Title of Design
Glyscreen

Design Challenge Addressed
Airport Operation and Maintenance

University Name
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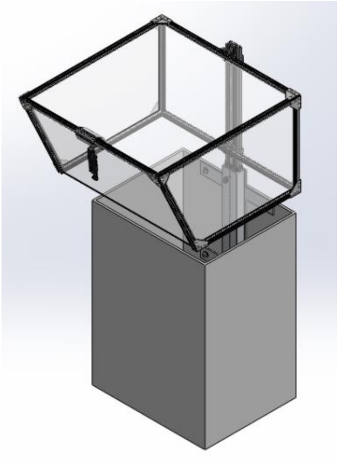

Executive Summary

The accurate application of deicing and anti-icing fluid to the aircraft is imperative for aircraft safety, reduced environmental impact, and reduced airline operating costs. Many airlines still operate less expensive, open-bucket deicing trucks, subjecting the operator to deicing fluid spray back from the aircraft, snow, wind, and rain. Using these open-bucket deicing trucks, the accuracy in application is reduced, reducing aircraft safety, over-consuming deicing fluid, and increasing airline costs. Closed-bucket trucks offer many advanced features, including an enclosed cab to protect the operator, but their costs remain high for an industry operating on a small profit margin. Other after-market enclosures for cabs are insufficient for use on deicing trucks. The design objective was to provide airlines with a low-cost, after-market enclosure compatible with deicing trucks designed to improve visibility conditions for more accurate application of deicing fluid. A dynamic design process utilizing sound systems engineering principles produced an enclosure using aluminum T-slot framing with scratch and ultraviolet resistant polycarbonate windscreens. The enclosure telescopes six inches to provide an optimum set-up for varying operators and features a windshield wiper to improve visibility. The plate is mounted to the inside of deicing truck buckets using six stainless steel bolts. Rigorous engineering stress analysis on the windscreens, frame, telescoping pole, welds, and bolts proved the design was robust and durable, ensuring survival in its extreme service environment. A prototype was developed, and additional changes that provided increased costs without sacrificing safety or quality were realized and incorporated into the design. Safety analysis was performed during the design process using the Preliminary Hazard Analysis. An analysis of the industry impacts shows that the product can be easily utilized due to its minimal efforts for configuration and its cost-effectiveness makes it financially viable for airlines.

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Problem Statement and Background

Aircraft deicing fluid (Type I) is used to remove built-up frost, ice, and snow on airplanes prior to departure and anti-icing fluid (Type IV) is used to prevent this same build-up. Even when the outside air temperature is above freezing, pilots often request deicing or anti-icing operations to remove ice and prevent further accumulation as the aircraft gains altitude. Ice poses a serious threat to aircraft. Ice reduces the lift by changing airflow over the wings, increases the drag, and increases the weight, all reducing aircraft performance. These factors can quickly lead to very dangerous situations. For these reasons, it is extremely important to aircraft safety that the proper amount of deicing fluid is utilized and it is applied correctly to critical aircraft surfaces.

One of the primary ingredients in deicing and anti-icing fluid is glycol. Glycol negatively impacts the environment as it decreases the amount of dissolved oxygen in water sources. This makes it especially hazardous to marine life. Glycol also has a sweet taste, and when ingested, can be equally harmful to terrestrial animals. Airport environmental officials and the Environmental Protection Agency are trying to reduce glycol use due to its adverse environmental impact.

Deicing fluid is also very expensive. Officials at TF Green State Airport in Warwick, Rhode Island (PVD) indicate the fluid has a cost of approximately $4 – $8 per gallon. A large commercial aircraft can require 500 – 1000 gallons of deicing fluid prior to departure. The cost quickly accumulates for airlines. Airlines operate on very tight budgets, especially as fuel costs continue to remain high, and ground equipment, including deicing trucks, is not always a high financial priority. Many deicing trucks used today are open-bucket, exposing the operator applying the deicing fluid to deicing fluid spray-back as well as rain, snow, wind, and cold temperatures. This decreases the accuracy and increases the consumption of deicing and anti-icing fluid for each airplane.

To combat these elements, closed-bucket trucks are manufactured and used throughout the aviation industry. They have been found to be incredibly effective. In a report published in 2000, the Environmental Protection Agency (EPA) indicates that closed-bucket deicing trucks could reduce deicing and anti-icing fluid use by approximately 30%. However, their cost is extremely high and aircrafts operating on tight budgets make limited investments in closed-bucket deicing trucks. Global Ground Equipment, a leading manufacturer in open-bucket and closed-bucket deicing trucks, indicated that they have explored the option of retrofitting open-bucket deicing trucks. They were unable to fully investigate this concept and bring a design to production due to limited funding. Other efforts such as computerized blend-to-temperature stations for blending glycol and water to the minimum concentration for ambient conditions as well as process changes for collecting and treating run-off water contaminated with deicing fluid are widely in-use at major airports.

