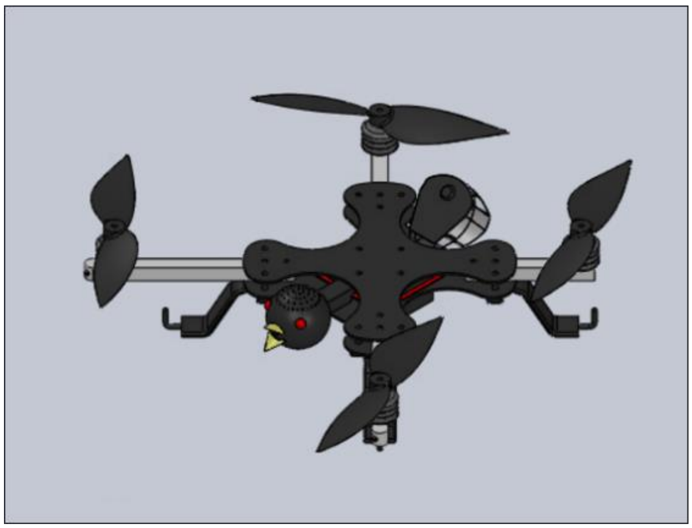
PennState College of Engineering

2019-2020 Airport Cooperative Research Program Design Competition
Airport Operation and Maintenance: Challenge C: Innovative approaches to address wildlife issues at airports including bird strikes.



Drone Repellent of Invasive Birds (D.R.I.B.)

Pennsylvania State University
Engineering Leadership Development Program

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1. Executive Summary

In addressing airport operation and maintenance challenges put forth by the ACRP competition, a mitigation solution to address bird strikes at airports was developed. Our team conducted extensive research as we learned about the scope of the problem and the current shortcomings of present solutions. The FAA estimates that the average financial loss due to bird strikes could be as high as $500 million annually, and with increasing air traffic, that number is steadily increasing every year[1]. As such, there is a great need for a more effective method to address airplane and bird interactions. The challenging part of the problem is that birds are adaptive creatures, and so current techniques only serve to deter them for a short period of time before they adjust and no longer become phased by deterrents.

In response to this knowledge, our team sought an innovative, humane, and effective solution, the D.R.I.B.: The Drone Repellent of Invasive Birds, a piloted drone that complies with FAA regulations and is outfitted with extensive methods of deterrents to prevent bird habituation. The drone will include UV lights at varying flashing frequencies, a speaker system with a variety of noises and tones, an odor emission system, as well as a replicated attachable prey to make the drone appear predatory. The drone will be easily deployed to scare away flocks surrounding airports and clear runways for safe use. With a complete monitoring system to pilot the drone and a charging base, the D.R.I.B is an expansive and effective solution that will not require extensive work to implement.

The cost and risks associated with the solution have been broken down and analyzed. By eliminating the need for currently used deterrents and mitigating a percentage of the $500 million annual financial loss estimate, the D.R.I.B. will be profitable in less than a year and prevent significant damage and danger to future flights.

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3. Problem Statement

According to the FAA, there were over 14,000 bird strikes at airports located in the USA in 2017 alone[1]. Bird strikes can delay flights, and in some occasions the aircraft will get damaged due to collision. This brings us to our problem statement which is that there are well over 10,000 bird strikes happening each year, and there is not an effective way to mitigate these bird strikes in a humane and long-lasting way. Therefore, we decided to tackle design challenge 1C: "Innovative approaches to address wildlife issues at airports including bird strikes" as provided by the Airport Cooperative Research Program (ACRP).

The current problems with this challenge are:

- No effective technology to prevent birds from interacting with airports
- Current techniques rely primarily on lethal resorts, inhumane approach
- Birds adapt very quickly so known methods will not work repeatedly

4. Research

Our initial research was aimed towards deciding if we wanted to study all types of wildlife, or if we wanted to narrow our scope to only birds. We found that 97% of all wildlife encounters at airports involve birds, so we decided to pursue a mitigation technique for bird strikes[2]. To determine how to decrease bird presence in airports and surrounding areas, we first conducted online research to learn about current mitigation techniques and various stimuli that are known to reliably deter birds. We divided our research into several key focus areas, the largest four being the impact of bird strikes, birds and their habits, current technology, and emerging technology. After conducting online research, we sought to learn more from experts and we contacted a number of stakeholders who provided their expertise.

4.1 Impact of Bird Strikes

Between 1990 and 2017, the FAA estimates there were approximately 194,000 bird strikes with civil aircraft in the United States alone, and at least 4,000 additional strikes on U.S. aircraft carriers outside of the United States[2]. These strikes have resulted in nearly 300 human fatalities since 1988, and over 250 civil aircraft have been permanently removed from service (or destroyed) due to bird strike damage. As aforementioned, the FAA estimates that the average financial loss due to bird strikes could be as high as $500 million annually, and with increased air traffic, that number is steadily increasing every year. The total number of reported strikes is also increasing every year, and in both 2017 and 2018, nearly 15,000 bird strikes were reported[1]. Most bird strikes occur very close to the ground during takeoff or landing, with over 70% occurring below 500 feet and over 90% occurring below 3,500 feet, comprising less than a 5-mile radius around the airport[3].

