Glycol Collection Cart: A Design for Small Airports

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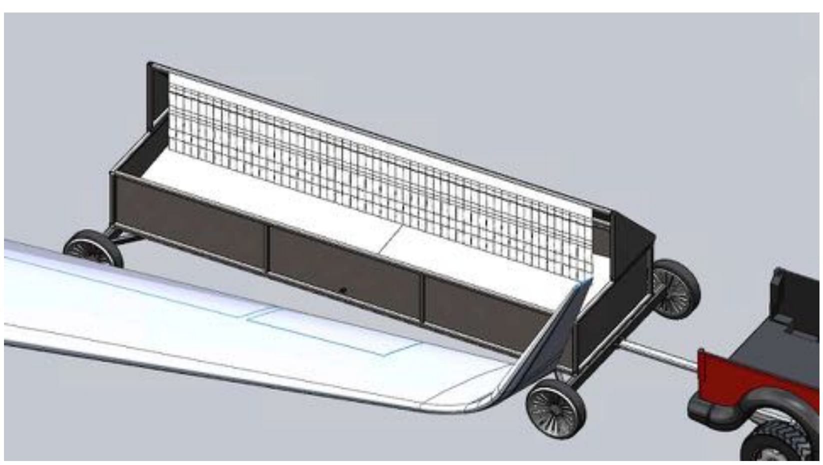
Airport Environmental Challenges

Michigan Technological University

Undergraduate Team Members:
Derek Cingel
Jared Langdon
Bryce Leaf
Ruth Maki
Douglas Pedersen
Amanda Moya
Alec Mitteer
(First semester only)

Advisor:
Dr. Paul van Susante

MTU Senior Capstone Design Program Director:
Dr. William Endres



Executive Summary

The act of removing ice greatly improves the performance of a plane, such as reducing the potential for losses in power and thrust, increasing lift up to 30%, and reducing drag by up to 40%. To keep the plane free from ice, chemical mixtures of water and glycol are applied, but up to 70% or more of the chemicals can run off the plane, which negatively impacts nearby water sources and ecosystems.

Airports can use up to 300 gallons of deicing fluid on one regional-sized aircraft, which can kill aquatic life in a body of water roughly the size of one backyard pool (around 10,000 gallons). The ethylene glycol in the deicing fluid strips the oxygen out of the water. This chemical also has been known to reduce the diversity and abundance of the aquatic community in ecosystems downstream of stormwater outfalls from airports, based on documentation from the Environmental Protection Agency in April 2012. Additionally, these bodies of water can also include aesthetic impacts such as odors, discoloration, and foaming in extreme cases.

The end-users at highest risk are the deicing operators directly handling the glycol applicators and the enclosed bucket operators controlling the applicators. Individuals who are part of the airport maintenance team responsible for filling storage tanks and frequent chemical checks could be affected positively by changing the glycol application and containment process. This report shows how an improved collection method would have a cost advantage for the airport and a high advantage for the surrounding environment, largely offsetting would likely add additional responsibilities for the maintenance staff. The collected glycol has the potential to be recycled, and small airports that do not already have collection methods can profit from the buyback prices recycling companies offer.

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1.0 Problem Statement and Background

Currently small airports, those with two or less commercial flights per day around the nation, those with two or less commercial flights per day, allow the de-icing fluid (glycol) to run off into the local environment. This causes environmental damage by reducing the amount of oxygen available in the water suffocating the local marine life.

When spraying the wings and the rest of the airplane at small airports the glycol runs onto the ground. From the ground the glycol makes its way to local marine ecosystems, where it causes the oxygen level in the water to decrease, causing local fish amphibians and other wildlife to die.

Current solutions to collection include having pads which are in one location and allow de-icing fluid runoff to collect in a storage area below and then run to a permanent collection area to be recycled. Most de-icing collection systems are similar to this idea. The problem with these systems is that they are large and expensive thus small airports cannot cost justify their implementation.Propositions for small airports include having mats that can absorb the glycol. There are also mitigation methods that heat the glycol to prevent the amount of glycol that is released. However, these solutions either raise ergonomic problems or don`t fully address the issue of preventing the glycol from running off into the environment.

In short, there is a gap in the environmental protection of local marine environments from glycol runoff and no system that can truly prevent a significant portion of the glycol runoff without either ergonomic issues or mass infrastructure upgrades. This problem aligns directly with solutions sought by the Airport Cooperative Research Program.

2.0 Literature Review

The team researched the scope of possibilities surrounding the environmental impacts of aircraft de-icing, including general vehicle operations, de-icing fluid composition and its effects on the environment, and existing collection methods. Research materials ranged from engineering standards to supplier websites.

2.1 De-icing fluid composition and its effects on the environment

The de-icing fluid typically consists of ethylene glycol, propylene glycol, and other urea compounds with ammonia to lower the freezing point of water that has accumulated on aircraft (akronbrass.com 2019). Type 1 and Type 4 are the two types of de-icing fluid that are the most commonly used at commercial airports. Type 1 is applied first after being heated to 150-180 °F to melt the snow and ice already on the plane. Type 4 is applied after Type 1 to provide a coating to protect the surface of the plane from snow and ice buildup before takeoff. Type 4 has a higher consistency of glycol (Ritter, S. 2019).

De-icing fluid is not directly harmful to human health but can flow into nearby bodies of water and reduce the oxygen levels. It can be harmful to human health when ingested, so it's critical to keep de-icing fluid away from drinking water sources. If released into wildlife habitats and ecosystems, de-icing fluid will kill fish, which reduces organism abundance and leads to a smaller variety of species (Boe, D. 2019).

2.2 Existing collection methods

Current de-icing fluid collection methods range from underground drainage, to vacuum trucks, and sloped pads. The underground drainage systems can have manhole-like drains placed on the ground around areas where the planes are de-iced. The drains lead to underground storage to be collected for disposal or recycling. Glycol recovery vehicles receive the leftover glycol on the ground after the plane rolls away (Office of Water, 2002). The vehicles act as vacuum sweepers that suck up any glycol and other liquids left after de-icing. The trucks have tanks to contain the fluids collected to be disposed of or processed for recycling. De-icing pads can be used at the ends of runways. The pads are sloped to guide excess de-icing fluid and contaminated rainwater (D. Holzman, 1997). These are not the only methods of containment on the market but are the main modes used at airports.

2.3 De-icing vehicle operations

Hybrid de-icing trucks use a method of forced air, which allows the operators to use hot air to assist the application of de-icing fluid (B. Chen et al 2016). This method uses less de-icing fluid while being able to remove snow and ice effectively. Hybrid de-icing trucks usually have enclosed buckets, which allows the operators to be protected from the outside weather. Traditional de-icing vehicles have an open bucket and only use nozzles that allow for up to 45 gallons/min of only de-icing fluid. Conventional de-icing trucks are cheaper when compared to hybrid trucks.

Both types of vehicles require multiple users - at least one in the truck and one in the bucket. The booms of both trucks have capabilities to move in both horizontal and vertical directions, which is controlled by the individual in the bucket (everyspec.com 1997). Both types of trucks have de-icing fluid containment tanks to hold and heat the fluid before application (norwegian.com 2016).

These areas of research helped the team understand the importance of keeping glycol away from waterways and wildlife, and also gave us insight on current applications and processes. Through the literature review, we were able to develop our engineering requirements revolving around the chemical consequences and labor involved in deicing.

3.0 Interaction with Airports

In the early stages of the project, multiple airports and airlines were contacted. Specifically, airports close to Michigan Tech's campus, and airlines that are commonly used. The airport contacts were used to gauge general problems they face, and the airline contacts helped to understand more of the processes behind de-icing. The most beneficial contact used was a manager from Skywest at Houghton County Memorial Airport (CMX). They were able to give the scope of the plane that flies in and out of Houghton, as well as give access to the de-icing truck they use. They were generous enough to show the team the deicing truck up close, as well as let the team observe a full deicing once winter conditions permit.