This project aims to reduce the amount of glycol used in aircraft deicing and anti-icing operations through the design and development of an after-market enclosure for use on open-bucket deicing trucks. The primary goal of this design is to provide a low-cost, effective apparatus for shielding the operator from deicing fluid that sprays back after hitting the airplane that is compatible with a variety of open-bucket deicing trucks. Secondary goals achieved with this design are to provide the operator some protection from harsh environmental elements such as snow, rain, sleet, and wind. Compatibility and cost goals drive the design, making a complete enclosure that provides ideal protection from the outside elements outside the scope of this design.

Literature Review

To facilitate the development of a windshield apparatus, literature and research was reviewed and incorporated from many sources at many phases during the design. FAA regulations, other government publications, patent searches, market competition, and technical information were collected and reviewed.

FAA Regulations and Documents

Jay Brolin, the Environmental Manager for the Rhode Island Airport Corporation (RIAC) suggested the FAA and other expert regulations be researched as they relate to deicing procedures and operations. It was found during this research that the Code of Federal Regulations (CFR) (2012) was integral in understanding the regulations of airport and airline operations during winter conditions. Sec. 121.629 proved especially revealing as it prescribes operating requirements in ice or pre-ice climate conditions. The section provides an informational overview of responsibility for deciding when climates require deicing procedures and insuring the procedures are followed. The section also highlights the specific duties of each operational position and allowable holdover times between deicing operations and departure. Furthermore, the 2012-2013 Holdover Time Tables were examined for detailed time concerns during deicing operations. Another useful document necessary for a comprehensive view of deicing operations was the Standardized International Aircraft Ground Deice Program (SIAGDP) (2008). This document, though not technically a legal document, provides input and recommendations from the international aviation community culminating in a compilation of general guidelines that can be applied in various winter climates around the world. Each of these documents was crucial to the concept development and solution generation phases of this project.

Other Government Publications

Other government publications were also reviewed as part of the literature search. Research was also conducted involving current operational procedures and regulations related to deicing. *Aircraft Deicing Operations* (Vasilyeva, 2009), the Association of European Airlines, the Federal Aviation Administration, and the United States Environmental Protection Agency were all important sources of background information for this design effort.

Patent Searches

Patent searches were conducted regularly throughout the concept and solution generation phases and yielded no conflicting patents. These searches were conducted through the United States Patent and Trade Office (USPTO) using conventional search tools to sort through the large number of relevant patent categories. Preliminary search terms included the following terms: deicing trucks, deicing operations, windshield apparatus, windshield wiper connection, windshield support system, windshield mount, windshield coatings, solar windshields, defogging process and defrosting process. After an initial examination of hundreds of patents, several were selected based on their relevance to the open-bucket deicing truck enclosure concept and potential conflict. The relevant patents are detailed in Table 1. There are current patents for windshields which can be mounted to various riding mowers and motorcycles, but no patented windshields or enclosures exist that are compatible with an open-bucket deicing truck. A thorough review of these patents found that the concepts generated did not infringe on any patents. The patent search was helpful in identifying the opportunity for using commercial-off-the-shelf components to make part of this assembly. Specifically, solutions for clearing the front viewing area with a windshield wiper apparatus and defogging spray were realized from this patent search and implemented in the design.

USPTO Number	Title	Category 1	Category 2
8,171,597	Wiper Mount and wiper apparatus	Clearing Windshield	Wiper
7,945,987	Wiper lever comprising a wiper arm and a wiper blade which is connected to the same in an articulated manner, for cleaning windows, especially windows pertaining to motor vehicles	Clearing Windshield	Wiper
5,753,047	Method, washer apparatus and cleaning agent for cleaning a glass window of a motor vehicle	Clearing Windshield	Coating
8,258,219	Coating composition for wiper blade and wiper blade manufactured there from	Clearing Windshield	Coating
8,043,421	Durable automotive windshield coating and the use thereof	Clearing Windshield	Coating
7,878,054	Barrier coatings for polymeric substrates	Clearing Windshield	Coating
7,138,186	Hydrophobic coatings and methods	Clearing Windshield	Coating
8,157,627	Air conditioning system for the passenger compartment of a vehicle	Clearing Windshield	Defrost/Defog
6,394,890	Defroster deflector	Clearing Windshield	Defrost/Defog
7,811,160	Operating device of vehicle air conditioner	Clearing Windshield	Defrost/Defog
5,514,035	Desiccant based cabin windshield defog/defrost system	Clearing Windshield	Defrost/Defog
6,066,372	Solar heated windshield	Clearing Windshield	Defrost/Defog
8,210,598	Wind blocker arrangement	Structure	Arrangement
7,784,853	Protection device for motor vehicles	Structure	Competitor
7,357,439	Widescreen mounting system	Structure	Mount
6,983,974	Windscreen device for motorcycle	Structure	Competitor
6,412,540	Structural protective windscreen	Structure	Windshield
6,196,614	Motorcycle windshield mount	Structure	Competitor
4,433,868	Cab for walk-behind tractor	Structure	Competitor