4.2 Birds and Their Habits

After understanding the safety implications and economic impacts of bird strikes, we turned our attention to the birds themselves and sought to learn about the nature of most strikes, the types of birds involved, and factors that influence the likelihood of a strike. 60-70% of bird strikes occur during the day, with peak times at dusk and dawn when large flocks tend to migrate. Two peak seasons are spring and autumn due to migration patterns, but late summer (July-August, or the end of the local nesting season) also emerges as a particularly dangerous time of year due to baby birds leaving their nests for the first time. These birds don’t yet understand the danger of planes, so they tend to take fewer measures to avoid planes when they see them, increasing the likelihood of a strike[4]. The most common species involved vary from region to region, but generally, gulls and doves are the most prevalent culprits, alongside waterfowl, pigeons, hawks, and many other species which are also common[5,6]. Shifting focus to bird deterrents, we found that the average bird's hearing range is between 1 - 4 kHz and that numerous tones within that range and various predatory calls could be effective auditory deterrents[7]. Furthermore, birds have four visual cone classes (compared to humans' three) enabling them to see color down into the ultraviolet range to detect small prey from afar[8]. Utilizing ultraviolet light to scare birds away is a largely unexplored frontier of research, but the idea is very intriguing. Finally, one last deterrent area worth exploring is an odor deterrent, as many birds have well-developed senses of smell and certain odors like peppermint oil are offensive to birds and provide reliable means of diverting birds from a specific area[9,10]. Confident that we understood how to scare birds away, our team moved into the next phase of research.

4.3 Current Technology

As previously discussed, the three primary areas of bird deterrents we explored were visual, auditory, and olfactory. These areas, along with physical deterrents, fall under the umbrella term 'direct management,' which involves airports dealing with birds directly as they enter airport grounds. Direct management techniques include firecrackers, lasers, propane cannons, flares, and the use of trained dogs or birds of prey[4]. The vast majority of airports have a multitude of these direct mitigation techniques at their disposal, due to birds' rapid adaptation and habituation to repeated stimuli[11]. There is another type of mitigation, known as passive management (or habitat management), focused on preventing birds from entering the airspace surrounding an airport in the first place and "reducing the carrying capacity" of the airport environment[4]. Passive management typically involves the removal of attractive landing sites, such as standing water (ponds), municipal waste disposal sites, potential nesting sites, and flat, open surfaces. Passive management is the more cost-effective option over many years or decades, as it has the potential to eliminate the problem altogether in the long run, but it's extremely difficult or impossible to employ optimally at most airports. As such, most airports utilize an integrated wildlife management approach, implementing methods of passive management where possible but primarily using a wide variety of direct techniques[12]. Rapid habituation is the largest problem currently facing airports, so the need for our solution to employ a variety of mitigation stimuli became increasingly apparent as we furthered our research.

4.4 Emerging Technology

Finally, our team began to look forward into currently emerging technology that offers potential solutions to the growing problem of bird strikes. As technology has evolved over the past decade, the FAA has grown more lenient regarding airports' internal use of drones for surveillance and inspection purposes[13]. Experts agree that drones could be the next frontier of bird strike mitigation, as a drone's ability to mimic predators is unparalleled by current technology. The primary drawbacks of airport-operated drones are safety implications, and the FAA offers strict regulations on unmanned aircraft in Part 107 of their regulations. For example, the FAA mandates that drones must be operated by a pilot at all times and the pilot must continually maintain a visual line of sight, though the use of an extra observer in constant communication is also permitted[14]. One other emerging solution is an advanced pyrotechnic launcher, enabling operators to manage large flocks from afar with one device/technique[15]. Shotguns are currently in use at numerous airports, but the safety implications and risks involved with live ammunition on the tarmac call for a safer, more comprehensive pyrotechnic solution in the future.

4.5 Stakeholder Research

After concluding our extensive research into the problem and the current mitigation techniques, we moved into discussing the problem with stakeholders and experts in industry. We needed a direct viewpoint about the problem, which our stakeholders were happy to provide. At first, we decided to contact some stakeholders from the ACRP contact list which was provided to us in correlation with the project. We corresponded with Barry Bratton[16], an airport and runway safety consultant as well as security and operations contact, both via email and video calls. After speaking with Mr. Bratton, we realized it would be game-changing for airports to have a consistently effective solution that birds could not adapt to over time. This statement shaped the progression of our design as Mr. Bratton and other stakeholders conveyed how truly adaptable birds are and emphasized the need for variability in a potential solution. We also spoke to Chris Babb[17], an environmental issues and compliance managing consultant who provided similar insights, as well as information regarding the diversity of airports and the variety of methods that are currently used.

After speaking with Mr. Bratton and Mr. Babb, we felt needed more firsthand knowledge on birds and so we decided to interview Dr. Margaret Brittingham, an avian professor at Penn State University, who specializes in wildlife management on private lands[18]. She provided great insight on bird behavior and how to approach bird strikes humanely. After speaking to Dr. Brittingham, another crucial stakeholder we reached out to was Samantha DiLorenzo[19], the head of the University Park Airport wildlife management team. We were excited to learn about her position and what her job entails so that we could better understand who would be using our solution, as well as what she would be looking for in future mitigation methods. Discussing the ins and outs of Ms. DiLorenzo's job was extremely helpful for our team to better understand the reality of the issue and how our solution would be used.

Finally, for both engineering and technical insights we contacted our Penn State alumni mentor Kristen Meihofer[20]. Kristen assisted us significantly throughout the entire design process and proved especially helpful in providing feedback on our cost-benefit and risk analyses. We remained in contact with these professionals throughout the design process and they provided their feedback at multiple points along the way; despite having first reached out to all of them in the research phase of our design process, we were fortunate to continually utilize their guidance and expertise as we began developing and refining our solution.

