AIRPORT ENVIRONMENTAL INTERACTIONS: MAKING SNOW AND ICE REMOVAL MORE ENVIRONMENTALLY FRIENDLY

HYDROPHOBIC AIRCRAFT PAINT TO REDUCE THE NEED FOR DEICING FLUID

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Executive Summary: Hydrophobic aircraft paint to reduce the need for deicing fluid

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The environmental impacts of chemical aircraft deicing are often overlooked. Deicing a large commercial aircraft may require between 500 and 1000 gallons of fluid. This can cost between $4,000 and $12,000 [1]. Depending on destination and weather, an aircraft may have to be deiced multiple times a day. The cost can clearly add up. Furthermore, there are intangible environmental costs. Runoff deicing fluid that enters nearby water bodies may consume high levels of oxygen during degradation. This diminishes the oxygen available to native aquatic organisms. Several studies conducted at various airports across the United States have also identified other potential hazards, including: increased ammonia and nutrient levels, death of fish and other species, and unnatural color and odor [2].

The Airport Cooperative Research Program (ACRP) seeks a solution that offers one of the following: improved means of complying with airfield deicing and anti-icing requirements, environmentally safe deicing products that are compatible with aircraft and pavement, or improved containment and cleanup of deicing products [3].

Our goal was to decrease the annual volume of runoff deicing fluid for an aircraft. We considered improved means of complying with deicing requirements as well as improved containment and cleanup procedures. Research involved contact with airport professionals as well as exploration of current deicing methods and procedures. Using this information, we identified themes and generated a POV statement. We were amazed to learn that only 60% of deicing fluid is accounted for by airports, per EPA airport deicing effluent guidelines [4]. The team decided that it would be life-changing if we could reduce the total fluid used for deicing aircraft to effectively reduce the volume of the 40% of chemicals unaccounted for in the process.

The team used various design thinking methods to generate concepts. Potential solutions included an ultrasonic mechanical deicing system, a better collection method for the runoff fluid, and a hydrophobic aircraft paint. A decision matrix revealed that a hydrophobic aircraft paint was the optimal solution, in terms of cost, time, energy consumption, effectiveness, and chemical volume. A prototype was constructed to demonstrate this idea. Using a model plane and commercial “Flex Seal,” the prototype effectively repelled water and prevented ice build-up in freezing temperature conditions. Though the “Flex Seal” product is by no means the suggested solution, it is representative of a more permanent hydrophobic aircraft film as an alternative to the temporary chemical bath currently used in aircraft deicing.

A risk assessment matrix revealed that the greatest risk associated with the hydrophobic paint concept was increased drag during flight. Because the paint itself has yet to be developed, the proposed solution is to devise a development team of both chemical and aerospace engineers to ensure that the product fulfills its deicing advantages while having a minimal impact on actual flight. A cost-benefit analysis also revealed that after Research and Development of the paint technology, the tangible benefits greatly outweigh the costs, with benefits being calculated as the money saved with reduced need for deicing fluid. It should be noted that the cost-benefit analysis does not account for intangible benefits of our solution. Reducing the amount of runoff deicing fluid leaves a lesser impact on ecosystems surrounding airports. Nearby water bodies are particularly benefited from reduced chemical runoff, with decreased death of aquatic species, as well lower levels of ammonia and unnecessary nutrients. In conclusion, development of a hydrophobic aircraft paint would reduce required deicing fluid and effectively reduce the volume of chemicals negatively impacting nearby ecosystems.

Research

Chemical runoff rarely enters the environment without negative consequences. Our team began research by exploring the environmental impacts of chemical deicing fluid. A literature review conducted by the EPA was able to synthesize nearly 100 documents studying the environmental impacts of airport deicing discharges. These studies identified both conclusive and suggestive evidence of environmental detriment. Most of them focus on water bodies directly receiving airport deicing pollutant discharges from various airports across the United States. The EPA literature review compiled a wide array of impacts: odor, foam, and color issues; violations of the Clean Water Act; anoxia; Sphaerotilus overgrowth; high ammonia levels; fish kills; permit violations; state water quality standard violations; high glycol levels; high nutrient levels; and aquatic species diversity loss [2].