Table 1. United States Patents Referenced

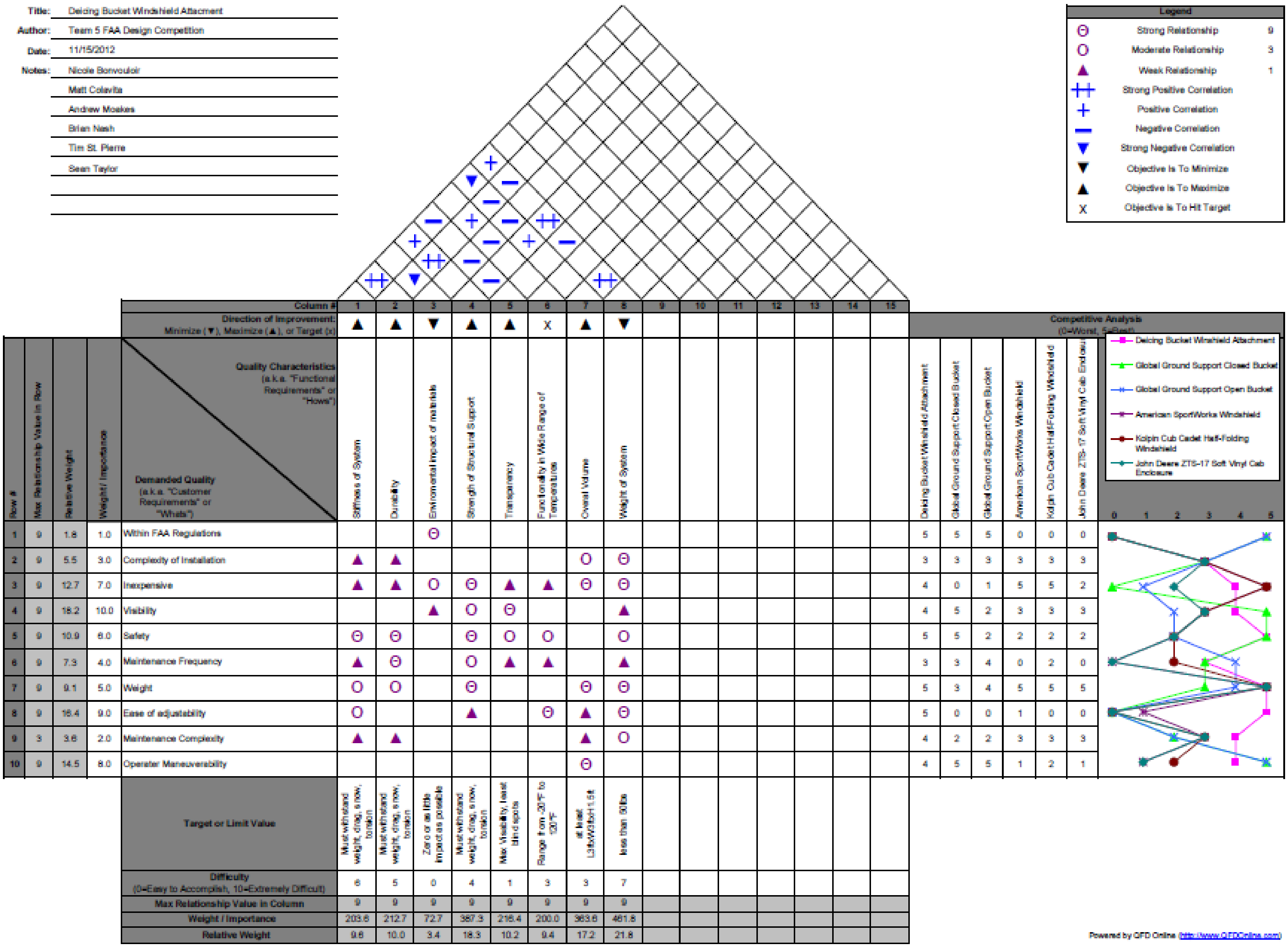
Market Competitors

A market competition analysis was conducted, and several product lines similar to the design concept were researched. A search of the industry leaders of deicing trucks, including Global Ground Support and Premier Deicers, revealed that no retrofit products exited for open-bucket deicing trucks to enclose the operator. Products outside the deicing truck industry were also researched to investigate the feasibility of converting them for this application. Though there were no direct conflicts found during the patent search, the searches provided a starting point for research into cabs and other retrofit windshields for products unrelated to deicing operations, such as tractors, mowers, and utility vehicles. Some of the companies which produce these products include Cub Cadet, John Deere, and Side by Side Sports. During this stage of research, these products were critiqued with a heavy focus on deicing truck dimensions, composition, and other functional and material concerns whose consideration was required given the extreme environment in which this design would operate. No such products were capable of adjusting to the required dimensions or capable of withstanding the extreme operating environment. A quality function deployment analysis, Figure 1, provided a visual model of the relationships between design specifications and a competitive analysis of preexisting products.