5. Problem Solving Approach

After conducting extensive research and communicating with various stakeholders, our team began to hone-in on some possible solutions after developing an extensive scope of the problem of bird strikes and the shortcomings of current solutions. As we gathered more information, we quickly started generating ideas and were able to identify themes from our research that would guide our future solution. Using these themes, we constructed five insight statements which later contributed to our brainstorming and final design selection as they reappeared in our decision matrix. With these guiding ideas, we moved into the concept generation phase of our design process.

Insight Statements:

1. Reducing implementation, operation, and maintenance costs is ideal.
2. Bird strikes are unpredictable in nature.
3. Bird populations and ecosystems should not be threatened.

4. Airport design and layout can be efficiently planned to minimize interactions between birds and the airports themselves.
5. Airports require innovative long-term solutions to bird strikes that vary to prevent birds' habituation

5.1 Concept Generation

We began the concept generation phase with a team meeting to spend time brainstorming solutions stemming from the insights and research we collected. A five-minute timer was set and with individual post-it colors, we all set to write down as many ideas as possible, both the more reasonable ones and those that were full of creativity but not very feasible. Afterward, we all shared and began to group the post-it notes on a whiteboard, and then returned to do the same activity again, building off of the ideas of one another, really working to empty our minds of all possible concepts. From here the groups of ideas were fleshed into different categories: those implemented directly on the airplanes, those implemented at the airports, others specifically put in hangars, and then any solutions implemented into the surrounding area. With each of these larger categories containing many ideas, we returned to certain research insights that would narrow them further and referenced ideas that stakeholders had mentioned. Active versus passive methods of mitigation came up in our research and so the majority of the ideas in the hangars and surrounding areas were more focused on passive methods, but we decided we wanted more active methods. As such, we began narrowing down our possible and were able to group our remaining ideas into six designs.

5.2 Potential Solutions

These six solutions were detailed further during another team meeting, as we created mock-up drawings and began to consider different technical aspects of each. We knew we would need to consider a wide array of deterrents to address birds' adaptable nature, and so each of the six possible solutions involved innovative deterrent techniques such as the uses of UV light, different sounds, and potent smells. The first three solutions physically attached to a plane; these included a sound cannon used during take-off and landing, UV lights on the wings which would flash at different intervals during the plane's ascent and descent, and finally a drone which would fly with the planes until they reached an altitude where birds would no longer interfere with flight.

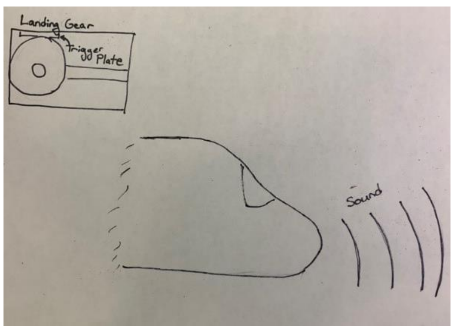


Figure 1: Sound Cannon

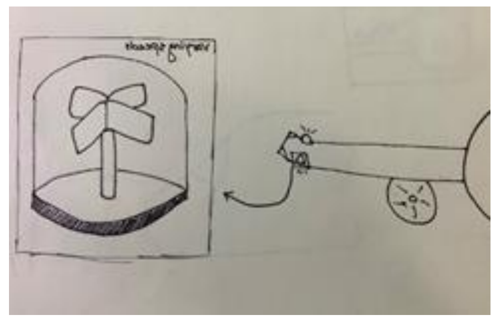


Figure 2: UV lights on Wings

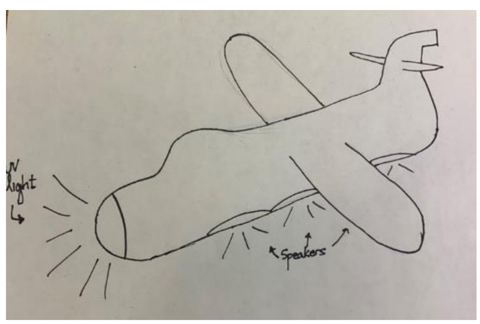


Figure 3: Drone with Built-In Deterrents

The next three mock-ups were ground-based solutions with similar deterrent ideas. The first was a UV spotlight that would be strategically placed near runways and airport perimeters and would deter birds from flying into the airport's vicinity. The second solution was similar, but incorporated a speaker system with varying noises and tones at different frequencies and intervals. The final ground-based solution was an odor-emitting apparatus that would cause airports to have a specific smell, such as that of peppermint oil, that would be deterring to birds but could be pleasant to humans.

