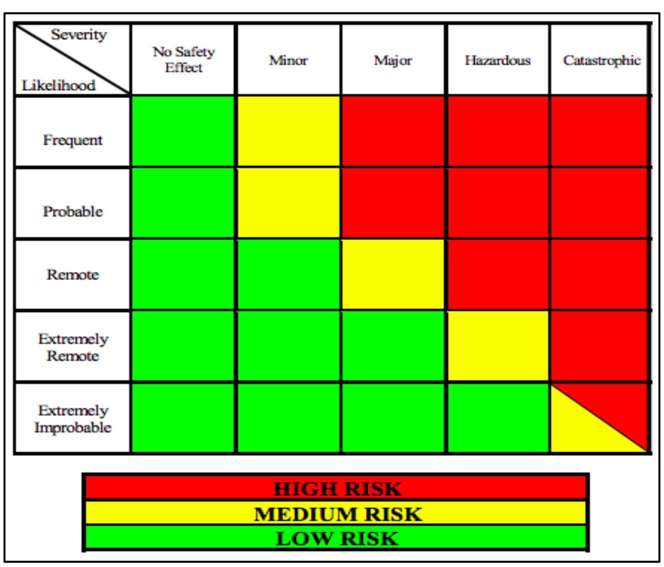


Figure 10 – Predictive risk matrix.

The FAA’s Safety Risk Management policies, as described in Advisory Circular 150/5200-37, includes the analysis of risk on the Predictive Risk Matrix, as seen in Figure 10, which determines the level of risk by event likelihood and severity of its worst possible outcome [16]. The table is color coded as such; green represents low risk, yellow represents medium risk, and red represents high risk. A low risk situation only requires documentation, a medium risk situation requires supervision but is acceptable, and a high-risk situation requires immediate, careful action to ensure the risk is altered to an acceptable level [16].

This proposal focuses on the advancing industry of UAS package delivery and the development of corridors between distribution centers and delivery sites. The FAA estimates that the commercial (non-hobbyist, non-military aircraft owned and operated by private corporations) UAS fleet will grow from about 42,000 at the end of 2016 to about 442,000, with the possibility of as many as 1.6 million, by the end of 2021 [12]. As there is currently no precedent for a national airspace crowded with hundreds of thousands of UAS, there is no defined set of risks. Without the regulation of the proposed corridor system, however, the risk of UAS versus aircraft and UAS versus UAS collisions would almost certainly be high. The FAA categorizes a collision between UAS and aircraft as “catastrophic,” and therefore “high risk” if it occurs at least once every 30 years [18]. While the proposed design does contain inevitable hazards, controlled and labeled flight paths are a requisite for minimizing the risks associated with the growing number of commercial UAS in the skies.

The most significant risk involved with commercial UAS flight is that UAS may enter restricted airspace or the flight path of an aircraft. A study performed by ASSURE illustrates that, while a UAS-airplane collision could have minor consequences in some cases, it could also cause severe damage depending on which part of the airplane is hit. The study shows that while UAS can have the same masses and move at the same speeds as some birds, they are more rigid; hence, collisions involving UAS are more severe than those involving birds [17].

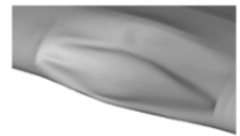
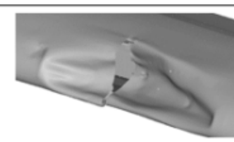
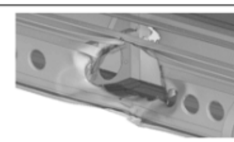
Severity Level	Description	Example
Level 1	• Undamaged. • Small deformation.	
Level 2	• Extensive permanent deformation on external surfaces. • Some internal structure deformed. • No failure of skin.	
Level 3	• Skin fracture. • Penetration of at least one component.	
Level 4	• Penetration of UAS into airframe. • Failure of primary structure.	

Figure 11 – ASSURE's security risk levels.