Observing a de-icing on a stormy day in Houghton brought multiple takeaways for the project idea. The first takeaway was that the de-icing operator spent over a minute spraying the fluid aimlessly onto the ground to warm the hose to be controlled easier. The second takeaway was that on a windy day, it was difficult to control the aim of the fluid - and this helped us eliminate potential project ideas of redesigning the nozzle of the hose. Another takeaway was the observation of excess airfield workers and vehicles. Having seen the deicing process, concepts were narrowed down, and there was a realization that containment would be the best course to decrease the environmental impacts of de-icing fluid.

Another useful contact was the engineering manager at Gerald R Ford International Airport (Grand Rapids, MI). Although GRFIA is not a small airport, they were a great source to understand what containment looks like at a large airport. Their ideas of how to improve their de-icing processes (like hybrid de-icing trucks) were far too expensive and unnecessary for small airports like CMX. They also introduced the concept of recycling glycol, which began the push to receive information on what recycling could look like for CMX. Communication with a manager from the US Ecology in Romulus, MI helped with the understanding of their recycling processes and options for recycling in Houghton.

Without interactions with airports, it would have been challenging to come up with a project idea. Through each interaction, something new was brought to attention that helped narrow down problems and solutions.

4.0 Problem Solving

4.1 Engineering Requirements

To determine how best to reduce the environmental impact of glycol, a list of engineering requirements and constraints were produced. These requirements show the performance metrics that need to be minimized or maximized in order to deliver the best possible design.

Arguably the most important requirement is the project cost. The original budget for the project was three thousand dollars. This was the amount allocated to build a prototype. It was of high priority to meet this, there was very little wiggle room if three thousand dollars was broken.

A close second, application time must not be extended much and preferably not at all. If the time increases, the airport will need to spend more money paying employees and also, more so, reuce on-time departure ratings by possibly delaying flights and losing customers. The amount of time it takes to remove the glycol from the collection device to a larger storage area also needs to be minimized in order to keep costs low.

In order for the design to be implemented it needs to be profitable or at least break-even. This is best accomplished by not only collecting the glycol runoff but also enabling the recycling of the glycol. The latter requires that enough of the glycol be collected in order to turn a profit. Thus, it was decided that twenty five percent of the glycol during runoff and eighty five percent of the glycol during initial heating would need to be collected.

The final item on the list of engineering requirements was causing no harm to the airplane, the worker or anyone or anything else. Part of this was to have a design which could be lightweight and not create ergonomic problems. The other part was to make sure an existing airport vehicle would be able to move the equipment. The initial value of fifteen hundred pounds was set for a scaled-down prototype due to the limited nature of our testing area. Ultimately though under eight thousand pounds is preferred as this is the highest weight that a full size pickup truck can tow.

Table 1. Engineering Requirements

Objective Name	Measurement Description	Priority	Direction	Target	Units of Measure
Project Cost	Target cost of entire project	4	Minimize	3000	dollars
Application Time	Amount of time it takes to deice the plane	4	Minimize	30	minutes
Containment Prior	Target containment of warm up solution	3	Maximize	85%	volume
Containment During	Target containment of applied solution	3	Maximize	25%	volume
Post Application Time	Amount of time it takes to move and drain solution to permanent location	3	Minimize	15	minutes
Vehicle Location	No contact with or damage to the plane	3	Maximize	3	feet
Mobility	Weight of design and fluid	3	Minimize	1500	lb

The engineering constraints deal mainly with existing procedures, such as spraying from a crane or the amount of time it takes before a plane needs to be sprayed again. Unlike the objective which are desired targets, these constraints must be satisfied for the design to be successful. Thus, the height of the boom must not be over reached or the distance away from the plane cannot be changed. Lastly, the equipment must work properly down to the limiting temperature.

Table 2. Engineering Constraints

Constraint Name	Measurement Description	Limits	Units of Measure
Lift Height	Vertical height of Class A vehicle boom	< 42	feet
Boom Reach	Horizontal reach of vehicle boom	< 40	ft
Holdover Time	Time between start of first application and when re-application is needed with no takeoff	<90	min
Outside Air Temperature	Allowable outside air temperature for effective deicing	-25	degree Fahrenheit

4.2 Preliminary Concepts and Ideas

As stated in the problem statement we chose to participate in the; Airport Environmental Interactions challenge due to the teams' strong feelings about helping create a sustainable environment for future generations. The other challenges, while important, didn't resonate the same way as helping to reduce the environmental degradation done by airports. Beyond the environmental challenge, the sub-challenge of minimizing the impacts of de-icing fluid resonated due to the cold climate in Houghton, MI. We knew we would have opportunities to see de-icing in-person.

After choosing de-icing as the main focus, the team needed to pick one idea from a list of many. In order to complete this, we used the Pugh analysis method to reduce the choices based on the engineering constraints and objectives (see the Problem Statement and Background Sections).

The first step was to break down the functions that the system would need to undergo. This stage was called functional decomposition, where all the required functions are identified and assured to complete through correlation with the requirements to ensure that every objective and constraint may be met. Following the functional decomposition came function level concepting, during which multiple ideas are generated for how to accomplish each function. Lastly is the system-level concepting where Pugh analysis compares combinations of function-level ideas to a datum (the original idea). Multiple rounds of system-level concept generation and assessment allows for the best system-level solution to emerge. When comparing our ideas to the datum, we consider if the new idea is better, similar or worse than the datum with respect to each objective and constraint. We went through three rounds of this, starting with an original idea and ending with our final design, a Glycol Collection Cart or (GCC).

The first stage started comparing nozzles, which can recollect the glycol or a nozzle that preheats the glycol to prevent the waste of glycol during the initial heating phase before the actual de-icing process. The winner of the first round was a de-icing bracket with forced air (without heating) as shown in Figure 1. This device showed potential in lowering the amount of glycol used but had a high production cost.

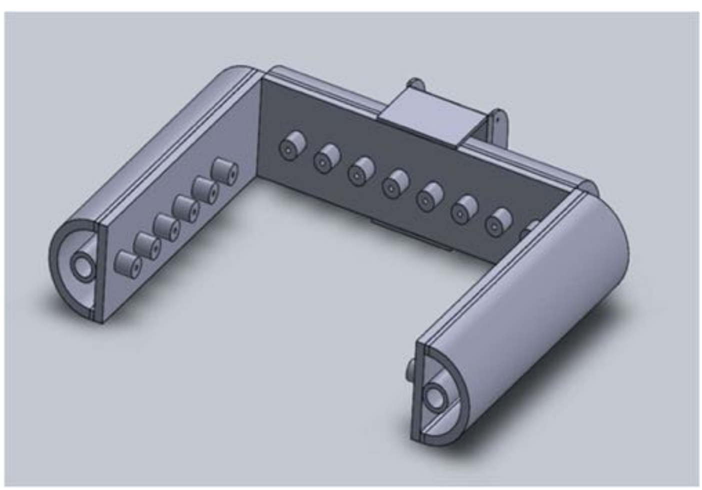

Figure 1. Deicing Bar with Forced Air

The second round of Pugh analysis compared the deicing bracket with compressed air heating devices and more efficient nozzles. The winner of this round was similar to the last round except that the bar is straight (see Figure 2), the glycol is heated and there's no compressed air.