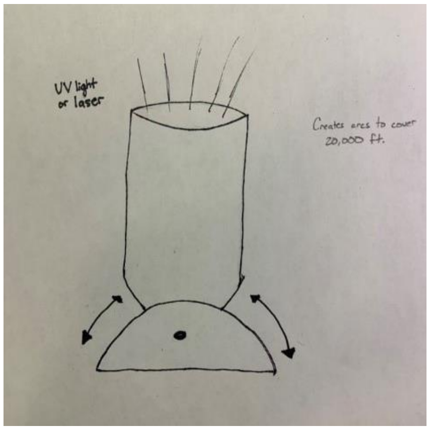


Figure 4: UV Spotlight System

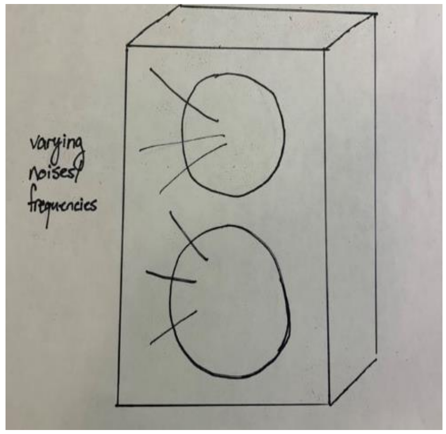


Figure 5: Speaker System

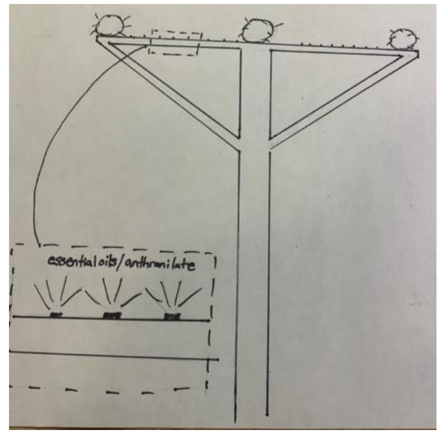


Figure 6: Odor Deterrent System

5.3 Concept Selection

With these six ideas, we felt confident moving forward into the concept selection period where we utilized a concept decision matrix to compare our potential solutions quantitatively based on values associated with our original themes and insights. We also considered basic design considerations, such as upkeep and implementation costs and difficulty, and evaluated each solution's overall ability to construct an inhospitable environment for birds. By weighing our categories differently based on how important we considered them to be, the decision matrix was an extremely effective tool at revealing which of our solutions best met our design criteria. We included all six of our original design solutions, hoping that our decision matrix would reveal the benefits of what we already began leaning towards, the drone solution. The drone did ultimately have the highest score on the matrix, followed by the UV spotlights and our odor deterrent system. The plane-attached solutions ranked low on cost and upkeep while the drone excelled in areas such as variability and what we considered to be innovation.

Table 1: Concept Decision Matrix

Values/Traits:	Cost	Variability	Effectiveness	Humane	Upkeep/Implementation	Human Interaction	Innovative	Inhospitality (Birds)	Total
Weight:	3	2.5	4	3	1.5	1	3	2	20
Sound on Plane	1	7	2	8	2	3	4	2	74.5
UV on Plane	1	4	5	7	1	10	8	4	97.5
Drone (Anti-bird)	3	10	8	7	3	6	10	8	144
Speakers around Property	8	7	3	8	5	1	3	3	101
UV Spotlights	7	6	2	7	4	10	7	5	112
Odor Deterrent	7	3	6	6	5	1	9	7	120

Returning to an outside perspective, we spoke with our alumni mentor, Kristen Meihofer, again about the solutions we had begun to develop. She pointed out that any solution that attached to a plane would not be financially feasible. Due to the sheer quantity of planes and the fact that the airlines are fiscally responsible for them rather than the airports, the cost estimate associated with such solutions would be too great. With this direct information, which was revealed by the weight of cost in the matrix, we decided to narrow our ideas down further to the three that ranked highest in the decision matrix. The three possible solutions are shown below, the D.R.I.B.: Drone Repellent of Invasive Birds, the UV Spotlight, and the Odor Deployment System.

Knowing that the D.R.I.B. had ranked the highest in the decision matrix, we reached out to our stakeholders again and sent them our three finalized designs, seeking their feedback on each. The D.R.I.B. again received the most positive feedback from Kristen and other stakeholders that we reached out to with these rough sketches. With this in mind, we moved forward into the prototyping phase to better understand these ideas and establish our final design selection.

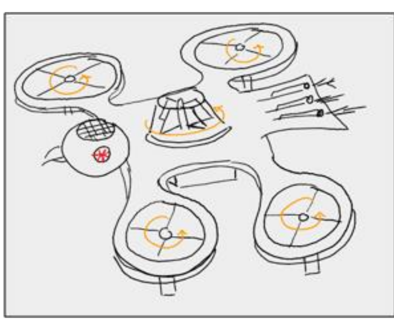


Figure 7: The D.R.I.B.

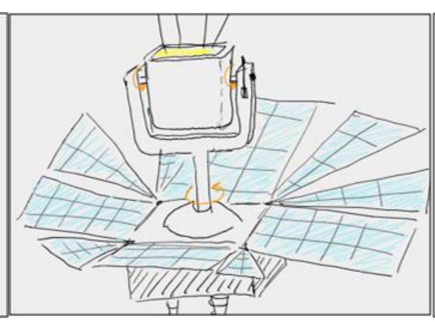


Figure 8: The UV Spotlight

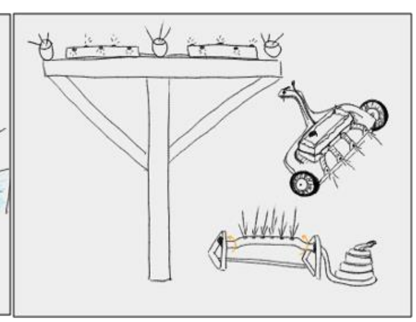


Figure 9: The Odor Deterrent System

6. Prototyping and Feedback

To develop a prototype, three alpha prototypes were considered first. After collecting feedback on these three prototypes, we were able to develop one finalized prototype and move forward with it. This complete prototype was then tested using integrative software, and it was again detailed to stakeholders and industry experts to receive their feedback.