ASSURE uses their own risk matrix to determine the severity of collisions between a UAS and aircraft, ranging from Security Level One to Four, as depicted in Figure 11. ASSURE also calculates the potential for a fire risk, if the UAS's battery was deformed yet not destroyed, generating enough heat to start a fire. Assuming the UAS to be a quadcopter, ASSURE calculates the risk matrix for a collision between UAS and both business and commercial transport jets, as outlined in Figures 12 and 13. The charts highlight the risk associated with collisions with multiple parts of the aircraft. The security risk of collisions ranges from level two to four, with the possibility of a fire, depending on where the aircraft is hit [17].

	Business Jet										
	Vertical Stabilizer			Horizontal Stabilizer			Wing			Windshield	
Case	BQV1	BQV2	BQV3	BQH1	BQH2	BQH3	BQW1	BQW2	BQW3	BQC1	BQC2
Severity	Level 3	Level 3	Level 2	Level 3	Level 4	Level 4	Level 3	Level 2	Level 2	Level 2	Level 2
Fire Risk	Yes	No	No	Yes	No	Yes	Yes	No	No	No	No

Figure 12 – Severities of collisions between a quadcopter UAS and a business jet.

	Commercial Transport Jet															
	Vertical Stabilizer				Horizontal Stabilizer					Wing				Windshield		
Case	CQV1	CQV2	CQV3	CQV4	CQH1	CQH2	CQH3	CQH4	CQH5	CQW1	CQW2	CQW3	CQW4	CQC1	CQC2	CQC3
Severity	Level 3	Level 3	Level 3	Level 3	Level 3	Level 3	Level 4	Level 4	Level 4	Level 3	Level 3	Level 3	Level 2	Level 2	Level 2	Level 2
Fire Risk	No	No	No	No	Yes	Yes	Yes	No	No	No	No	No	No	No	No	No

Figure 13 – Severities of collisions between a quadcopter UAS and a commercial transport jet.

With the proposed corridors, the UAS will bypass airports and will travel at 550-700 feet (assuming this height will be allowed by the FAA), lower than aircraft flight. This will reduce the likelihood that a UAS would collide with an aircraft, reducing the risks from "high risk." There is an "extremely remote" possibility that a UAS will mistakenly leave the corridor, or an aircraft would enter it. However, because of UAS sense-and-avoid technology, which uses sensors to detect objects in the line of flight and allows the UAS to proactively maneuver away, the UAS should be able to maneuver around the aircraft [22]. The design will also implement geofencing technology, which allows the pilot to set boundaries for the UAS's flight [35]. If the UAS hits the boundary, it will stop and instruct the pilot to maneuver away or will maneuver away automatically [35]. In addition, using Global Positioning System (GPS) technology will allow for operators to track UAS and ensure that the latter remains on course. These technologies will ensure that the UAS does not leave the corridor, thereby reducing the risk of collision with other aircrafts. There is a chance that despite the use of sense-and-avoid and geofencing technologies, there will be a UAS-aircraft collision, however as this is "extremely improbable" (rarer than every 30 years), the risk is maintained at the "medium risk" level [18]. Ideally, changes in FAA regulations can lower the severity of certain UAS-aircraft collisions from "catastrophic" to "hazardous," thereby reducing the risk to "low risk;" currently, regardless of outcome, any UAS-aircraft collision is categorized as "catastrophic" [18].

Another potential risk is the possibility of collision between two or more UAS traveling through the corridor simultaneously. The event would likely result in destruction of the drones and their packages, and the possibility of falling debris would be potentially "catastrophic" if above a densely populated area [18]. However, the corridors will be situated above less populated areas unless necessary, so the likelihood of the UAS-to-UAS collision causing debris to fall onto individuals on the ground is reduced. Furthermore, as mentioned above, the proposed design requires utilization of UAS sense-and-avoid technology, which will aid in early detection and maneuvers around the other UAS. Therefore, the likelihood of such an event would be reduced from "remote" to "extremely improbable" and the risk would therefore be mitigated to "medium risk." In addition, UAS will not operate in severe weather conditions to reduce the likelihood of collisions caused by impaired vision. As mentioned earlier, it is anticipated that the severity of certain UAS collisions could be formally lowered to “hazardous”, thereby reducing the risk to “low risk.”