Technical Information Used During Engineering Analysis

Appropriate peer-reviewed texts were utilized and referenced during the technical analysis of this design. Many commonly utilized engineering textbooks, including *Shigley's Mechanical Engineering Design* (Budynas, 2009), *Mechanics of Materials* (Gere, 2009), and *Fluid Mechanics* (White, 2008) were referenced regularly as well as peer reviewed articles, including *The Physics of Glaciers* (Cuffy, 2010). These textbooks are all rigorously peer-reviewed and reference more advanced books and manuscripts. The use of these books and journal articles in a comprehensive engineering analysis allowed for an efficient, but rigorous structural analysis of the open-bucket deicing truck enclosure.

Ergonomics, a high priority in this design, were also appropriately researched. The MIL-STD-1472G: Design Criteria Standard – Human Engineering (2012) was the corner piece of the ergonomic design and theoretical analysis. The body dimensions for the ninety-fifth percentile male and fifth percentile female were determined through this standard, allowing an initial spatial design to be specified in the engineering requirements.



Title: Deicing Bucket Windshield Attacment
Author: Team 5 FAA Design Competition
Date: 11/15/2012
Notes: Nicole Bonvoulouir
Matt Colavita
Andrew Moskos
Brian Nash
Tim St. Pierre
Sean Taylor

Legend		
Θ	Strong Relationship	9
O	Moderate Relationship	3
▲	Weak Relationship	1
++	Strong Positive Correlation	
+	Positive Correlation	
—	Negative Correlation	
▼	Strong Negative Correlation	
▼	Objective Is To Minimize	
▲	Objective Is To Maximize	
X	Objective Is To Hit Target	

				Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Competitive Analysis (0=Worst, 5=Best)					
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▲	▲	▼	▲	▲	X	▲	▼													
Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	Stiffness of System	Durability	Enviromental impact of materials	Strength of Structural Support	Transparency	Functionality in Wide Range of Temperatures	Overall Volume	Weight of System								Deicing Bucket Windshield Attachment	Global Ground Support Closed Bucket	Global Ground Support Open Bucket	American SportWorks Windshield	Kolpin Cub Cadet Half-Folding Windshield	John Deere ZTS-17 Soft Vinyl Cab Enclosu
1	9	1.8	1.0	Within FAA Regulations			Θ													5	5	5	0	0	0
2	9	5.5	3.0	Complexity of Installation	▲	▲					O	Θ								3	3	3	3	3	3
3	9	12.7	7.0	Inexpensive	▲	▲	O	Θ	▲	▲	Θ	Θ								4	0	1	5	5	2
4	9	18.2	10.0	Visibility			▲	O	Θ			▲								4	5	2	3	3	3
5	9	10.9	6.0	Safety	Θ	Θ		Θ	O	O		O								5	5	2	2	2	2
6	9	7.3	4.0	Maintenance Frequency	▲	Θ		O	▲	▲		▲								3	3	4	0	2	0
7	9	9.1	5.0	Weight	O	O		Θ			Θ	Θ								5	3	4	5	5	5
8	9	16.4	9.0	Ease of adjustability	O			▲		Θ	▲	Θ								5	0	0	1	0	0
9	3	3.6	2.0	Maintenance Complexity	▲	▲					▲	O								4	2	2	3	3	3
10	9	14.5	8.0	Operater Maneuverability							Θ									4	5	5	1	2	1
				Target or Limit Value	Must withstand weight, drag, snow, torsion	Must withstand weight, drag, snow, torsion	Zero or as little impact as possible	Must withstand weight, drag, snow, torsion	Max Visibility, least blind spots	Range from -20°F to 120°F	at least L3ftxW3ftxH1.5ft	less than 30lbs													
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	6	5	0	4	1	3	3	7													
				Max Relationship Value in Column	9	9	9	9	9	9	9	9													
				Weight / Importance	203.6	212.7	72.7	387.3	216.4	200.0	363.6	461.8													
				Relative Weight	9.6	10.0	3.4	18.3	10.2	9.4	17.2	21.8													

Powered by QFD Online (http://www.QFDOnline.com)

Figure 1. QFD Analysis

Problem Solving Approach

Logistical planning during the design process was largely dependent on the tools widely available in modern industry settings. Specific emphasis during the planning phase was placed on Microsoft Project, Google Drive, Sakai (unique to URI), Excel Project Plan documents, and the Excel Timesheet. Although Google Drive deemed most useful to the group, Microsoft Project was utilized and updated regularly in order to accurately and effectively enumerate tasks, deliverables, goals, and their respective due dates. Figure 2 shows the second semester plan.