6.1 Alpha Prototypes and Feedback

The three solutions selected from the decision matrix were first discussed as a team to determine the key features of each idea. Their complete descriptions are as follows:

D.R.I.B.: Drone Repellent of Invasive Birds- This drone takes three approaches to deter birds. First, varying frequencies and sounds are emitted to scare birds from the area. Then, strobing UV light and odor deterrents are used to make an inhospitable environment for birds. The airport can predetermine the drone's paths to prevent collisions. It is an automated system that would not need complete employee oversight. We recommend at least two drones per airport so that there would always be a drone in the air.

UV Spotlight- The UV spotlight is a humane solution to bird strikes and is completely invisible to humans. It can direct UV lights of varying frequencies in any direction at varying speeds, to deter birds and reduce their adaptability to the system. It only affects birds as the UV lights are invisible to humans. Once implemented, it will be a fully self-sustaining system powered by solar panels. The UV spotlight also comes with an app, allowing for complete automation of the lights, during dawn and dusk for example. It can pair with a phone or computer application where the airport can see the status of all their UV spotlights oversee their performance.

Odor Deterrent- This three-tiered approach looks to spread an odorous chemical, likely peppermint oil, around the airport as an odor deterrent for birds. The main mister set attaches to the FAA-required light bars at the end of each runway. The vehicle-attached spreader and sprinkler system reach to the other parts of the airport. It creates an environmentally friendly solution to develop inhospitable airport conditions for birds at a low cost.

To accompany these ideas, we created alpha prototypes in the form of storyboards, detailing each solution's life and integrity. More in-depth designs were also produced for the various software that would accompany the products, as well as detailed designs of each prototype. These prototypes were shown to stakeholders and our alumni mentor to help determine the most feasible solution.

The feedback we received from our stakeholders was very beneficial to narrowing our decision. From this feedback, our decision matrix was reaffirmed, and we received a consensus the drone seemed to be the most effective option for mitigating bird strikes, as it provides an integrative approach with multiple deterrents. At this stage, we learned that the automated nature of the drone we envisioned is not in compliance with FAA regulations, but rather that drones require a human pilot at all times. The UV spotlight seemed to be the next most effective solution, but it would need to work in the daylight as well to be truly effective, which is problematic because the atmosphere is flooded with UV light from the sun during the day. We also learned that the odor deterrent idea is not variable enough to provide a long-term solution. Using the same scent all the time, while it may be effective at first, may not be an effective deterrent in future use if it's used continuously. We also learned that airports are not allowed to attach anything to the light bars at the end of each runway, so we'd have to find a new location for the odor misters. Another major concern was the volume of odor spray that would be needed to cover an entire airport constantly. These solutions must be cost-effective for airports, so we had to pay closer attention to cost considerations as we moved forward with prototyping.

Using this feedback, we determined that the D.R.I.B. should be pursued as the final prototype. Due to its employment of multiple deterrents and its high variability, it will be the most effective solution to mitigate bird strikes humanely.

6.2 D.R.I.B. Prototype Specifications

To create a stronger prototype, we used the CAD software SolidWorks to create a physical representation of the D.R.I.B. For the initial CAD prototype, we took a standard drone model and added several of our unique features. Firstly, a predator bird head was added to the front to house the speaker and a video camera so that the operator can see from the drone's perspective. We then implemented a tubing system throughout the interior of the drone, connected to a bird tail-shaped container. This container holds the liquid odor for the D.R.I.B. to disperse through the blades of the drone. Finally, caps were added to the front arms of the drone where UV lights can project outwards in front of the drone. The drone also features automatic hovering, as well as an automatic return to base when the battery reaches 10%. When the battery reaches 10%, the remote will prompt the pilot, as shown in Figure 11, and upon pilot confirmation the drone will begin to autonomously navigate back to the charging base. To comply with FAA regulations, the pilot will still retain full control and can easily override the automatic return with any input. To accompany this prototype, we also modeled a charging station for the D.R.I.B. that comes with a socket to connect the remote for charging. The charging station features magnets that connect perfectly with magnets in the legs of the drone to ensure a secure battery connection for charging. The remote has a large screen with views from the D.R.I.B., along with various controls that the pilot can manipulate. Using GPS, the pilot can see where the drone is in relation to the runways or other areas of hazard, along with its relation to the charging station. The pilot can also adjust the variability of each deterrent, such as the frequency or sound emitted, and they will push a button to dispel odor, which increases variability and saves money as it will not be spraying all the time. The operation of this prototype either requires constant line of sight from the pilot or use of observers to comply with FAA regulations.