The risk assessment has been conservatively calculated and as technology advances, the risk can only be lowered; hence, the UAS corridor design is feasible and reliable.

VI. Interaction with Airport Operators

David Hickling, airport operator and industry expert, made a visit to Binghamton University to discuss the project design. Hickling joined the class on March 22, 2018 to discuss the Greater Binghamton Airport’s outlook on UAS management and risk assessment. Hickling is the Commissioner of Aviation at the Greater Binghamton Airport in Johnson City, New York. An avid UAS enthusiast, Hickling is the owner of a recreational UAS and is the former chairman of the UAS committee of the New York Aviation Management Association, which looks out for the interests of aviation in New York State. He provided feedback on the group’s proposal and answered questions from the students.

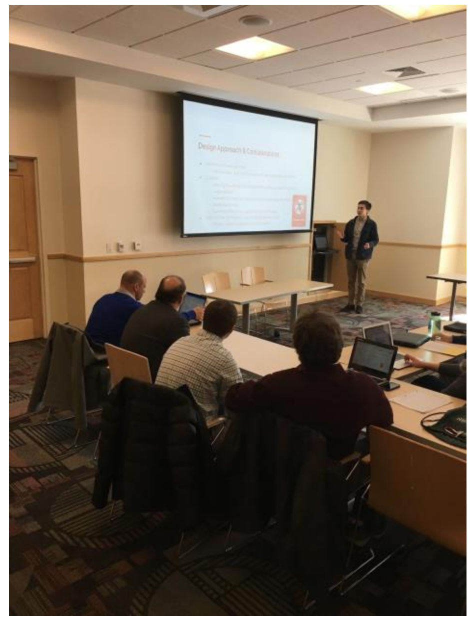


Figure 14 – Daniel Kaufman presents during David Hickling’s visit.

By the end of the student-led presentation of the project, as seen in Figures 14 and 15, Hickling was very encouraging of the design, while also noting the risk considerations. He believed the project was feasible, saying that private companies and government organizations would almost certainly invest in this type of technology. Regarding the risk analysis, Hickling thought that the team did not overlook any potential hazards; he praised the redundancy in assessing the various risks. According to Hickling, the small UAS rule, Part 107, was rushed to achieve its current legal status. Hickling admitted that justifying the risk analysis may be the greatest challenge due to the current constraints surrounding UAS interaction with the NAS. However, the Part 107 rule as well as other safety regulations regarding UAS are open to change and can be modified to suit the increasing use of commercial UAS activity.

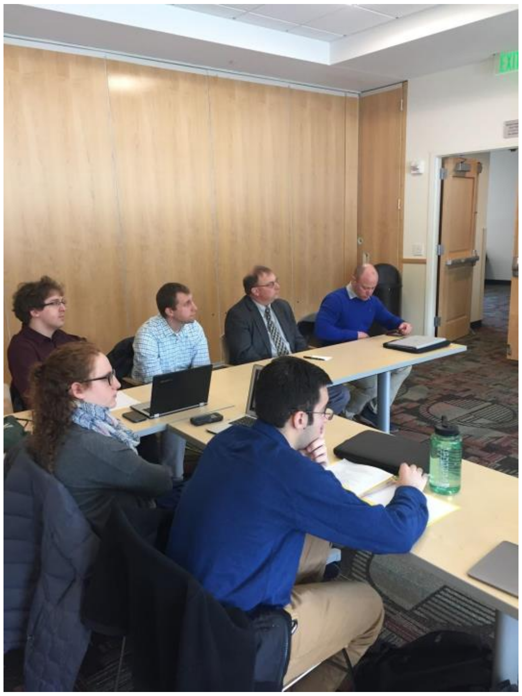


Figure 15 – David Hickling (back; second from right) watches a student presentation attentively.