In order to fully understand the problem, our team started by reaching out to airport professionals with firsthand experience of the deicing process. The team contacted Chris Babb, an environmental issues and compliance managing consultant at Landrum-Brown, who directed us to useful information regarding the process and its regulations. After reviewing EPA airport deicing effluent guidelines, the team was amazed to realize that airports are only required to collect 60% of deicing fluid after the deicing process [4]. This leaves 40% of fluid unaccounted for and able to enter nearby ecosystems as chemical runoff. Our team decided that it would be ground-breaking if we could reduce the total volume of chemical fluid used to deice a plane over the course of a year. This would effectively reduce the volume entering the surrounding environment.

To better understand the deicing process, we explored deicing mechanisms beyond chemical deicing. Ice protection systems (IPSs) may be thermal, mechanical, or chemical (fluid or icephobic).

Thermal IPSs involve melting ice or preventing its buildup with thermal energy. The heat provided is high enough to either evaporate or melt the ice. These are known as “evaporative IPSs” and “running wet IPSs,” respectively. Thermal IPSs require high amounts of thermal energy. Because of this, they are typically only used for small, crucial surfaces of the aircraft, including propellers, data sensors, windshields, and engine inlets.

Mechanical IPSs involve a force that sheds the ice from the skin of the aircraft. This force is most often generated with pneumatic deicing boots. Deicing boots are thick pieces of rubber which are attached to the leading edge of an airplane. To shed the ice, air is pumped into the boots, which causes the ice to crack and fall off [6]. There are other emerging mechanical IPSs, such as ultrasonic deicing and electro-impulse deicing.

Chemical deicing is used most often. This involves a chemical bath of diluted deicing fluid. Most of the deicing fluid is made of either ethylene glycol or propylene glycol. Ethylene glycol is low cost and more effective, so it is widely used. However, ethylene glycol is more harmful. For instance, if ingested, it depresses the central nervous system and can be fatal to humans even in small quantities. Through our research, it became apparent that there are several mechanisms to deice aircraft, but the accepted mode is particularly harmful to the environment. With this we proceeded with the design process.

Design Process

After conducting research and reaching out to our stakeholder, the team developed themes and insight statements using design thinking methods. We wanted a solution that was environmentally friendly, situational, and effective. Using these themes and the information we gathered, we conducted a brainstorming session using the “brainswarming” method. This involved the team coming up with ideas and connecting them from our sub goals to our resources in order to create solutions. Our sub goals were mechanical, thermal, and chemical deicing processes, while our resources included stake holders, shopping sites, and the learning factory. This design thinking method allowed us to generate a map of solutions which is depicted in figure 1 below. After assessing these solutions using a decision matrix, we decided to go with the hydrophobic coating due to its low cost and time to implement.

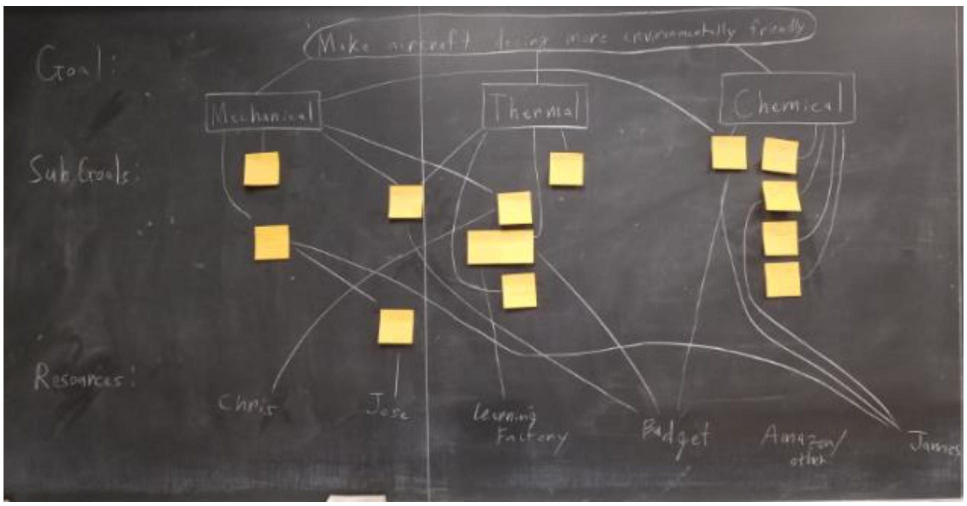

Figure 1. Solution map for alternative deicing methods created from brainswarming activity.