Figure 10: Solidworks DRIB, Charging StationFigure 10: Solidworks D.R.I.B., Charging Station

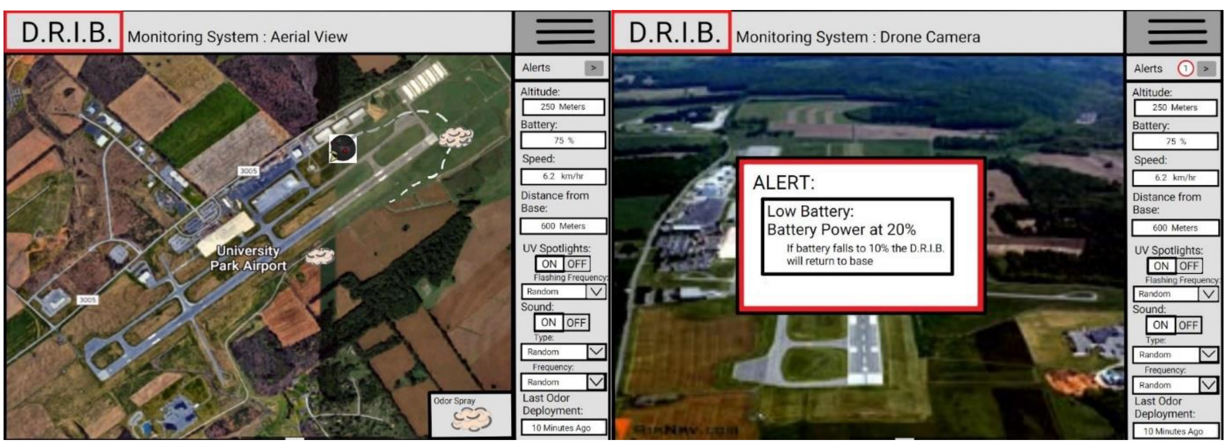


Figure 11: Remote Control Interface

6.3 Testing and Feedback

To test the prototype against various elements, we ran analyses in SolidWorks to find concentrated stress points and potential failure sites. It was determined that there is a slight strain on points connecting the front arms to the body, but not severe enough that it could ever cause fracture or failure due to repeated use or high strain. Motion studies were also conducted to make sure all parts of the drone work cohesively.

The prototype was then detailed again to many different industry experts and stakeholders to receive their feedback. As we spoke to each stakeholder, we continued to make improvements to the D.R.I.B. design in between meetings to show the stakeholders the newest iterations of the prototype. Dr. Brittingham recommended that we add hooks to the drone so operators can attach a stuffed dummy bird to simulate a predator bird carrying prey[18]. She also gave us recommendations about eye placement to make the drone look more predator-like. Another stakeholder, Ms. DiLorenzo, recommended using methyl anthranilate instead of peppermint oil because it is a more commonly used deterrent in the field and would have a lower likelihood of clogging the odor misters[19]. Methyl anthranilate is offensive (but humane) for birds and is pleasant smelling to humans. We were also told to consider adding a diffracted green laser to work with the UV light, as sufficiently diffracted lasers are also approved under FAA regulations[21]. Concerns were also raised for having an entire team dedicated to this solution, but any trained maintenance staff or runway operators could act as an observer or drive the pilot around in a vehicle to maintain line of sight. These individuals would largely be retrained or repurposed employees from current wildlife and runway teams. Thanks to all the great feedback we received, we were able to advance and refine our prototype to greater detail.