Hickling provided some significant and insightful critiques for the project design. He recommended looking at VFR corridors as a comparative model for the UAS corridors, as VFR corridors exist in high-density areas and allow for flight without ATC contact. He noted that the corridors should have a mechanism to separate commercial from hobbyist UAS. To ensure that UAS will not exit the corridors — accidentally or intentionally — Hickling suggested incorporating geofencing technology into the corridor system. Regarding minimizing risk of airport interference, he proposed increasing the distance between corridors and the airspace immediately surrounding runways to ensure a safe separation.

In addition to meeting with David Hickling, one team member — Solomon Barer — conversed with Michael Fox of Sikorsky Aircraft. Fox provided information regarding his job designing airframe structures. Additionally, Fox spoke to two of his teams at Sikorsky about their thoughts on the corridor and redundancy systems for safety purposes, receiving positive feedback.

The class unsuccessfully attempted to contact Amazon's public relations department as well as the Northeast UAS Airspace Integration Research (NUAIR) Alliance.

VII. Projected Impacts

a. Introduction

The team has made it a priority to acknowledge, and meet, goals set by the FAA in their Portfolio of Goals and Strategic Plan. This proposal is also closely related to the commercial goals set by companies such as Amazon, Domino's, Wal-Mart, etc. The commercial potential for such companies is greatly enhanced by this proposal. The proposed system's process for implementation is both simple and clear, adding to its ability to become reality. Affordability and utility of the system have both been a priority the development of the proposal. Along with the affordability of the final system, the total cost of the implementation of the process must also be considered.

b. Meeting FAA Goals

The implementation of this proposal will satisfy many of the FAA's goals and values. The FAA's mission is the safety and efficiency of America's airspace [36]. This proposal is a solution to a problem on the horizon. Soon, UAS delivery will be a major component of commercial operations. The proposed air corridor organizes and controls the flight of countless UAS in the sky. The chaos without such a system could be catastrophic. Roadways do not have the most efficient layout. This is because civilization has been built within it, and it has developed around what is constantly being upgraded. The most efficient road may not be able to be built because there is already a building and another road there. With this proposal of a highway in the sky, the most efficient pathways can be determined without the conflict of pre-existing infrastructure. This is the case not only because it occurs in the sky, but also because it is done from scratch. A super-efficient city could be developed if it was completely designed before it was inhabited. A perfect grid system with all points equally accessible. With each of these aspects compiled, the team's vision for the air corridor is complete. The FAA also states it is "accountable to the American public" [36]. In the current environment, this includes accommodating commercial UAS delivery. The FAA also prides itself on its innovation [36]. The future is filled with UAS soaring the skies, in a safe and orderly fashion.

c. Commercial Potential

The air corridor proposal holds an extreme amount of commercial potential. In fact, this specific proposal is intended for commercial use only. As the commercial potential for UAS becomes more clear, public calls for a system with a 30-minute delivery time are to be expected. While numerous companies will utilize this corridor, Amazon and its "Prime Air" program will act as an example to serve as a baseline. Presently, about 86% of Amazon's packages are within the five-pound UAS weight limit [37]. With the use of UAS delivery, Amazon does promise a 30-minute delivery time [9]. This possibility is extremely appealing to consumers. It was estimated that Amazon spends about $6 on each package delivery with mainstream delivery methods but could potentially spend less than $1 each using UAS delivery [15]. The benefits of this strategy are clear and of great magnitude.

As this proposal is ratified, more and more companies will take advantage of the benefits it will bring. Furthermore, additional fulfillment centers will be built to reach an even greater population. However, there is already an extensive number of people within the eligible range. Each fulfillment center has a radius about it encompassing the people it can reach. As fulfillment centers become more densely packed as more facilities are constructed, their areas of influence may meet; this creates a massive field of operation with few gaps within the field. As shown in