For prototyping, we purchased Styrofoam planes as shown in Figure 2 and different hydrophobic materials to demonstrate how our idea would work. We painted Flex Seal on the first plane and observed that water was repelled from it when wet. From this, we learned that it was effective at repelling water, but it greatly increased the weight and efficiency of the plane. This made us search for a lighter coating to serve the same purpose. For the second plane, we added a layer of Scotchguard to create a lightweight solution. The second plane was more effective at repelling water but was a temporary solution because it wears off over time. From this, we learned that the final coating would have to be as lightweight as possible and be able to last around 5 to 10 years before being reapplied. A future prototype of our solution would require a coating to be developed and tested in order to maximize its effectiveness and lifetime, while minimizing any added drag or weight.

Figure 2. Sequence of prototypes for the hydrophobic aircraft coating: (1) alpha prototype, and (2) beta prototype.

SOLUTIONS

After researching several ice protection systems (IPSs) including thermal, mechanical and chemical methods, we narrowed down to three most feasible solutions which were an ultrasonic mechanical deicing, a hydrophobic coating covering the aircrafts, and having a better method of collecting runoff chemicals.

The ultrasonic deicing method is the mechanical way to deice the aircrafts. An ultrasonic actuator would be placed inside the leading edges of both wings. Since the interface between the surface of an aircraft and ice is weak against shear stress, the wave sent out by the actuator would generate enough shear force to break the bond between the ice and the surface [8]. There is a research of using the ultrasonic deicing for helicopter rotor blades. By sending out the ultrasonic vibration, the thin layers of ice have proven to be shed during the wind tunnel testing [9]. The ultrasonic method seems to be a promising solution for the future as it has benefits including it being cost effective and environmentally friendly. However, the ultrasonic method for deicing is fairly a new method and is still in a researching phase, and it is not yet ready to be implemented for commercial application.

Better collection method is the solution to improve current methods of collecting the runoff deicing fluids. We turned out heads back to think about that current deicing method using the chemicals may be the most effective way of deicing although those chemicals are harmful to the environment. Therefore, we came up with an idea of having better collection of runoff chemicals. The Environmental Protection Agency (EPA) only requires airports to treat 60 percent of runoff chemicals, so the better collection method will collect and treat the rest 40 percent. Improved drainage and pipe systems will be implemented throughout runways, docking areas, and designated areas where deicing chemicals are sprayed to aircrafts. Since the deicing method itself stays the same, the effectiveness of this method is proven, however, it would not eliminate the use of harmful chemicals.

The hydrophobic coating is the method of applying an extra layer of hydrophobic coating on top of the existing paint of the aircrafts. A hydrophobic technology is already widely used in many products, such as a spray for car windows, shirts, and shoes, and a flex seal for home repairment. By covering the aircrafts with hydrophobic coating, water molecules will be repelled from the surface, therefore ice will not be formed in first place. Last year, there was a development of hydrophobic coating for cockpit windows put to the test [10]. However, a further research of the hydrophobic coating is needed in order to account for increasing drag and weight that may affect aerodynamics. When the hydrophobic coating is applied to the entire body of the aircraft, a contact angle of water to the surface will be more than 90 degrees to have less contact surface for water. A less contact surface will result in a small force of interaction between the water and the aircraft. Since the water will be “sitting” on top of the surface of the aircraft, it can easily be blown away by an air compressor or will be removed by itself when the aircraft is moved around by a pushback tractor. Unlike the current method of spraying deicing fluids every time before the aircrafts taking off, this coating will be semi-permanent that only needs to be painted once every 5 to 10 years at the same time when the aircrafts are regularly painted.

With these three solutions, we considered five factors and created a decision matrix as shown in Figure 3. Each category was weighted differently depending on its importance. Less chemical volume was weighted the most since our goal is to decrease the annual volume of runoff deicing fluid for an aircraft. Based on researches on each solution and our knowledges, we gave sub scores for each factor from 0 to 5. For instance, the ultrasonic deicing method received 5 on less chemical volume factor since it does not use chemicals at all. The hydrophobic coating method received 3 because the material of the coating itself would be chemical but it would enter not ecosystems. Better collection method received 1 because deicing method itself was unchanged in this solution. Other sub scores were scored in a similar manner, and then multiplied by the weights to calculate the total score.