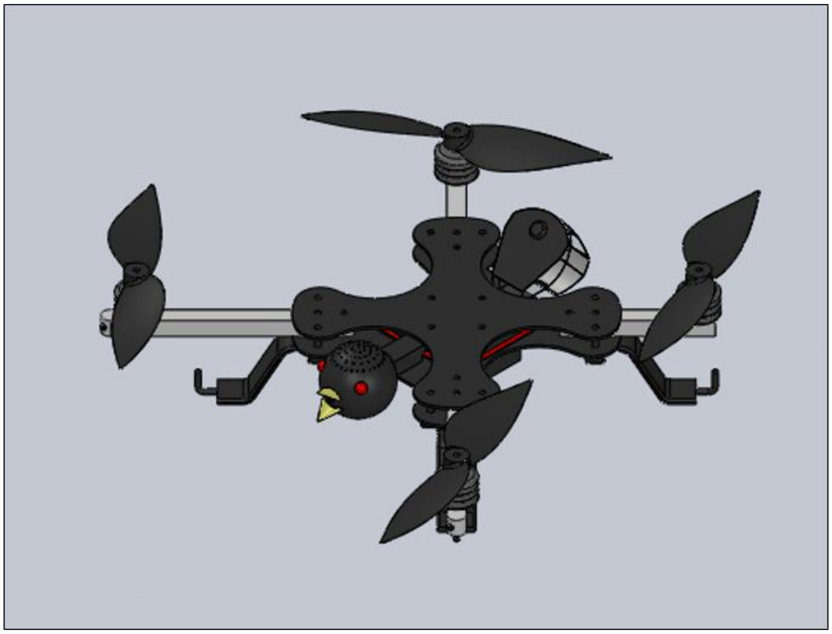


Figure 12: D.R.I.B. after Testing and Feedback

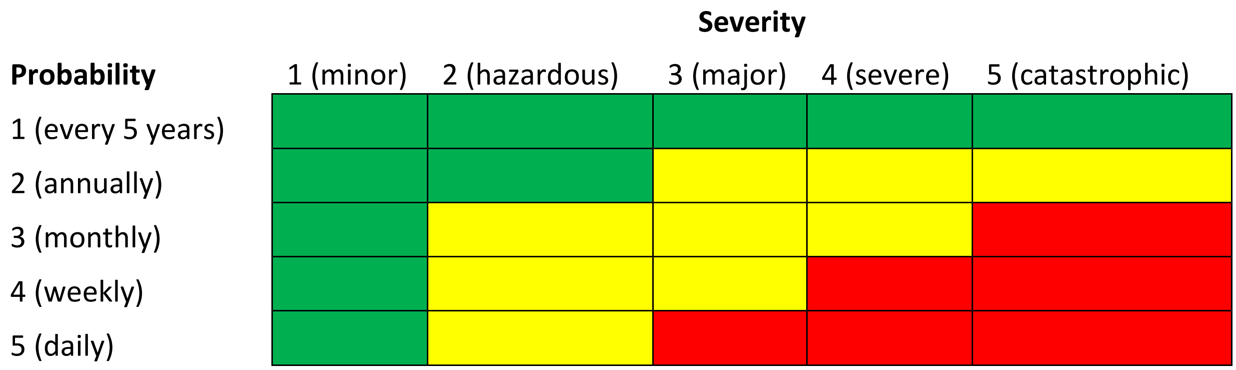
7. Safety Risk Assessment

After we had developed a strong, detailed prototype, we evaluated a list of potential hazards using a risk assessment matrix. We devised a list of 13 possible hazards and ranked them according to their probability and severity. We then organized them according to value (product of probability and severity) and built-in mitigation plans if the value fell in the yellow or red areas of the chart shown below.

Table 2: Hazards and Mitigations

1	Hazard	Value	Mitigation	New Value	New Mitigation	Final value
2	battery dies / out of resources	16	warning - low battery	12	pilot must fly home at 10%	0
3	loss of range/sight	16	camera, observers	8	defined boundaries	2
4	plane collision	15	camera, observers	10	defined boundaries, alert system	5
5	water damage	12	airtight covers	2	-	-
6	hacked	10	encryption	5	-	-
7	overheating	9	open design	6	-	-
8	bird collision	8	webcam	2	-	-
9	operator control loss	8	hover if no input 5s	2	-	-
10	lightning strike	5	no operation in storms	0	-	-
11	theft	5	acceptable	-	-	-
12	radio interference	5	prescribed frequency	1	-	-
13	fatigue	4	acceptable	-	-	-
14	charging malfunctions	2	acceptable	-	-	-

Table 3: Risk Severity Chart



Of our 13 hazards, three were acceptable risks without any mitigation techniques in place, and these hazards were deemed either highly unlikely or of very low severity. For the other ten, we decided to build in measures to further eliminate the risk. Only two hazards (plane collision and loss of range/sight with operator) resulted in a risk value greater than zero after we employed two built-in mitigation techniques, largely due to the severity of such an occurrence, but they both fell into the green area of the chart and were finally deemed acceptable. Notable modifications include: no operation in storms due to sensitive electronics, webcam installation, backup hover-in-place system if no pilot input is detected for 5 seconds, a return to base/pilots must fly to charging base at 10% battery, and pre-defined no-fly zones using GPS. We estimate that by lowering all of these risks into the green areas of the chart, we effectively transfer or eliminate the risks to an extent that the drone will remain wholly profitable and safe, even when accounting for the possibility of each of these hazards simultaneously.

8. Evaluation

After assessing the risks and modifying our prototype to a finalized version, we finally felt comfortable evaluating the profitability of the D.R.I.B. system. We were able to do so using a cost-benefit analysis to prove the economic feasibility of the system to the airports.

Customers' primary concern with emerging technological solutions like the D.R.I.B. is typically cost, and our research has shown that the benefits of the D.R.I.B. greatly outweigh the costs of operation, even when accounting for the high annual cost of labor associated with our trained pilots and observers.

8.1 Evaluation of Customer Needs

During the process of inventing the D.R.I.B., we had the opportunity to talk to many stakeholders and customers that gave us input in what we should include in our final design. After conducting extensive interviews, we had developed a clear understanding of our customers and the direction in which to take our solution. We recognize that safety is one of our customers' top priorities, especially when implementing new technology in busy airspaces. Customers want a solution that doesn't impede airport operations and can be more effective than current mitigation techniques. One concern that arose from customers was the fear that the drone would propose more of an inconvenience and danger to airport operations as an added component in the airspace. As mentioned briefly in the risk assessment, we addressed this concern by implementing GPS-controlled no-fly regions surrounding runway space to ensure the safety of use of our solution. By implementing safety measures, we worked to be cognizant of our customers' needs. We then proceeded to consider another key component of our customers' needs, and with our final prototype now established, we could consider the cost of our proposed solution.

8.2 Cost Analysis

Table 4: Costs Associated with D.R.I.B.

Costs				
Category	**Item**	**Quantity**	**Price**	**Total**
Upfront	Drone	3	$2,859.00	$8,577.00
	Installation	56 hrs	$27.00/hr	$1,512.00
				$10,089.00
Annual	Pilot	2	$80,000.00	$160,000.00
	Observer	2	$56,000.00	$112,000.00
	Refills and Maintenance	1 lightbulb, 2 gallons odor	$285.00	$285.00
Total recurring				**$272,285.00**
Total 1st year				**$282,374.00**

When evaluating our costs, we anticipated airports to purchase three drones on average; airports are continually paying their staff, so they should consistently have at least one active drone in the air to maximize profits. To evaluate the cost of the drone materials and components, we referenced online market values for similar equipment. Using information from Ms. DiLorenzo, we estimated that certified airport drone pilots earn an average salary of $80,000, and we estimate that airports can train and repurpose two of their existing employees (part of installation cost), retaining a similar salary[19]. The drone will cost $272,285.00 to operate annually, but the first year will also include the upfront costs of the equipment and installation coming out to the first-year total of $282,374.00.

8.3 Benefit Analysis

Table 5: Benefits Associated with D.R.I.B.