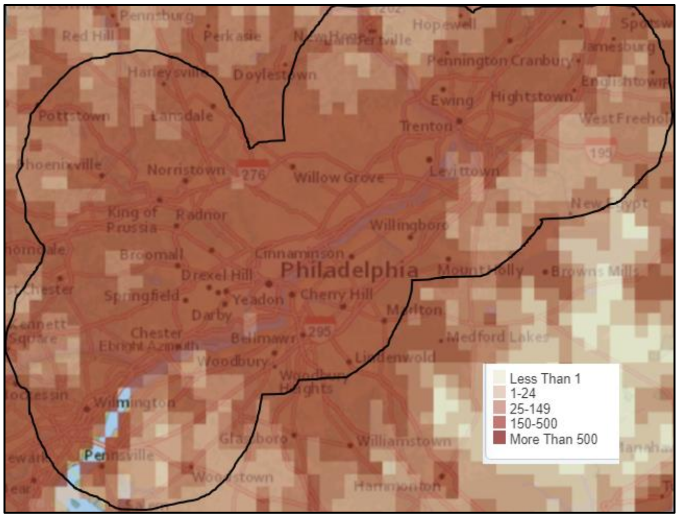


Figure 16 – Population density map with overlaid fulfillment center ranges in the Philadelphia area.

Figure 16, the scope of presently active fulfillment centers is mapped over suburban Philadelphia. Also shown is the population density of said region. In this small, specific district, the potential benefits are enormous. As this endeavor expands, it would positively impact both the consumers and commercial companies in grand respects.

d. Process of Implementation

For the proposed system to work and improve the safety of delivery via UAS, there must be concessions made by the FAA in their regulation guides for the flight of UAS. The FAA must modify their current regulations for UAS flight altitude and the "line of sight" rule, allowing commercial UAS to fly higher than 400 feet and out of the line of sight of the operator. Assuming the regulations are changed, implementation of the system could continue through the purchase of delivery UAS by companies interested in using the delivery corridors. These UAS would be regulated by the FAA and be able to communicate with other UAS in the same corridor. This assists the sense-and-avoid technology in keeping the UAS from crashing into one another and adds another layer of safety to the proposal. A transfer of information between companies, the FAA, and customers would need to occur to inform all parties of the new technology. This would entail the formation of a new database. Finally, the companies could start delivering by drone based on the main corridors and the pathways specific to each city.

The implementation process around airports is even more simple and involves little to no work by airport operators, merely an awareness of the corridors around them. The planned corridors will be set up in such a way that they are far enough from the end of the runway for an aircraft to take off and land normally, clearing the corridor by the required 500 feet. The only responsibilities of aircraft or tower operators are to be familiar with the idea of the corridor and alert the FAA in the case of an emergency. In the system, aircraft will have the technology to know the GPS coordinates of the corridor and the location of each UAS. This would be very similar to a VFR corridor. Aircraft would have an essential no-fly area in a section of airspace. With a system such as this already in place, the commercial corridor can be implemented using similar strategies. The alterations around airports negate the possibility of a delivery UAS crash with other aircraft, optimizing the safety of the corridors.

e. Affordability and Utility

This endeavor is most definitely feasible. There is no construction involved; only written material such as the official regulations and programming aspects such as the piloting and navigation systems must be newly-developed. While there are many companies that may elect to use UAS for deliveries, for a company worth over $700 billion, Amazon will have no problem procuring the UAS fleet to carry out this endeavor [38]. For a project with profits this promising, Amazon will undoubtedly invest heavily in making their commitment. As previously mentioned, the only creation that must take place is the purchasing and commissioning of UAS, the passing of regulations, and the system of UAS flight paths. As fulfillment centers continue to pop up across the nation, more and more people will be eligible for Prime Air and similar programs.

f. Cost Analysis

Although the primary goals of the proposed corridor system are to improve safety and decrease the unpredictability of UAS delivery, UAS delivery is also very cost effective, as seen in Figure 17. The corridor system itself will cost nothing to implement, as it is more of a rule than a tangible object. Overall, airports will have no costs associated with the implementation of a UAS delivery system of any kind, so it is more reasonable to understand the cost effectiveness through the eyes of each company. With an initial fixed cost per UAS of approximately $500, with the potential of lowered costs due to new technological developments, corporations could purchase thousands of UAS to deliver their packages. For a normal package in a delivery truck, the cost of delivery is $6, with a $2 last-mile delivery cost alone. For delivery by UAS, however, the estimated cost per delivery is $0.05, a significant decrease when compared to the cost of typical truck delivery [37]. After a multitude of shipments, delivery by UAS will become more cost efficient than delivery by truck, as the savings will quickly pay for the cost of the UAS.