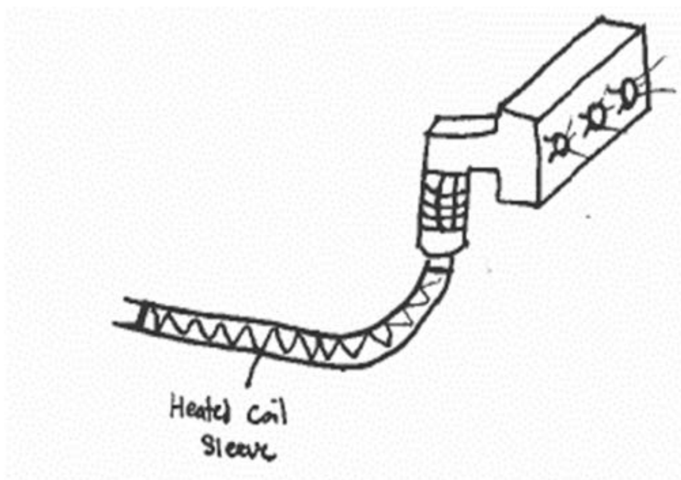

Figure 2. Handheld Spray Bar with Electric Heater.

The last round of pugh analysis shifts the focus from nozzles and heating apparatuses to collection and reducing the spread of glycol. The winner, in the end, was the Glycol Collection Cart.

This was due to the fact that collecting the glycol this way is inexpensive, simple in use, and requires little time to produce. The cart also allows airports to use their own existing equipment. For example, they can use an existing pick-up-truck or front-end loader. This provides tremendous benefit by reducing the hassle involved with the GCC.

The goal of the project has been to implement a method of collection for small scale airports that are not required to have any means of collection. These include airports that have two or fewer commercial flights per day. Cost and convenience were the driving concepts that fueled the ideas behind the project. Airports are already fighting a limited time schedule to complete the deicing process and keep planes on schedule. Airport personnel will not be open to implementing our solution if it causes too much of a disruption in the process. Through contact with the Houghton County Memorial Airport (CMX), the team learned that airports are not interested in system changes unless it will save them money. The small airports have a strict budget and operating costs that must be followed with the consideration of having only two flights per day. This is why it is essential that the solution remains within the constraints of being simple and able to utilize existing resources.

When figuring the details for the project, factors like application time and containment of deicing fluid were also deemed necessary, so the real challenge was finding a way to satisfy these requirements to meet the level of convenience for potential airfield use.

The first idea for the project focused around the application of the fluid and to manipulate the flow rate at which the glycol left the nozzle. The team did more research on this potential solution to find ways to concentrate the spray. After being invited to watch the deicing process at CMX, it is evident that the current flow rate is essential to the operation. The massive flow of glycol is needed to remove excess debris like snow and ice. The wind conditions were also observed to have a significant effect on the rate of glycol exiting the nozzle. A lower flow rate would disperse more quickly with the impact of wind and would result in more glycol ending up on the ground rather than the wing. After observing the deicing process, an observation was made about the warm-up process for the hose connected to the deicing truck. The airport personnel responsible for deicing the plane spend 1-2 minutes spraying glycol onto the ground to warm up the hose. This is done to reduce the stiffness in the hose caused by the cold in order to navigate the nozzle along the wing.

This observation helped move the team's focus on the collection of glycol. A calculation was done to find the amount of glycol wasted each day and a total amount for the year just in the warm-up stages of the deicing process. It is estimated that CMX uses around 78,310 gallons during the deicing months. After looking further into the problem, the team was able to learn that there are glycol recycling companies that accept collected glycol to be recycled and resold as other low percentage glycol products. The team reached out to US Ecology, Inc. to learn more about the recycling of glycol. After a discussion with US Ecology, we learned that they accept collected glycol from airports. If the glycol percentages are high enough (15% or more), the US Ecology will pay for the collected glycol or offer the airport personnel reduced prices on glycol.

4.3 Prototype Manufacturing and Testing

The first significant idea leading up to the full-scale model was to build a reduced-scale prototype of a cart which can collect glycol as it splashes off of the wing during the de-icing process. The full-scale design is approximately 18 feet long and 6 feet wide. However, due to various size and manufacturing limitations with regard to the build-up facility at Michigan Technological University (MTU), a demonstration-scale prototype was deemed necessary. The prototype was scaled to approximately one-third of the intended final 18 foot-long full scale model. The prototype's final dimensions were approximately 6 feet long and 4 ft wide, without taking hitches into account (see Figure 3).

Due to the global COVID-19 pandemic, MTU had to close its campus to all non-essential personnel for the remainder of the semester, resulting in a halt in production during the manufacturing process. Because of this, the team was rendered unable to finish creating the fully-functioning, approximately one-third-scale prototype (see Figure 4).

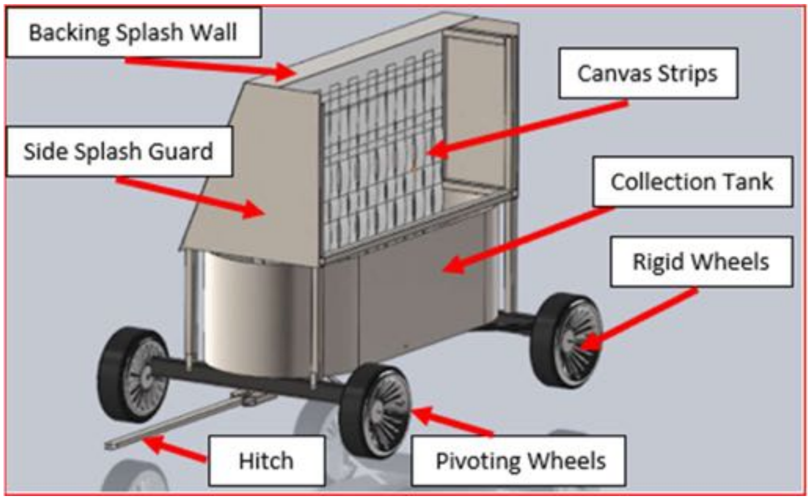

Figure 3. Prototype CAD Model

Figure 4. Partially Built GCC Prototype

Because of this unfortunate arrival of COVID-19, previously planned testing stages were also forced to be canceled. FEA was considered as a potential replacement for testing, however it was determined that most FEA simulations that would be useful surrogates for physical testing would require computing resources that were no longer available to us. One thing we were able to simulate was the path of the cart from one wing to another (screenshots of which can be found in Figures 9-10). This helped demonstrate that the cart will not require excessive amounts of time and space in order to maneuver it from one wing to another

5.0 Technical Description

5.1 Cart Design

The design of the GCC consists of a Trailer, Collection Area, a Pivoting Top, and two sets of Fabric Damping Strips (see figures 5-7).