After discussions with James Corson, a mentor for the Penn State Engineering Leadership Development Program (ELDP), and considering the decision matrix, we decided that covering the aircrafts with the hydrophobic coating would be the best solution. The use of hydrophobic coating would be able to reduce the volume of runoff deicing fluids while neither decreasing its effectiveness in terms of deicing nor increasing the cost comparing to the current method.

Decision Matrix

	Goal:	To decrease the annual volume of runoff deicing fluid for an aircraft		
	Total Score:	**54**	**58**	**28**
	Solutions:	Ultrasonic Deicing	Hydrophobic Coating	Better Collection
Factors of this decision	**Weight (0-5)**	Subscore (0-5)	Subscore (0-5)	Subscore (0-5)
Cost	2	4	5	2
Effectiveness	4	4	4	2
Energy Consumption	3	1	4	3
Less Chemical Volume	5	5	3	1
Time Takes to Implement	1	3	5	2

Figure 3. Decision Matrix

TESTS

After the team decided on our solution, we began to test our idea on the alpha prototype mentioned above in Figure 2. To test we would simulate inclement rainy weather by repeatedly pouring water of the hydrophobic coated wings. After some water was left on alpha prototype after testing, we reviewed our design with ELDP mentor James Corson to identify how the coating could be improved. The team decided to add another coating of scotch guard water repellent to the plane creating the beta prototype as also mentioned above in Figure 2. This redesign helped repel water better and after testing there was a visible difference between the two prototypes. At the state that our current prototype was at it was difficult to conduct more measurable tests because the product is still a representation of the concept. Once a hydrophobic paint is developed it could go on to more measurable tests such as in a wind tunnel to study drag or in a freeze chamber to see effects of actual ice and snow interactions with the coating.

Prototype evaluation by industry professionals was very helpful in identifying room for growth. A common theme in the feedback we received was that more research needed to be done on how the hydrophobic paint would affect the drag and weight of an aircraft. Although we were not able to perform calculations for drag, because the paint is not yet developed, the increased weight was considered in our cost-benefit analysis. We also propose that aerospace engineers conduct extensive tests and simulations as the paint is being developed in order to quantify the impacts that the hydrophobic paint would have.

Risk Assessment

Once the team decided on our final solution of the hydrophobic coating, we presented our idea to stakeholders to receive feedback on our ideas and areas of concern with the solution. The two main issues that were brought up was the fact that a new coat of paint will greatly affect the aero dynamics of an aircraft increase drag. Figure 4 (1). To help mitigate this issue, the team decided that during the R&D phase of creating the coating we will make sure that there are the proper aerospace and chemical engineers working on the project to help decrease the drag effects. Ideally the new paint will resemble the current paint with no change in drag at all. If that is not possible it will be important to recalculate fuel consumption and other aspects so that the aircraft travels safely. Figure 4 (1.a.). The other risk that was brought up was that what happens if this coating does not last forever. Figure 4 (2). To help resolve this issue the coating will be inspected regular Figure 4 (2.a.) and will be treated like typical aircraft paint. Currently aircraft are painted every five to ten years so our hydrophobic coating will also follow that lifetime and the reapplication will just be treated like normal maintenance. Figure 4 (2.b.).

Severity / Likelihood	No Effect	Minor	Major	Hazardous	Catastrophic
Frequent			1		
Probable		2			
Remote	2.a.	2.b.			
Extremely Remote	1.a.				
Extremely Improbable					

Figure 4. Risk assessment matrix

Cost-Benefit Analysis

We developed a cost-benefit analysis based on how much money it would cost to implement our solution, as well as how much airports would save. The values in Table 1 below represent the costs and benefits for one plane over the course of ten years. For the costs, we considered research and development, painting, increased fuel cost, and production cost. Research and development would pay for hiring two graduate students and any materials and equipment they would need to create prototypes and a final hydrophobic coating. Painting covers the cost of paint, painting equipment, and painters, assuming the price of the paint is twice the price of the current paint used on planes. The increase in fuel cost was calculated from comparing the density of a hydrophobic coating that already exists to the density of the current paint used on planes. From these calculations, we identified that the coating would increase the weight of the plane by about 250 lbs. Looking at the average miles a plane travels, the fuel efficiency of a Boeing 737, and the current cost of fuel, gave us the dollar value below. The last cost is the production cost, which represents the price of equipment, materials, and employees to manufacture and ship the coating. The benefit from implementing our solution is the reduced cost in deicing chemicals. Assuming the coating would eliminate about 70% of the current chemical volume used (the existing hydrophobic coating prevents 70% of water molecules from bonding), this would save \$5.88 million. From these costs and benefits, we arrived at a value of \$3.06 million that would be saved per plane over ten years.