	UAS Delivery	**Truck Delivery**
Fixed Cost (per unit)	$500	$30,000
Number of Units	1,000	5
Total Fixed Cost	$500,000	$150,000
Cost per Delivery	$0.05	$6.00
Average Total Cost (100,000 deliveries)	$505,000	$750,000

Figure 17 – A table showing the unit and total cost for each type of delivery system, indicating that UAS delivery is immensely cost-effective.

VIII. Summary and Conclusion

The FAA and other organizations have discussed plans for new policies and regulations regarding UAS that will help integrate them into the NAS. Since UAS are becoming more popular with the advances of technology, private users and companies are finding more ways that they can be beneficial. Therefore, there is a need for a new plan to be developed that will finally integrate UAS into the NAS. After researching the topic, what was found is that there has been little to no major progress. If there were to be designated airspaces and UAS highways, integration would be more feasible allowing for the significant increase in UAS traffic. It is a necessity for a completed plan to be developed and enacted that will safely and efficiently integrate UAS to fulfill the FAA's goals.

With the different types of airspace, the places a UAS can be flown are very restricted. For example, in the airspace surrounding airports, UAS are strictly forbidden. If they fly too close, aircraft are put at risk of hitting a UAS, thus putting the lives of people in danger. Therefore, before the operator flies their UAS, the operator must always research the altitude limits and then abide to the many regulations set up by the FAA. One of these regulations is that the UAS must remain in sight of the operator during the entire duration of operation. If UAS are used for commercial use, this poses a tremendous problem. To try and solve this problem, different ideas were proposed by the team for the integration. Some of these involved basing the UAS at different types of locations, the height at which the UAS would fly, and the path they would take to get to the consumer. After much debate and research, the students at Binghamton University – State University of New York have developed a system of corridors for commercial UAS use in the NAS. The team has researched the many regulations and safety concerns regarding UAS and have developed a system to set up corridors from the distribution center where the UAS will be operated. From the center, the corridors will expand over the surrounding area to allow for the UAS to reach consumer homes and locations. These corridors dedicate certain airspace that is between 550 and 700 feet in altitude for the UAS so that they are significantly less likely to collide with other aerial objects. If implemented, the corridors will enable commercial companies to deliver and ship items to consumers in a significantly faster more cost-effective manner compared the current method of delivering those items.

Appendix B. Description of Binghamton University

Figure 18 – The Harpur Quad at Binghamton University.

Binghamton University, pictured in Figure 1, was founded in 1946 [39]. Binghamton is a public university part of the State University of New York (SUNY) higher education system, consisting of six individual colleges: Harpur College of Arts and Sciences, College of Community and Public Affairs, School of Management, Decker School of Nursing, Thomas J. Watson School of Engineering and Applied Science, and the School of Pharmacy and Pharmaceutical Sciences [40]. The university has a 40% acceptance rate and 91.7% freshman retention rate [41]. Binghamton University was originally founded to educate local veterans returning from World War II as a branch of Syracuse University [42] and has grown to fill a 930-acre campus with over 130 academic programs [43]. Named Harpur College, it was officially designated the State University of New York at Binghamton in 1965 and renamed Binghamton University in 1992 [42]. Today, the student body consists of 13,694 undergraduates and 3,615 graduate students, 15.9% of which are international students coming from 117 different countries [42]. Modeled after Oxford University, there are six distinct residential communities, each which its own collegiate professor and student government [43]. The university is also home to 21 Division I athletic teams [43].