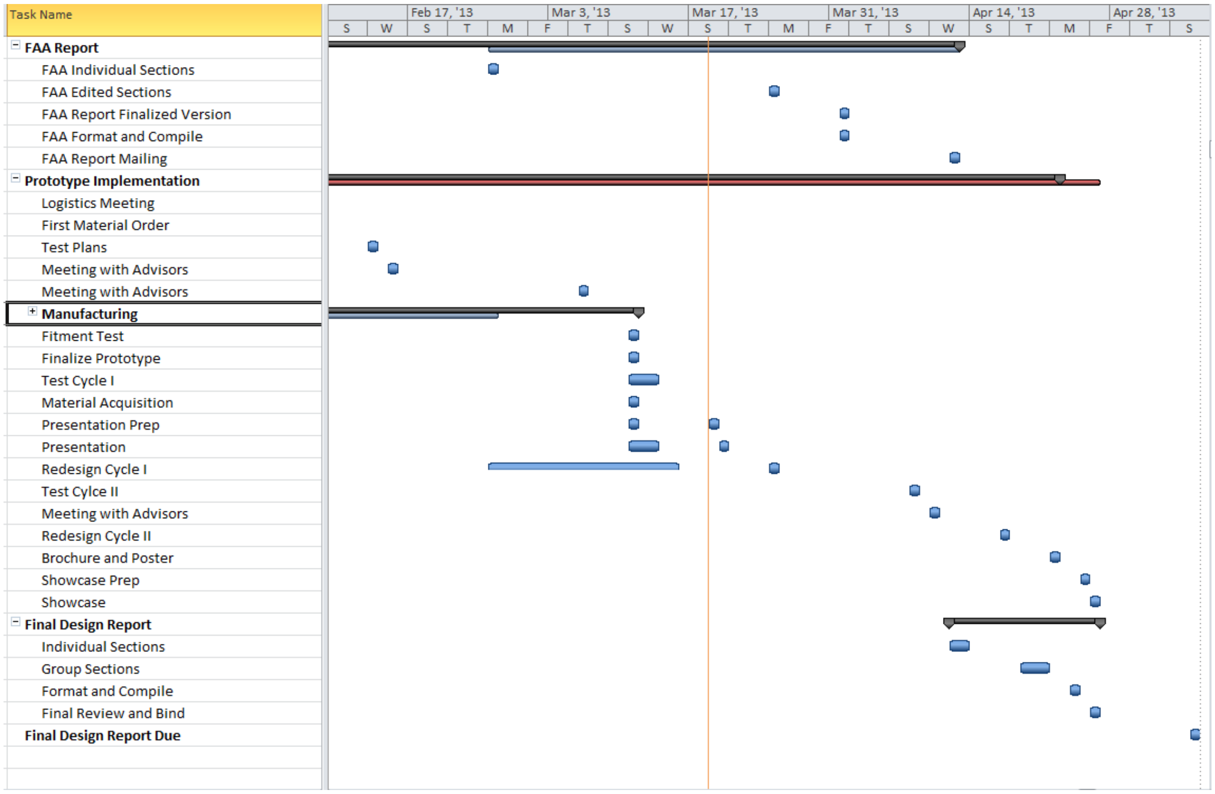

Task Name
FAA Report
FAA Individual Sections
FAA Edited Sections
FAA Report Finalized Version
FAA Format and Compile
FAA Report Mailing
Prototype Implementation
Logistics Meeting
First Material Order
Test Plans
Meeting with Advisors
Meeting with Advisors
Manufacturing
Fitment Test
Finalize Prototype
Test Cycle I
Material Acquisition
Presentation Prep
Presentation
Redesign Cycle I
Test Cylce II
Meeting with Advisors
Redesign Cycle II
Brochure and Poster
Showcase Prep
Showcase
Final Design Report
Individual Sections
Group Sections
Format and Compile
Final Review and Bind
Final Design Report Due

Figure 2. Microsoft Project Plan

Sound systems engineering principles were utilized throughout this project. Concurrent engineering practices were implemented to ensure that the design approach would be efficient, effective, and thorough. Manufacturing and operational factors were heavily considered alongside the engineering design factors at each stage. A flow chart was created to show that the team conducted literature reviews, patent searches, and market and industry research in order to ensure knowledge regarding this problem was obtained and understood prior to design. Using this knowledge, detailed design specifications were derived from the original customer requirements. These design specifications are summarized in Table 2 and provided guidance and direction on all engineering matters as the design was developed.