Table 1. Cost-Benefit Analysis

Cost Analysis	
Research & Development	\$700,000
Painting Cost	\$600,000
Fuel Cost Increase	\$124,000
Production Cost	\$1,400,500
Total Cost of Investment	\$2,824,500
Reduced Chemical Cost	\$5,880,000
Total Savings	**\$3,055,500**

ENGINEERING LEADERSHIP

Throughout this project our team has learned many important lessons in how to be good engineering leaders. First our team realized the important of a document of communication to hold all the members accountable for their actions and what we expect from everyone. Whenever conflict came up amongst members, we used our assigned conflict mediator to help start a discussion and work though the problem. As the team took turns being leads, we also figured out what type of leadership style worked well for each member. For example, sometimes the quitter members of the team did well leading with situational participating while other members may have led with a different style. Also, we learned as leaders that although there is a typical engineering personality every engineer may be different and because of that team dynamics will always be changing. Because of this, it is important for a leader to adapt to their team to be a successful leader.

APPENDIX A: STUDENTS AND FACULTY

Student Contact Information

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SOUTH KOREA

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Faculty Contact Information

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Appendix B: Penn State Engineering Leadership Development Program

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 work load 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: Non-University Partners

Chris Baab: cbabb@landrum-brown.com

Chris Baab is an ACRP contact working in the environmental issues and compliance division at Landrum-Brown as a managing consultant. His expertise in his field helped lead our research in understanding the current deicing methods used at large airports and the current regulations that are set in place by the government to regulate the deicing process.

James Corson: jcorson_08@yahoo.com

James Corson is an Alumnus of Penn State University and a practicing engineering. James Corson assisted the team by providing feedback from a current engineer's perspective as we discussed with him possible solutions. James' feedback was crucial in the selection of our final solution. James was also able to provide helpful insight to the team on our prototype that prompted us to redesign and improve our results.

Appendix D: Design Submission Form

Airport Cooperative Research Program
University Design Competition for Addressing Airport Needs
Design Submission Form (Appendix D)

Note: This form should be included as Appendix D in the submitted PDF of the design package. The original with signatures must be sent along with the required print copy of the design.

University Penn State University

List other partnering universities if appropriate:

Design Developed by: ❑ Individual Student ☒ Student Team

If student team:

Student Team Lead: Seth LaPorta

Permanent Mailing Address 31 Rock Ridge Road, Upper Black Eddy, PA 18972

Permanent Phone Number 610-392-7230 Email sdl5273@psu.edu

Competition Design Challenge Addressed:

Airport Cooperative Research Program Design Challenge

I certify that I served as the Faculty Advisor for the work presented in this Design submission and that the work was done by the student participant(s).

Signed M Handley Date 4/2/19

Name Meg Handley, Paul Meister, Mary Walker

University/College Penn State University

Department(s) School of Design, Technology, and Professional Programs,; Engineering Leadership Program

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Appendix E: Evaluation of the Educational Experience

Students

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?

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

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

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

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?

Faculty

l. 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?

5. 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 the 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.

APPENDIX F: REFERENCES

[1] https://en.wikipedia.org/wiki/Deicing_fluid

[2] https://www.epa.gov/sites/production/files/2015-06/documents/airport-deicing_environmental-impact-and-benefit-assessment-final-2012.pdf

[3] http://vsgc.odu.edu/acrpdesigncompetition/wp-content/uploads/sites/3/2018/09/2018-2019-ACRPGuidelines.pdf

[4] https://www.epa.gov/eg/airport-deicing-effluent-guidelines

[5] https://www.faa.gov/documentlibrary/media/advisory_circular/ac_20-73a.pdf

[6] https://www.boldmethod.com/learn-to-fly/systems/how-deicing-boots-work/

[7] https://pubs.acs.org/cen/whatstuff/stuff/7901scit5.html

[8] https://www.sciencedirect.com/science/article/pii/S0378778817302633#bib0220

[9] https://www.aero.psu.edu/palacios/rotorcraft.html

[10] https://www.gknaerospace.com/en/newsroom/news-releases/2018/gkn-aerospace-develops-revolutionary-hydrophobic-coating-for-cockpit-windows/