Forbes ranks Binghamton University #31 among public colleges, #65 in research universities, and #61 in universities of the Northeast [43]. *Money* places Binghamton University at #33 in “Best Colleges for Your Money 2017” [44].

Appendix C. Description of Non-University Partners

a. Greater Binghamton Airport (David Hickling)

David Hickling is the Commissioner of Aviation at the Greater Binghamton Airport in Johnson City, New York. Hickling earned a Bachelor of Science in Aviation Management from Hawthorne College while serving in the United States Air Force. He then worked as a flight instructor and charter pilot and transitioned to a career in airport management in 1996. In 2006, Hickling was appointed Deputy Commissioner of Aviation at the Greater Binghamton Airport and to the position of Commissioner of Aviation in 2015 [45]. Additionally, he is the former chairman of the UAS committee of the New York Aviation Management Association, which looks out for the interests of aviation in New York State.

Hickling visited Binghamton University on March 22, 2018 to discuss the Greater Binghamton Airport's outlook on UAS management and risk assessment. An avid UAS enthusiast, Hickling provided feedback on the group's proposal and answered questions from the students. Among other insights, he suggested incorporating geofencing technology into the proposed corridor design and comparing the UAS corridor system to VFR corridors.

Appendix E. Evaluation of the Educational Experience

a. Student Response

1. Did the ACRP Design Competition provide a meaningful learning experience for you? Why or why not?

The ACRP Design Competition provided a meaningful learning experience. We learned about airports and airspace in addition to the growing industry and regulatory environment surrounding unmanned aircraft systems. The Competition exposed students to literature research, technical writing and editing, group collaboration, and deadlines. Some of the students had never completed extensive research prior to this project, and so those students became familiar with the processes of finding reliable sources and relevant information. Working on a project with a group divided into smaller teams has prepared us for professional opportunities that will require teamwork, communication, and efficiency. Moreover, the Competition has evoked a genuine appreciation for complex engineered designs and systems.

2. What challenges did you and/or your team encounter in undertaking the Competition? How did you overcome them?

We faced a number of challenges; for example, the lack of prior knowledge about aviation made preliminary research much more difficult. The team had to become familiar with all of the terms used in the researched documents before it could examine the significance of what was written. Towards the beginning of the competition, the goal of our project was a bit unclear, which made research difficult in that there was an overload of information available on the internet. As the course progressed, the team refined its ideas and found the right sources. The Design Team also faced challenges in outlining the specific details of the corridors; the Engineering and Graphics Team had to learn how to use the software needed to make the necessary images. Low enrollment in the class initially created concerns regarding the team's ability to complete the proposal. The Risk Assessment and Strategies and Approach teams were combined, its members making a small adjustment to do the work of two teams.

3. Describe the process you or your team used for developing your hypothesis.

A joint phone call between the course professors and the student leader took place prior to the start of the semester to discuss potential topics of interest. Once the semester began, all students met together to discuss and brainstorm potential ideas. We narrowed the ideas down to three main topics: boarding bridge automation, fleet emissions analysis, and UAS corridors. After researching the topics in depth, we realized that boarding bridge automation had already been patented and implemented. Then, between fleet emission analysis and UAS corridors, the latter garnered more interest. Once the topic was chosen, each team wrote a summary of literature review, after which we discussed all previous research and literature to arrive at our hypothesis.

4. Was participation by industry in the project appropriate, meaningful and useful? Why or why not?

Participation by industry contacts in the project has been meaningful, critical, and validating. The two course professors, Chad Nixon and Zachary Staff, have been consistently helpful throughout the project. They provided knowledge that the students lacked and gave feedback on specific questions each class day. David Hickling, Commissioner of Aviation at the Greater Binghamton Airport, visited the class and listened to the group's presentation of the proposal. He gave us a professional perspective and talked about what the design could incorporate to improve safety and feasibility. The internet simply cannot provide every answer or explanation. An aviation professional such as David Hickling provides an important face-to-face meeting that benefits the entire project team.