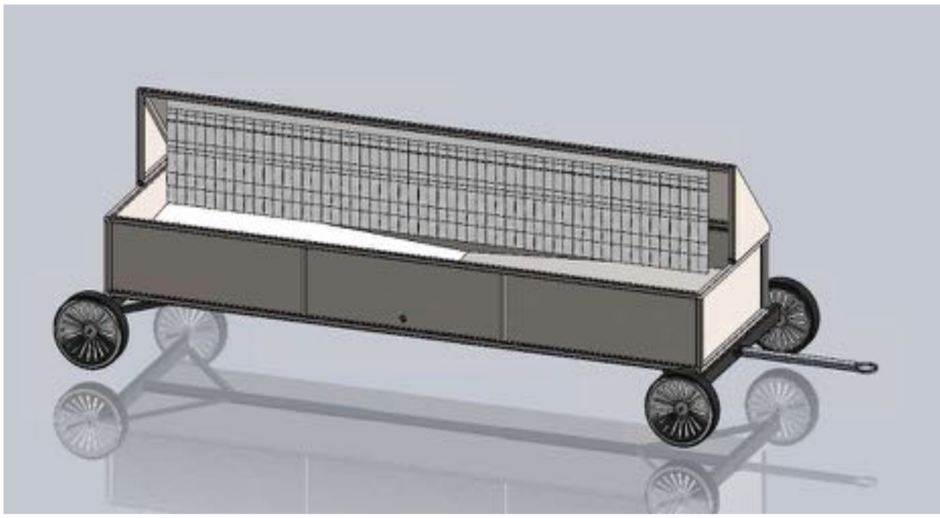

Figure 5. Full-scale Glycol Collection Cart Assembly

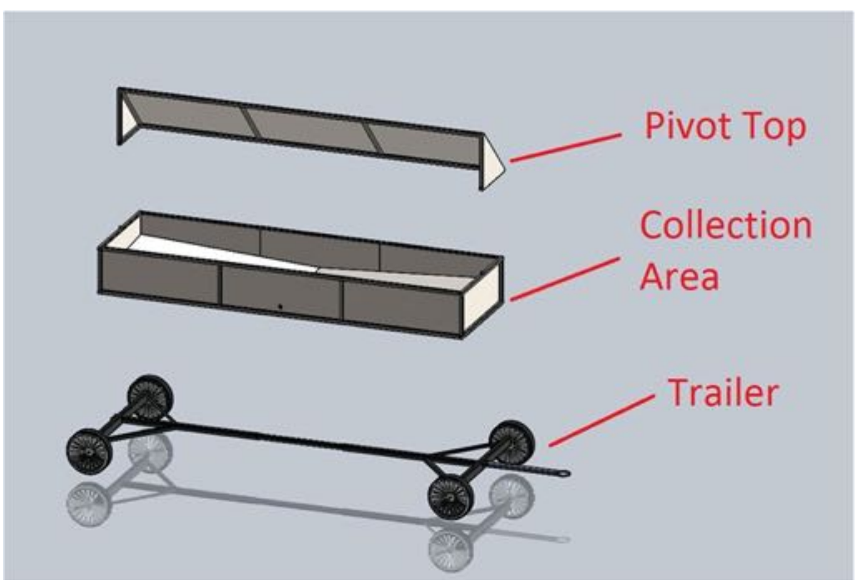

Figure 6. GCC Basic Explosion

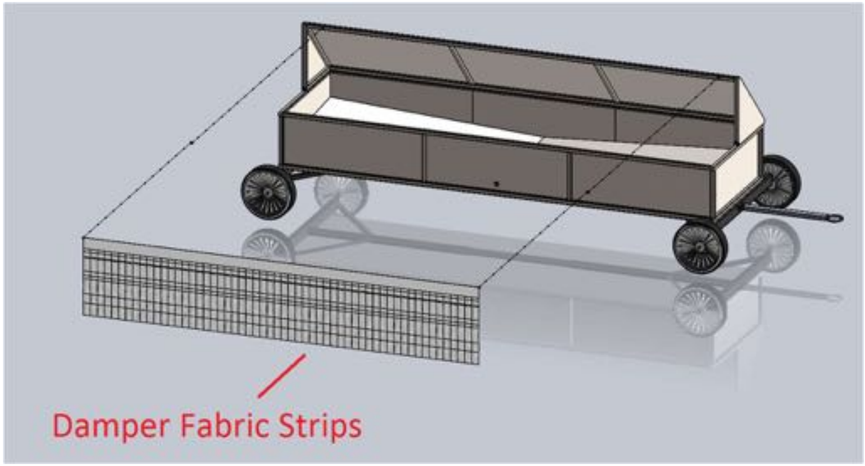

Figure 7. GCC Damper Strips Explosion

The Damper Strips help reduce the splashing that may occur if the glycol hits the metal. The Trailer (Figure 8) can either be a modified purchased part or custom-made. It consists of 4 purchased wheels rotating about a fixed axle and retained by a set of cotter pins and washers. The axles are 4 fixed circular rods, welded to the trailer frame. The trailer frame itself is also consisting of a welded set of tube stock and angle iron. At one of the ends there is a pintle-style hitch on heavy-duty hinges for easy attach- and detach-procedures.

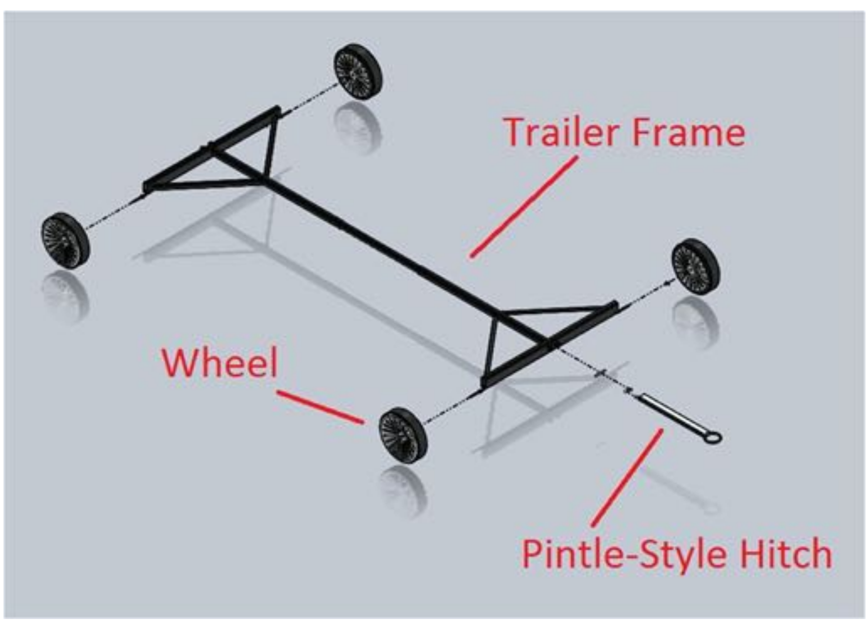

Figure 8. Trailer Explosion

Instead of having a second hitch the cart will have a rotating splash guard which can be flipped from one side to the other when backing the GCC into its position on either side of the plane. This in turn reduces the time that it would take to hitch and de-hitch if the splash guard were unidirectional (non-flippable). Note that this requires a second set of damper strips on the other side/edge of the splash guard (not shown in the figures).