No.	Requirement	Specification	
Mechanical Compatibility			
1a	Minimum Width	38 inches	
1b	Minimum Length	30 inches	
1c	Maximum Total Weight	70 lbs.	
1d	Bucket Mounting	No Structural Modifications	< 10 Bolt Holes
1e	Bucket Size Compatibility	Adjustable	
Electrical Compatibility			
2a	Maximum Voltage	12 Volts	
Operation			
3a	Controls	Operable with Gloves	
3b	Hose Access	-25° to +25° in Horizontal Plane	
3c	Emergency Shut-Off Valves	Access to	
3d	Hose Use	6 inches Vertical Clearance from -90° to +90° in Horizontal Plane	
3e	Visibility	Unrestricted	
Service Environment			
4a	Temperature Range	≤ - 40°F	≥ 125°F
4b	Materials	Corrosion-Resistant	
4c	Wind Speeds	≤ 40 knots (46 mph)	
4d	UV Degradation	Resistant or Provide Indication Prior to Failure	
4e	Humidity	Up to 100%	
4f	Electrical Components	Rated for Outdoor Use or Protected	
Visibility			
5a	Protection Range in Horizontal Plane	-135° to +135°	
5b	Protection Range in Vertical Plane	60° to 120°	
5c	Clearing Front-View of Fluid	50% of Area	
5d	Clearing Front-View of Fog	100% of Area	
Operator Use			
6a	Minimum Vertical Clearance	74 inches	
6b	Maximum Lifted Weight	50 lbs.	
Cost			
7a	Maximum Total Cost	$1,750	

Table 2. Design Specifications

After the specifications for the windshield frame were established, the preliminary design phase was initiated, with primary efforts focused on concept generation. Brainstorming of an overhead enclosure introduced the basic concept of a nearly cubic design. This would make for ease of modeling, construction, and testing as well as decreased product and assembly costs. Critical details, including the dimensions, were investigated and developed during this phase. Most notably, a review of deicing operations videos made it apparent that the front of the enclosure had to be set at such an angle to allow the operator to lean over the bucket and see and spray downward, when above their application areas. Twenty-five degrees from the vertical plane made a satisfactory compromise between ergonomic needs and stress limitations on the frame. Cardboard box engineering was utilized to provide a low-cost, easily-assembled prototype to verify this angle and other critical dimensions. Three basic concepts were developed to create this enclosure. The first concept used machined aluminum panels welded together with polycarbonate windscreens bolted inside the panels. This concept is shown in Figure 3.The second concept, shown in Figure 5, featured hollow aluminum to form the frame with polycarbonate windscreens bolted to the panels. The third concept utilized 80/20 T-slot extrusions for the frame and secured the windscreens inside the slots, seen in Figure 4.

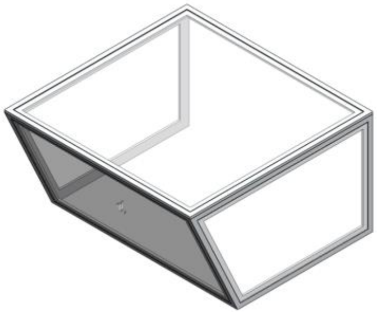


Figure 3. Concept 1 Solid Model

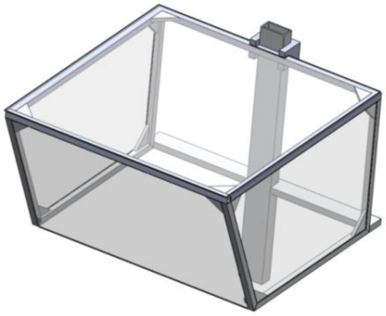


Figure 5. Concept 2 Solid Model

Figure 4. Concept 3 Solid Model

A decision matrix, shown in Table 3, details the systematic evaluation of each concept and the justification of the use of the third concept, the 80/20, Inc. aluminum frame.

Parameter	Weight	Aluminum Welded Plate	Aluminum Square Hollow Tube	80/20 Al Tube
Cost	5	3	3	3
Safety	5	5	4	4
Compatibility	5	2	2	3
Environmental Impact Reduction	4	2.5	2.5	2.5
Durability	4	5	4	4
Compliant	4	5	5	5
Ease of Operation	4	5	5	5
Weight	5	2	3	4
Practicality	4	3	3	3
Cost Savings	3	2	2	3
Ease of Maintenance	3	3	3	3
Ease of Assembly	2	2	2	2
Innovative	2	1	1	1
Appearance	1	4	4	4
Total	255	167	163	180

Table 3. Concept Decision Matrix

Attention also had to be focused on how the enclosure would be attached to different deicing buckets. Whatever support structure used would need to be very simple in form, so that it could fit to a variety of buckets. Since the height of the windshield needed to be adjustable, the support plate needed to allow for vertical motion. It would also have to be mounted in such a way that there would be minimal interference between the operator and key controls behind the boom connection. The team settled on a design that uses an aluminum U-channel welded to an aluminum mounting plate for telescoping motion and six bolted connections to the back of the bucket. This design allows for compatibility with many different bucket geometries simply by configuring the aluminum mounting plate with no other changes to the rest of the design.

A handful of variations and additional features to the design were proposed, and the affordability and other impacts of each were negotiated among all members. Some of the more elaborate ideas that were eliminated due to their high costs and design complexity included a hinged doorway, heated defogging strips inlayed in panels, defrosting blowers, and dimensionally adjustable framing. The team concluded that the final design would require framing, panels, adjustable height, windshield wiper, and an applied anti-fogging agent.