5. What did you learn? Did this project help you with skills and knowledge you need to be successful for entry in the workforce or to pursue further study? Why or why not?

We learned to work better as a team by ensuring that communication was clear and frequent between team members. Regardless of one person's contributions, a team can only successfully complete a task if each member is held accountable. Teamwork, time management, and writing are all aspects of this project that will prove indispensable in future academic and career settings. Each one of us will at some point be a part of another group, be responsible for meeting deadlines, and be judged by our writing abilities. We learned a significant amount about airports, airspace, and drone regulations in the United States; regardless of career plans, this technical knowledge will only benefit us in the future. As some of the team members are engineering students, this project has given them an opportunity that most other engineering students will not experience, especially at an undergraduate level.

b. Faculty Response

1. Describe the value of the educational experience for your student(s) participating in this Competition submission.

The ACRP University Design Competition provides a valuable opportunity for students to learn about and formulate solutions to real problems in the aviation industry. The type of experiential learning that the Competition offers is valuable for students as they prepare for graduate school or the workplace. Such an opportunity is not typically included in the curriculum for freshman and sophomore students, and the Competition provides this early in their college careers. Through the Competition, our students have started with minimal knowledge of aviation and learned to identify, research, and develop a concept to solve a specific problem. In addition, our students had to consider risks that may occur as a result of the implementation. Through their work, the students have researched and designed a project that could have significant impacts on how customers receive food, packages, and other items.

2. Was the learning experience appropriate to the course level or context in which the competition was undertaken?

Yes. All of the students on the team are undergraduates; five are in the second semester of their freshman year, two in the second semester of their sophomore year, and one in the final semester of his senior year. Most of these students have had limited opportunities to work in a team setting, as many introductory classes available to freshmen and sophomores have much higher enrollment and fewer interactions with other students. The ACRP University Design Competition brings a small group of students with varying academic interests together to work as a team. The effort required constant communication and cooperation to ensure that submitted documents meet the course requirements. As the course is offered in the spring semester, our students had to ensure that they were always able to meet set timelines. These timelines required the teams to work cooperatively and adequately manage their time to meet specific deadlines. All of these elements are vital to the learning experience that will be useful for these students as they continue their education and move to professional fields.

3. What challenges did the students face and overcome?

There were several challenges for our students to overcome as they completed the proposal. All eight students had limited to no knowledge of the aviation industry, which required additional time for them to learn about the key topics that relate to our proposal. We worked with our students early in the semester to ensure that they understood basic information concerning airports and airspace; also, students were required to complete further research to confirm that they were competent in the areas necessary for their proposal. In addition, the type of research completed in this course is not typical for students at the beginning of their college careers—particularly for the seven freshman and sophomores—and included concepts and requirements that may not have been covered in many of their previous experiences. The ACRP University Design Competition maintains a strict deadline that requires the project leader to ensure that the submission schedule was followed. The project leader frequently checked in with each team to see what progress was made and set up portals for team members to share work efficiently. In addition to meeting deadlines, the students had to work within the University Calendar, including two breaks prior to the submission date and the typical winter weather of Upstate New York that led to the cancellation of classes, which included the day in which a visit from an airport representative was planned. The students worked effectively under these limitations and ensured that submissions were made in a timely manner to meet the Competition's required schedule.

4. Would you use the Competition as an educational vehicle in the future? Why or why not?

Yes. The format and structure of the Competition is ideal for this course at Binghamton University and has been utilized for many years. This project allows students to not only work on a challenging academic exercise, but to work on one with real world applications that could potentially impact the way consumers receive products. This experience will be valuable as they continue through their academic career and move into the workforce.

5. Are there changes to the Competition that you would suggest for future years?

The ACRP and FAA have ensured over multiple years that that the suggested research topics remained relevant, and we recommend that the practice should continue. Each year we observe changes in the aviation industry as new topics become prominent. It is important that the Competition continues to include new, relevant, and interesting topics each year to prevent overlap of research submissions and to allow students to continue contributing to the development of solutions to modern day problems.

Appendix F. Reference List in Full

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