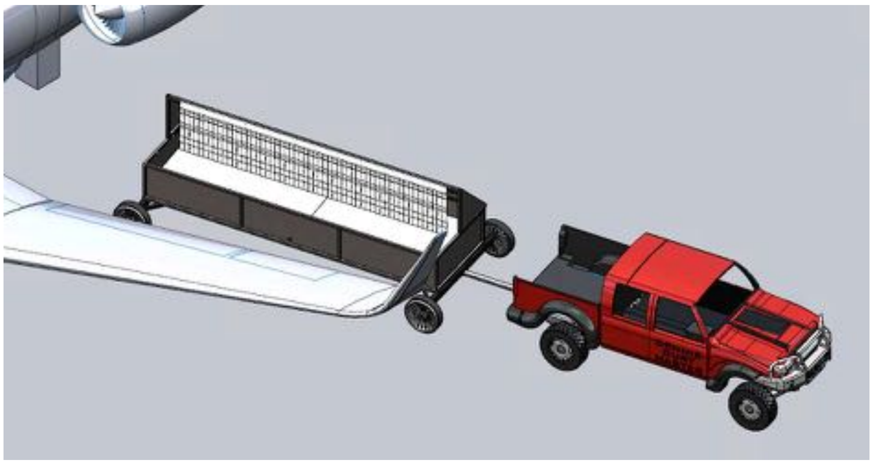

Figure 9. Scale comparison of GCC compared to Airplane Wing

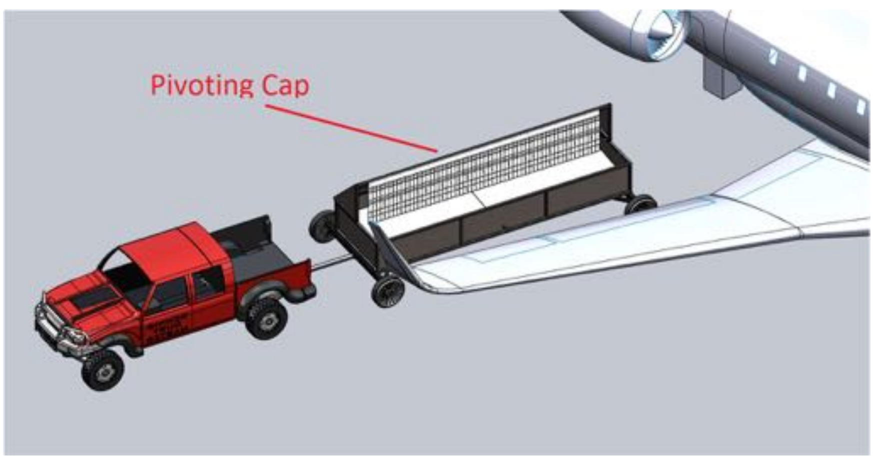

Figure 10. GCC on other side of plane to show need for pivoting top

The Containment Area (See Figures 11-14) subassembly is made up of a steel tubestock structural frame; a sheet steel outer base shell, consisting of 3 bottom sheets and 8 side panels; and two sheets of steel inside of the shell, slanted such that it will direct the liquid into a ½-inch valve-style spigot, located as indicated in Figure 11. This valve is threaded for easy interface with a matching hose for transfer into whichever storage vessel the airport finds most convenient. In addition, the splash guard (Figure 14) also consists of 3 sheets of steel acting as a backboard, as well as 2 sheets on each end to partially enclose the area.

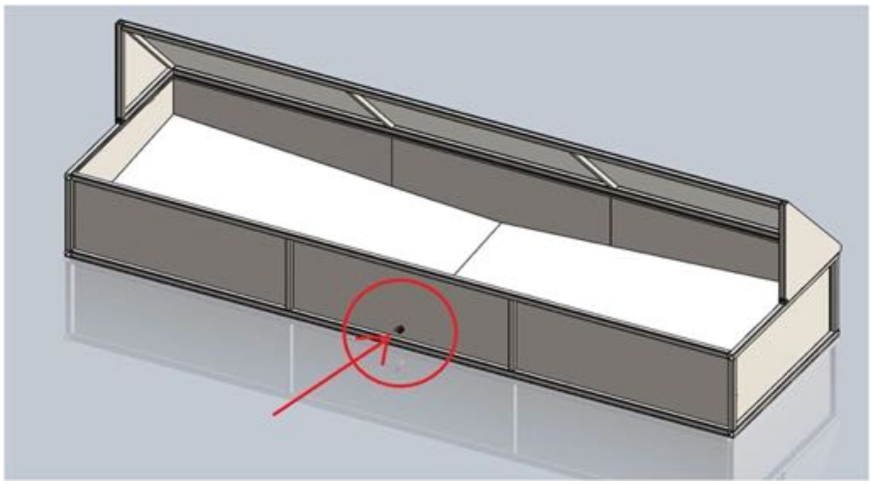

Figure 11. Glycol Containment Unit and Spigot

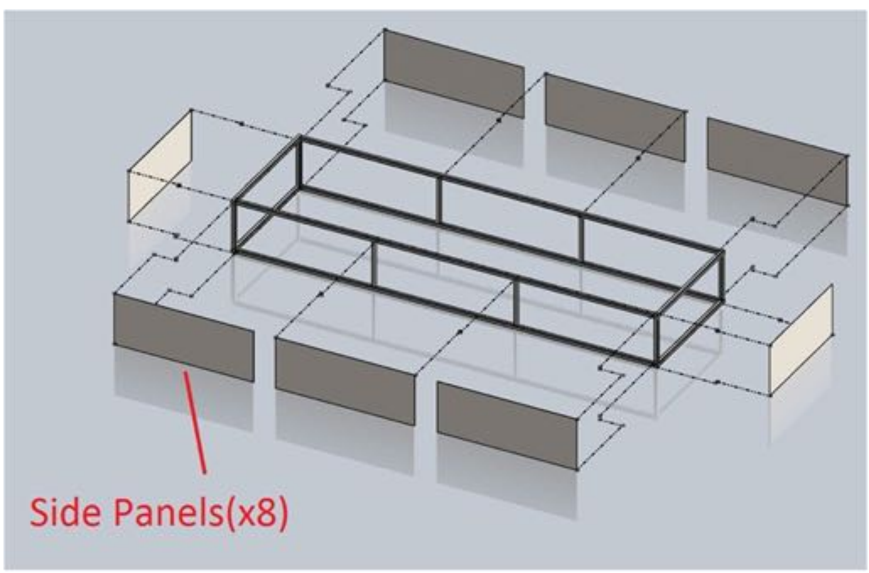

Figure 12. Glycol Containment Unit side panels

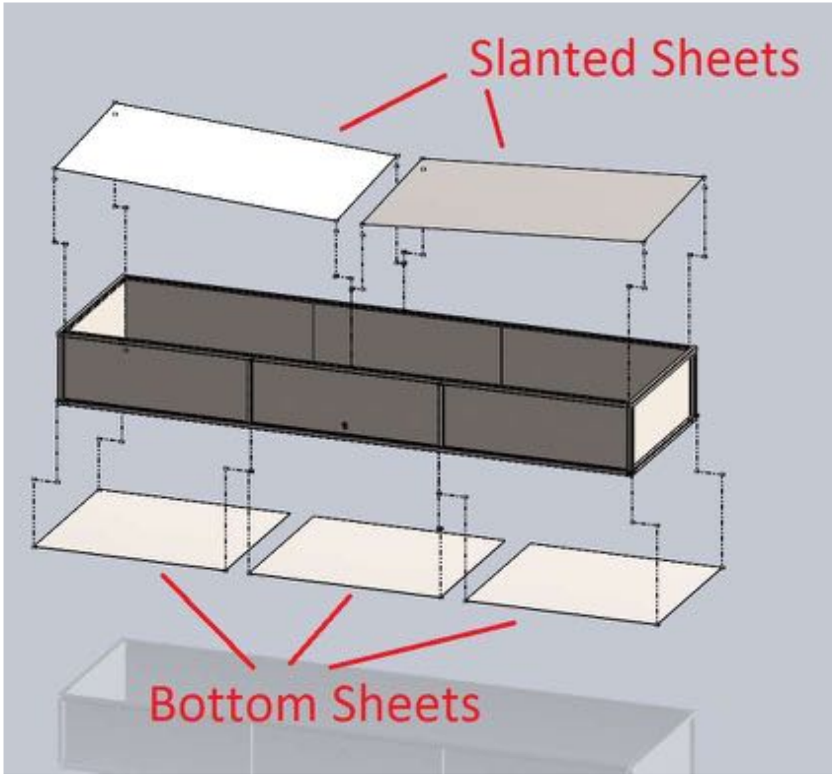

Figure 13. Glycol Containment Unit bottom & slanted sheets

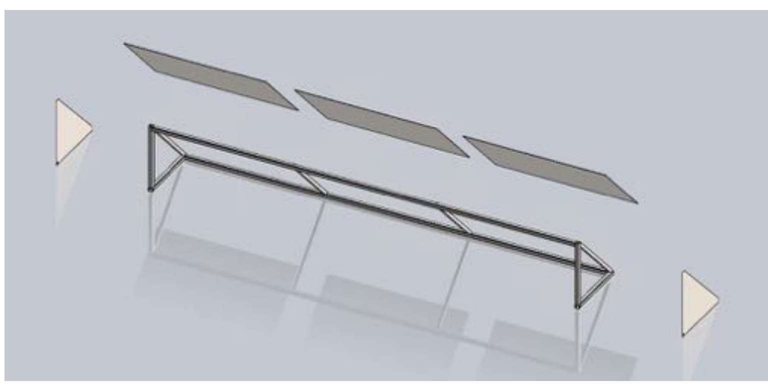

Figure 14. Glycol Containment Unit splash guard

5.2 Safety - DFMEA

The design failure modes and effects analysis was refined throughout the project. The top three areas of potential failures are cart disconnections, damage to the airplane, and fluid overflowing from the cart. The actions to reduce the risk priority number are minor changes to the design. These changes will increase the safety of both the workers, passengers, and the environment.