With a concept realized, the critical design phase was initiated, and analysis was conducted. Stress analysis on the bucket connections, frames, and polycarbonate windscreens were completed. Details on these analyses can be found in the Technical Aspects section of this report. Detailed solid models were generated to check for interferences and engineering drawings were produced.

With the design finalized, prototype assembly was conducted. Budgetary constraints required initial redesign efforts to decrease costs. These redesign efforts included a shorter bucket mounting assembly and shortened weld lengths. Relevant analyses were conducted again to ensure safety was not compromised on these efforts. While these changes led to notable cost savings, additional savings needed to be realized for prototype development. At this critical junction, the distinction between the product design and the prototype design became apparent. The prototype was built to best resemble the product design as financially possible. Changes such as replacing stainless steel bolts with steel bolts, scratch-resistant polycarbonate with donated acrylic, and manufacturing many custom parts on-site led to significant cost savings in prototype development without sacrificing the integrity of test and evaluation events.

With a prototype designed, its assembly commenced the test and evaluation phase with the fitment test, an investigation into the mechanical compatibility of the assembly. Other test and evaluation events included an ergonomics test to investigate operator comfort during routine use, a visibility test to investigate the operator’s ability to see with the enclosure in place, and an operator protection test to investigate the ability of the design to shield the operator from the elements. Strength tests to simulate snow loading and side wind forces were also conducted. Detailed test documentation, including test plans, test reports, and a test matrix were generated and maintained during this phase.

After testing is completed, results should indicate what needs to be changed for future redesigns, increased safety features, and also market implementation.

Safety Analysis

Both the safety of the deicing aircraft as well as the deicing truck operator has been a primary goal in this product and its design. The purpose of this product is aimed at increasing the accuracy of deicing fluid application. This creates safer conditions for the departing aircraft and ground personnel. The open-bucket deicing truck enclosure is also designed with safety of the operator in mind. The design is dictated by engineering requirements that put safety as the highest priority. The requirements address visibility issues related to safety including clearing the viewing area of fluid and fog and protecting the operator over critical dimensions. The requirements also address environmental issues linked to safety including wind, corrosion, temperature, and UV exposure. In order to systematically identify, evaluate, and mitigate risks during the design process, the Preliminary Hazard Analysis (PHA) tool was utilized. The PHA was modeled after the example provided in the FAA Advisory Circular (2010) 150 Introduction to Safety Management Systems for Airport Operations. Risk severity and likelihood were analyzed using the benchmarks set forth in AC-150, and the resultant risk was determined using the FAA's five-by-five predicative risk matrix presented in the FAA Safety Management System Manual (2008).

The design effectively responds to risks in its operating environment. A minimum safety factor of two was used throughout the design; however, many safety factors far exceed this minimum providing an extra degree of conservation. The structure's frame and the windscreens are rated for all loading conditions, including side, top, and front drag forces due to wind. The bolted connections to the deicing truck bucket have also been rigorously analyzed and approved for each of these loading conditions. A windshield wiper on the front windscreen helps keep the front viewing area clear of deicing fluid, snow, and rain and provide optimum visibility to the operator. An anti-fogging spray is applied to the inside of the enclosure prior to use to prevent the formation of fog and reduced visibility due to the body heat of the operator. The open-back design allows operator easy and rapid access to the emergency shut-off valves located on the deicing truck boom. All components are rated for performance over a range from subzero temperatures that could be encountered during operation to high temperatures to which the enclosure could be exposed in storage or parked on the ramp during the summer months. The windscreens are resistant to UV degradation, aiding to maintain a clear viewing area for the operator, and they are impact resistant, mitigating the effect of strikes from falling debris or snow. All materials are made of corrosion-resistant aluminum, stainless steel, or plastics to prevent premature degradation and failure of components due to prolonged exposure to water and moisture.

The PHA was an effective tool, driving many of these safety design factors, by identifying and evaluating risks and motivating mitigation approaches. Details on each individual item in the PHA can be seen in Table 4. Of particular note is the hazard that the bucket enclosure limits operator visibility. A risk item associated with this is that the inaccurate application of fluid leaves ice on critical aircraft surfaces. The large loss of life and damage to aircraft that would occur from this risk classify its severity as catastrophic. Without considering any mitigation plans, the likelihood of this occurring is remote. Analyzing these ratings in the predictive risk matrix shows the risk is high. Mitigation in the design includes techniques for clearing the front viewing area of fluid and fog as well as the elimination of a bottom support in the front to reduce blind spots. Even after mitigation and a change in likelihood to extremely remote, the catastrophic severity of this risk still classifies it as a medium risk. While no other risks in the PHA remain as high as the example illustrated above, the same process was conducted for each PHA item. Many of the other risks in the PHA are due to the environment in which the enclosure operates. These risk items include corrosion, UV degradation, loading due to high winds, and the large service temperature range. Effective mitigation in the design reduces these environmental risks to low, and thus can be considered acceptable.