Benefits	
Less Physical Damage to Planes	$96,700.00
Reduction of delayed flights	$41,892.00
Repurpose Wildlife Management Team	$272,000.00
Reduction of Wildlife Management Materials	$86,000.00
Total	**$496,592.00**

For the benefits of the D.R.I.B., we used data for an average U.S. airport and averaged the total financial impact of bird strikes. For example, the reduction in physical damage was calculated by dividing $500 million in estimated annual loss by the 5,170 registered public airports in the United States[2]. Regarding the reduction in flight delays, Ms. DiLorenzo estimates that the use of the D.R.I.B. will result in a 70% reduction in total bird strikes, and we used 2018 flight delay data to calculate the total resultant savings[19,22]. For the repurposing of existing wildlife management teams, we estimate that existing teams of six can be reduced to three, with the repurposing of those three to the drone operation team[19]. Finally, evaluating the annual estimated savings of airports themselves due to operations and repairs at $86,000, we arrive at our total annual benefits of $496,592[23]. This results in a first-year profit of $214,218.00, and an annual profit of $224,207 every following year. According to these estimations, the D.R.I.B. will pay for itself in just under seven months (207 days) and begin turning a profit from there, with a benefit to cost ratio of 1.82. Due to the high initial cost, we would consider recommending the D.R.I.B. first to military airports and very large commercial airports, then marketing to medium-sized and smaller airports once we have a proven solution and can decrease costs[19].

Appendix A: Contact Information

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Appendix B: University Description

Penn State University is an institution of higher education in Pennsylvania. It houses the college of engineering which includes numerous engineering degrees at both the undergraduate and graduate levels. The college of engineering supports an undergraduate minor in engineering leadership in which undergraduate engineers can build the non-technical skills to support the great technical skills they are developing through their engineering curriculum. The engineering leadership development program offers students classes in project management, leadership education and development, business basics, and cross-cultural teaming. Students in the minor are dedicated to building these skills in addition to the technical workload required of their discipline's curriculum. The engineering leadership program also offers a graduate program in the form of a Master of Engineering and an online graduate certificate in Engineering Leadership and Innovation Management.

Appendix C: Description of Non-University Partners Involved in the Project

No university partners were involved in the project.

Appendix E: Evaluation of Education Experience Provided by the Project:

Student Perspective:

1. Did the Airport Cooperative Research Program (ACRP) University Design Competition for Addressing Airports Needs provide a meaningful learning experience for you? Why or why not?

We felt as though the ACRP Competition did provide a meaningful learning experience as it allowed us to practice moving through the entirety of the design process as we worked to solve a real-world problem in a meaningful and innovative way, applying our engineering and leadership skills.

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

It was challenging to gather all the required information to get a clear scope on the problem as well as try to make an innovative solution that could be feasibly put in place in a real airport setting. In terms of gathering the information, we were in contact with many experts from a large range of fields that provided their insights both to the problem in general and then feedback on our solution. This also helped us test our innovative solution against realistic viewers who were able to make very useful feedback notes that helped us create our real-world solution.

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

After researching the problem largely independently as a team and working to get a good handle on it, we reached out to several provided stakeholders who had firsthand experience mitigating bird strikes at airports to better understand the problem from their perspective and what would be crucial to our final solution. As such we were able to identify the audience of our solution, what would be game-changing for them, and propose that to be the central idea guiding the rest of our design solution. As such, we formed our point of view statement which was essentially our hypothesis behind the design.

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

The participation by industry in the project was all of the above, as we talked to industry partners such as the given stakeholders as well as some local airport staff members we were able to engage with them professionally while gaining meaningful insights to the problem we were addressing and receiving great feedback on our final solution. As such it was very useful as we were able to gear our design towards those that it would ideally serve.

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 a lot about how to work in a team and progress through phases of the design process. We learned to think critically and creatively and then how to analyze our innovative solution via cost and risk analyses. All these skills will most definitely aid us as we move towards our positions in the workforce. Being good problem-solvers will essentially be our future job descriptions as engineers and we will be working in teams our entire lives, as such, we feel that this project prepared us amply to pursue future careers or further study.

Faculty Perspective

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

Students in our leadership course are learning how to lead within the engineering context. This project provides an exceptional and organized experience for our engineering students to apply the knowledge and their personal leadership style as they lead their teams throughout the semester. The challenges provided mimic a real-world experience giving students an opportunity to practice both technical and non-technical problem-solving skills.

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

Yes, the learning experience was appropriate for the level of our students and fit within the context of our learning environment, per the note above.

3. What challenges did the students face and overcome?

Students faced some challenges getting in touch with experts and through that learned how important it is to talk with the "user" in order to come up with the best solution. Some students tried to jump ahead to the solution and not work through the design process to use all the information gathered in order to come up with a creative solution. They learned that user-centered research is important when coming up with solutions to challenges.

4. Would you use this competition as an educational vehicle in the future? Why or why not? Are there changes to the competition that you would suggest for future years?

Yes. We plan to continue to use it based on the organization, the well thought out options for projects, the support, and industry contacts. If you could make some of the appendices an online form and allow for one submission of some of the appendices if a group is turning in multiple projects.

5. Would you recommend any changes to the ACRP competition? No

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18. Margaret C. Brittingham, Ph.D., Professor of Wildlife Resources, Penn State University

19. Samantha DiLorenzo, Wildlife technician and airport specialist, USDA-APHIS Wildlife Services and University Park Airport

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