Table 3. Design Failure Modes and Effects Analysis (top 3 RPNs)

Function or Requirement	Potential Failure Modes	Occurence	Severity	Detection	RPN	Actions to Reduce RPN	Revised Occurance	Revised Severity	Revised Detection	Revised RPN
Safety	Cart disconnects from the tugging vehicle	2	9	5	90	Adding a failsafe to engage brakes if the cart becomes separated from the tugging vehicle	2	3	5	30
Durability	Punctures to the airplane or the cart in a collision	2	9	4	72	Add cushions or safety features to the outside of the cart to reduce damage and potential harm from the cart sliding. Also add snow/studded tires to help reduce slipping	2	6	4	48
Collection Performance	Deicing fluid spills over side	2	5	7	70	Add a grate or wave guard to break the sloshing and contain fluid	1	5	3	15

Collisions to the aircraft could cause delays costing the airlines money on top of the costly damage to the aircraft. On top of the cost, collisions could cause harm to workers and passengers. Attaching manual brakes to each wheel will be able to hinder the movement of the cart at any time. The driver will park their vehicle, get out of the truck, and utilize the brakes to at least two tires. The other safety consideration is that if either the driver backs into the plane or if the brakes fail. Padding will be added to the four corners of the cart. This will prevent significant damage from occurring due to accidental impact.

A failure of collection could be if the driver has to speed up or slow down in such a way to create waves in the cart big enough to spill out onto the ground. Not only is this a potential hazard for workers, but for the environment as well. The goal of the project is to reduce the harmful effects that glycol has on the environment, and a major spill defeats this goal. To mitigate these waves or sloshing, a grate or wave guard can be placed at the top of the cart to constrain the sloshing.

6.0 Feasibility

Keeping in mind that the focus of our project is based around small scale airports where budgets are low, and profits are minimal, the design had to be cost-effective. With the cart design, the goal is to have two collection purposes. The first use of the cart will be to collect the glycol that is generally sprayed onto the ground to warm up the hose before the de-icing begins. The cart will be backed into place near the operator elevated in the boom and remain stationary while glycol is sprayed into the cart. Under normal wind conditions, the goal is to collect 85% of clean glycol during the initial warm-up stage. From the team's observation of a plane de-icing at CMX and the flow rate capabilities of the spray nozzle, it was estimated that 9.35 gallons would be collected per warm up.

After the warm-up stage, the cart will be backed into place, remaining stationary while running parallel with the wing of the plane to collect both runoff and deflected glycol. Figure 15 gives a visual for the orientation of the cart during the deicing process.

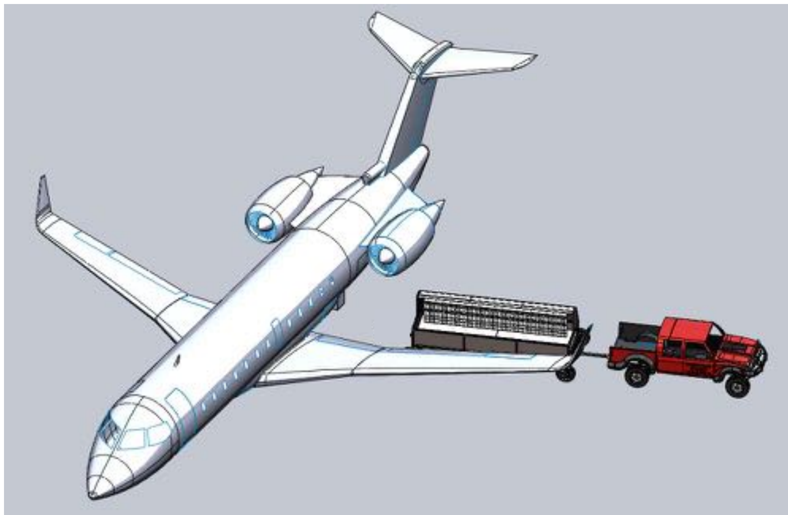

Figure 15. Orientation of cart with respect to wing

The budgets of the smaller airports are tight, so the cart was designed to work largely with existing equipment and operators already involved in the deicing process. The cart will be moved around with an existing pick-up truck readily available onsite. The connection on of the cart will be a pintle hitch for quick connection and disconnection to the pick-up truck. During the deicing process, the team noted a total of three operators involved in the process. The third operator that normally sits on the passenger side of the deicing truck is responsible for doing a physical inspection on the wings after they are de-iced. This operator can be used to maneuver the separate truck and cart into place. The operator can still get out and do his inspection before moving the cart to the other side of the plane. Using the third operator can minimize costs needed for any additional labor.

Timing is also a very important part of the process in order to keep the aircraft on schedule. The team is aware of time that incorporating this collection method may add. Using proper training and planning for the new process, the additional added time is estimated to be minimal; the cart would be moved during the same period as the de-icing truck.

Upon completion of the de-icing, the plane will take off, and the glycol will need to be drained from the cart for permanent storage until it is picked up for recycling. A small gas (or electric) pump and hose will be used to pump the collected glycol from the cart into a plastic storage container inside the hangar. With a flow of 164 GPM, the glycol can be emptied from the cart in a matter of minutes. The plastic storage container will be purchased and has been factored into the overall material cost of the cart along with the pump and hose. The storage container has a 2,000 gallon capacity allowing enough glycol storage for multiple weeks at a time until it can be picked up. There is also a secondary draining system which is a drain hole tapped with a 0.75-inch diameter spigot. This can be used as a back-up system if there is an issue with the pump. The drain hole can also be used to clean and empty the cart of debris build up like dirt.

The maximum amount of glycol expected to be collected during a single de-icing is about 85 gallons. The cart has enough storage for over 1,000 gallons, which leaves excess room to do multiple de-icing operations before draining and storing the glycol in a permanent poly tank. After talking with US Ecology, the highest buyback prices offered come from a higher percentage glycol generally at 15% glycol purity. Something considered was the potential for dilution of the glycol collected once it is sitting in the cart. Exposure to snow and rainfall can dilute the glycol purity. To account for this, a calculation was done based on worst case rainfall which was over two inches. The result confirmed that a worst-case scenario would still result in a collected glycol purity over 20%. Keeping this in mind, it would be best to empty the cart every couple of days to reduce the pollution and dilution of the collected glycol, as this would reduce the buyback price.

7.0 Impact

To prove the efficacy of our design, we explored many factors including recycling benefits, cost analysis, manufacturing analysis, and future projections to show that this cart design is feasible with returns on the investment. As stated earlier, the use of glycol in de-icing planes is effective, but the process is expensive, and thousands of gallons end up in the environment on an annual basis. Our designed product has the potential to both reduce costs and the amount of glycol that ends up in the environment.

As the product stands, our team predicts that, at a minimum, we can expect to capture 25% of the glycol used during the de-icing process, and during warmup, it is expected to reach 85%. Based on these expectations, this eliminates around 18,000 gallons from ending up on the ground, which is a considerable impact on the current runoff amount. If we look even further there are roughly 5,000 public airports in America if 3,000 are small airports and, if half of those are north or mountainous enough to need de-icing and their winters average two months. Then with a 25% capture rate for glycol and 300 gallons maximum used for de-icing, this cart could prevent 6.75 million gallons of glycol from entering the ecosystem each year.

The importance of the impact of our design is evident, and to further show this, a cost analysis model was developed to show the cost of investment vs. the return rate of glycol. This model includes a bill of material which accounts for all costs for the material which is used to manufacture our product. Additionally, a manufacturing model is used to determine the cost to assemble and produce our product. These costs of investment are then placed against the return rate on recycled glycol which ultimately shows that the investment is cost effective and will end up paying for itself before the product’s lifetime is over. Figure 16 in section 7.5 shows the effects that the buyback rate of the glycol has on the payback period of the cart. For example, if the recycling company offers a 5% buyback on the cost per gallon of glycol, it will only take 3 years for the cart to be profitable.

7.1 Competition Goals

The goals for this competition included raising awareness about the ACRP and highlighting the importance of the airports to the National Airspace System infrastructure. The competition gets students involved with current issues surrounding airports. Students are provided a meaningful opportunity to contribute ideas and potential solutions to these issues. While the competition also provides a challenging educational experience, it also raises awareness for students who have an interest in focusing their careers in the airport industry.

The team was able to conceptualize airport operations to be able to find a problem area and then went on to utilize contacts in this industry. Through this educational experience, the team was able to develop a genuine interest in improving operations at small airports and spread awareness of the importance of airports and the ACRP.

7.2 Affordability

After discovering how tight the budgets are at small airports, the cost to implement the cart design into everyday operations became a major driving factor for the project. Exact numbers for a yearly budget were not provided, but it was made clear that any additional cost can cause a major disruption to yearly revenue. Although implementing the cart into everyday operations would have an upfront cost, buyback prices for recycled glycol would cover this cost within the first few years of use,

It is affordable to send the collected de-icing fluid to a recycling center such as US Ecology. A representative from US Ecology gave confirmation that if the fluid sent for recycling has at least a 15% glycol purity, there is potential for transportation costs to be covered by the company. There is also potential for rebates and discounts on future glycol purchases if the composition exceeds this percentage. With prices of deicing fluid around $6.80 per gallon, any discount on pricing will help reduce costs for the year. Type 1 deicing fluid consists of up to 70% glycol, and because the cart is designed to collect the fluid before ground contact, it is likely that the collected glycol sent to US Ecology will exceed the 15% composition threshold. Even with 6” of snow on both wings of the plane, this will only decrease the concentration down to about 28% glycol. This is a worst-case scenario if the plane is not kept in a hanger during heavy snowfall.

7.3 Cost Analysis

In order to show that our product is not only a viable solution to our problem, but also cost effective, and worth the investment, a cost analysis was developed. This system shows the steps that are involved in manufacturing as well as including labor and material cost.

To develop a cost estimation for our product a sum of the purchased materials and components with the additional cost of labor cost (including overhead factor). Labor costs are based on total production time of each operation in manufacturing and are subject to small variances. The labor cost is based on total production time. This includes setup, manufacturing and operations, inspections to meet engineering requirements, testing of assembled units, and clean up.

7.4 Purchased Material and Components

All prices used in the cost analysis system are for one single unit to be manufactured and do not consider a mass production. All prices used in the system are actual prices for each material and component. No materials are subject to bulk discounts and materials donated or discounted are included at usual pricing (no free or discounted materials). Table 4 below gives the individual material cost for each section of the cart. Included in the procedure accessories cost is pumping equipment and a storage container to hold the glycol when the cart is emptied.

Table 4: Total Material Cost

Sub Assembly	Total Costs
Tub Frame	$3,300.00
Tub Frame -Weldment	$640.71
Trailer	$2,524.31
Hitch	$210.00
Procedure Accessories	$1,810.15
Total	**$8,485.43**

7.5 Cost Estimation Table

The cost analysis was done using an Excel sheet and is summarized below (Table 5). This table contains the details for each component and each operation used in manufacturing the GCC. The assembly for each component is based on a one-day assembly production. Each operation is a step in the assembly process with similar operations categorized under the same operation.

Table 5: Manufacturing Cost Details

Manufacturing Cost Details							
	Oper. 1	**Oper. 2**	**Oper. 3**	**Oper. 4**	**Oper. 5**	**Oper. 6**	**Total**
	Cut material to length and prep for welding	**Jig Setup**	**Tack and weld**	**Assemble welded sub assemblies together.**	**Inspect or test**	**Cleanup**	
a. **Total time** to complete operation (HOURS)	2	1.5	1.75	1.5	1	0.5	**8.25 (Hours)**
b. **Labor rate** for operation	$60.00	$60.00	$60.00	$60.00	$60.00	$60.00	
c. Labor cost (a*b)	$120.00	$90.00	$105.00	$90.00	$60.00	$30.00	
D. Overhead factor	1	1	1	1	1	1	
e. Equipment factor	0.5	0.5	0.5	0.5	0.5	0.5	
f. Special operation/ Tolerance factor	0.25	0	0	0	0	0	
g. Labor / Equipment Cost c*(1+d+e+f)	$330.00	$225.00	$262.50	$225.00	$150.00	$75.00	**$1,267.50**

Table 5 breaks down the manufacturing process by taking into account the time and labor rate for each of the operations. The total labor cost for each operation is simply the amount of time to complete an operation multiplied by the hourly rate of each operation. Included also is costs for basic overhead and equipment costs to cover the expense of materials not directly subjected to our product (welding materials, Equipment materials, Basic overhead.

Our product design had the potential to manufacture our scaled prototype glycol collection cart at a very reasonable time and expense. This is due to the simplicity of our design and the focus of removing any part which requires special machining. All parts are of simple geometries and size which allows the manufacturing to essentially be as simple as possible and allows us to manufacture our product for a total expense of $1,267.50. This not only enables us to produce our prototype at a minimal cost but foretells the likelihood of delivering product to our customers at a price which allows for a greatly increased return on their investment while also profitable to the businesses manufacturing and selling the product. Ultimately, manufacturing at a low cost allows for a shorter payback period with recycling de-icing fluid.

Again under normal wind conditions, the goal for collection during the deicing of plane wings is to collect 25% of excess glycol. Based on the assumption that the collected glycol has at least 15% purity, a buyback range of $0.20 to $0.44 per gallon, and assuming 25% collection is achieved, the cart was estimated to pay for itself in a range of years. At $0.20 per gallon (3%) it would take 9 years to be profitable. At $0.27 (4%) it would take 5 years, $0.34 (5%) per gallon would take 4 years, and at $0.44 per gallon (6.5%) it would take 3 years to be profitable. Figure 16 below gives a timeline for profits based on these buyback prices.

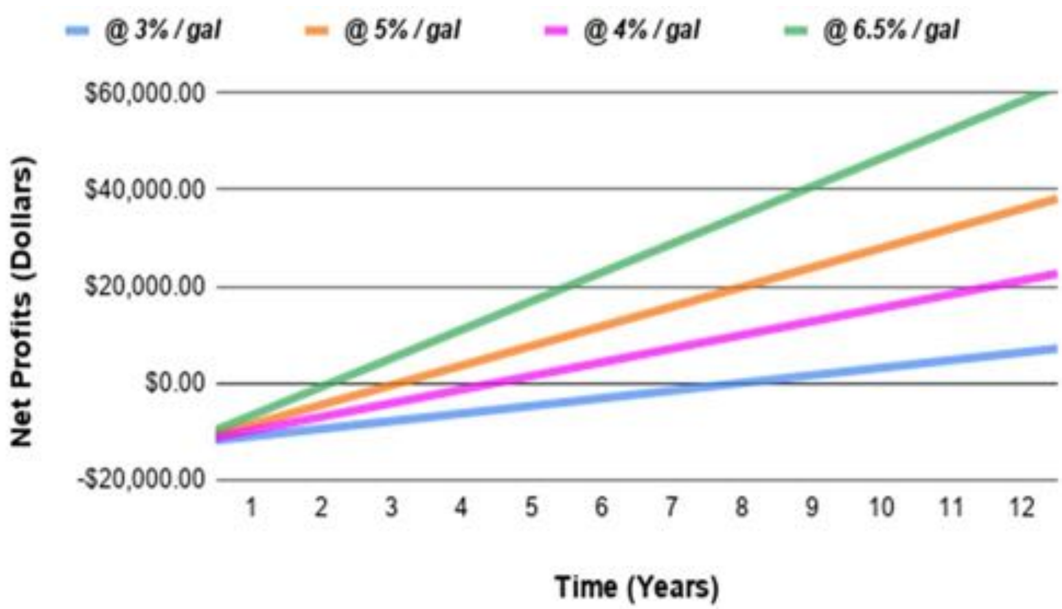

Figure 16: GCC Initial Investment Payback Period

7.6 Potential for design

Our design gives airports the opportunity to decrease the environmental interactions of de-icing fluid in a convenient and inexpensive way. Airport personnel and industry experts were impressed with our simple idea to collect glycol before it hits the ground and believe this project has a future in the industry. This project not only allows small airports to be more environmentally friendly but to make a profit while doing so. Airports will be able to treat this as open-ended design. They will be able to change the height of the GCC as well as what hitches are used to name a few possibilities. This will allow almost every small airport around the nation to use a version of the GCC, without having to buy any other new equipment.

8.0 Conclusion

Our team would love to improve the relationship between small airports and the local environment. That is why the passion behind this project is to introduce a non-invasive element to the deicing process to help preserve local marine life as well as save money for the airports in the process. It is our hope that this may be considered by the ACRP as a viable option for small airports to adopt during the winter months. The price point of the initial investment may seem steep, however, as demonstrated, this can quickly turn a profit. It is simple and requires minimal changes to current operations. It is our view that these factors, as well as the project’s Honorable Mention at the 2020 MTU Senior Design Expo, far outweigh the cost, and the environment will thank you for your service. Our team would also like to thank you for your time and consideration.

Appendix A - List of Contact Information

Undergraduate Students:

Derek Cingel
djcingel@mtu.edu

Jared Langden
jmlangdo@mtu.edu

Bryce Leaf
bleaf@mtu.edu

Ruth Maki
rrmaki@mtu.edu

Douglas Pedersen
dspeders@mtu.edu

Faculty Advisor:

Dr. Paul van Susante
pjvansus@mtu.edu

MTU Senior Capstone Design Program Director:

Dr. William Endres
wjendres@mtu.edu

Appendix B - Description of university (from mtu.edu)

Michigan Technological University, founded in 1885, is a public university located in Houghton, Michigan. Michigan Tech's vision is to create possibilities, inspire learning, and exceed expectations. The undergraduate student body is composed of around 5,800 students with opportunities in more than 120 areas of studies. 63% of the student body is enrolled in the school of engineering, and as of Fall 2018, there were 1,448 students enrolled in mechanical engineering.

Michigan Tech's undergraduate mechanical engineering is 34th in the US and has ranked in the top 27 nationally for the number of degrees awarded for 35 consecutive years. Students enrolled in mechanical engineering at Michigan Tech are introduced to hands-on experience early in the curriculum. They experience Mechanical Engineering Practical courses before their senior capstone to test their capabilities through internship-like experiences to prepare them for the future.

Along with it's high ranking, students are attracted to Michigan Tech's location in the beautiful rural area of the Keweenaw Peninsula, also known as the historic Copper Country. The nature surrounding Michigan Tech provides endless opportunities for students to enjoy the outdoors. Winters can be extreme in the Upper Peninsula of Michigan, but this doesn't stop students from getting out and skiing, snowboarding, snowmobiling, hockey, and broomball.

Appendix C - Non-university contacts

Dennis Hex, Airport Manager, Houghton County Memorial Airport

Nicole Johnson, Skywest Manager, Houghton County Memorial Airport

Roy Hawkins, Planning Engineer, Gerald R. Ford International Airport

Casey Ries, P.E., Engineering & Planning Director, Gerald R. Ford International Airport

Stevens Butler, Operations Service Manager and Environmental Coordinator, Delta Airlines, Gerald R. Ford International Airport

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 Michigan Technological University

List other partnering universities if appropriate: N/A

Design Developed by: ☐ Individual Student ☒ Student Team

If individual student:

Name

Permanent Mailing Address

Permanent Phone Number Email

If student team:

Student Team Lead: Ruth Maki

Permanent Mailing Address 1013 Heather Heath Dr. Howell, MI 48843

Permanent Phone Number (517) 974-3484 Email rrmaki@mtu.edu

Competition Design Challenge Addressed:

Airport Environmental Interactions

Making snow and ice removal more environmentally friendly

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 William J. Endres cn=William J. Endres (MTU), o=Michigan Technological University, ou=Dept. of Mechanical Engg -- Engg Mechanics, email=wjendres@mtu.edu, c=US 2020.05.01 12:28:45 -04'00' Date May 01, 2020

Name * William Endres, Ph.D. | Assoc. Prof. and Director, ME Senior Capstone Design Program

University/College Michigan Technological University

Department(s) Dept. of Mechanical Engineering-Engineering Mechanics

Street Address 1400 Townsend Drive

City Houghton State MI ZIP code 49931

* Dr. Paul van Susante served as the team's immdiate advisor under our program model; Dr. Endres is the main point of contact with overall responsibility for the program, having interaction with all teams.

Appendix E - Evaluation of educational experience

Student Questions

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?

Yes, before starting this challenge I wasn't even aware that de-icing of the plane was an event that happened. Looking back I know that it must have happened but never thought about it. The larger piece to this project was the fact that glycol has such a negative environmental impact. I never realized how it removed oxygen from the water killing local aquatic life.

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

One major challenge we had was Covid-19. We originally had plans to build and test a roughly ⅓ scale model prototype however, about half way through the building process we were no longer able to go on campus. This in turn made us go virtual for the rest of the project. However, this made for learning new communication and time management skills we wouldn’t have learned without such unfortunate events.

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

We were able to provide a hypothesis after doing an initial literature review. After agreeing on the idea of improving deicing methods, we split off and researched different areas of deicing. Once compiling all of the information, we decided it would be a great idea to redesign the nozzle that’s attached to the hose in an attempt to decrease the amount of glycol used during deicing. Once December came and we could go observe a deicing, it was decided that a collection method would be more beneficial than a new nozzle for airports that don’t already utilize collection. We then went on to design the collection cart.

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

Participation was extremely helpful for the team. Without our contacts with the airports, airlines, and recycling company, we wouldn’t have gotten nearly enough data or feedback to have a credible design. It would have been inappropriate and challenging to not get feedback or real data from industry experts, because we would never know if our project would make it in industry . It was also very meaningful to extend our industry contacts as young engineers to be able to keep these positive interactions in our back pockets for future opportunities.

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 the entire process from start to finish from deciding which challenge we were going to take to how we were going to take it on. Then we used all of our knowledge about software and hardware (where applicable). This will help us understand the engineering process when we starting working full time.

Faculty Questions

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

The value is that the students get to think about a real open ended problem with real stakeholders and they have to phrase the problem, possible solutions and evaluations in such a way as to explain their data and analyses to everyone as well as in a convincing manner to the competition audience.

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

Yes, it could be a bit more hardware centric, but the analysis part and scope were fine.

3. What challenges did the students face and overcome?

Lack of a clearly defined scope and hardware component at first. Then later the shutdown due to COVID-19 and remote work.

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

Yes, if a group of students is interested in the particular topics offered.

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

Some help with contacting stakeholders for specific competition topics may be helpful to get the teams started. Not a requirement, but would be a huge help to get started early.

Appendix F - References

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