In addition to safety considerations driving this design, the safe operation of this product throughout its lifecycle is emphasized in the operating procedures. Operating procedures for this product prescribe a daily inspection of the open-bucket deicing truck enclosure prior to use, much like an airplane undergoes a pre-flight check prior to flight. This inspection prevents catastrophic failure caused by conditions or events occurring overnight, such as a vehicular accident involved the parked deicing truck with the enclosure attached. The daily inspections are also intended to identify operational problems, such as a windshield wiper failure, prior to deployment.

No.	Hazard	Risk	Justification	Severity	Severity Rationale	Likelihood	Likelihood Rationale	Initial Risk	Mitigation	Residual Risk
1	Bucket Enclosure Limits Operator Visibility	Inaccurate Application of Deicing or Anti-icing Fluid Leaves Ice on Critical Aircraft Surfaces	Fluid build-up on the windscreen or blind spots caused by the frame could reduce operator awareness of ice on airplane	Catastrophic	Risk could lead to aircraft crash, resulting in loss of life and equipment	Remote	Risk could occur but it is unlikely as enclosure should enhance visibility from the current open-bucket levels	High	Mechanism for Clearing Front Windscreen, No Blind Spot on Bottom of Front Windscreen	Medium
		Inaccurate Application Causes Injury to Ground Personnel	Fluid build-up on the windscreen or blind spots caused by the frame could reduce operator awareness of ground personnel	Major	Risk could lead to injury/death for ground personnel or damage to equipment	Remote	Risk could occur but it is unlikely as enclosure should enhance visibility from the current open-bucket levels	High		Low
2	Bucket Limits Access to Emergency Valves	Delay in shutting off hoses in an emergency situation	Mechanical interferences due to the enclosure could impede access to emergency shut-off valves	Hazardous	Risk could lead to injury for ground personnel or damage to equipment	Extremely Remote	Risk could occur but it is highly unlikely given the rarity of these events combined with the enclosure's simple design	Medium	Open-back design, Reducing structural framing in back	Low
3	Electrical Equipment Operation in Water-Filled Environments	Electrical Fire	Electrical equipment exposed to rain, snow, sleet, and deicing fluid could short circuit	Hazardous	Risk could cause injury/death to deicing truck operator but minimal risk to others	Remote	Risk could occur under heavy precipitation conditions without adequate protection, but not likely under normal circumstances	High	Use of outdoor-rated electrical equipment and/or adequate protection	Low
4	Windscreen Impact	Operator Injury Due Windscreen Failure From Subjected Impact	Windscreen could be subject to falling debris or ice	Major	Risk could cause injury to deicing truck operator but minimal risk to others	Remote	Risk could occur but it is unlikely due to the position of enclosure on the airfield	Medium	Use of Impact-Resistant Polycarbonate Windscreens	Low
5	High Winds	High Winds Cause Frame Failure	High winds could create drag force on the enclosure, leading to excessive loading	Major	Risk could cause injury to deicing truck but minimal risk to others	Remote	Risk could occur if wind gusts are higher than reported by ATIS	Medium	Frame Designed For Maximum Wind Conditions of Deicing Trucks, Safety Factor	Low
6	Corrosive Environment	Frame Failure Due to Corrosion	Prolonged exposure to rain, snow, sleet, and deicing fluid could cause corrosion of metal components	Major	Risk could cause injury to deicing truck but minimal risk to others	Remote	Risk could occur, but signs of failure would be present before catastrophic failure	Medium	Use of Corrosion-Resistant Materials	Low
7	UV Environment	Windscreen Failure Due to UV Degradation	Prolonged exposure to the sun, including while the unit sits on the ground during summer, could cause UV degradation	Major	Risk could cause injury to deicing truck but minimal risk to others	Remote	Risk could occur, but signs of failure would be present before catastrophic failure	Medium	Use of Materials Resistant to UV Degradation	Low
8	Large Temperature Range	Temperature Fluctuations Cause Failure	Extreme temperature range could alter material properties, reducing strength	Major	Risk could cause injury to deicing truck but minimal risk to others	Remote	Risk could occur, but signs of failure would be present before catastrophic failure	Medium	Use of Materials Rated for Temperature Range	Low
9	Heavy Objects Requiring Lifting	Operator Injury When Adjusting Height	Operator could injure him/herself while adjusting enclosure height due weight of lifted load and minimal maneuverability in confined spaces	Major	Risk could cause injury to deicing truck but minimal risk to others	Remote	Risk could occur, but additional nearby workers would mitigate the likelihood	Medium	Lifted Weights in Accordance with OSHA Standards	Low

Table 4. PHA Table

Technical Aspects

The engineering analysis performed on the open-bucket deicing truck enclosure is detailed below. A weight analysis was performed on the assembly to ensure the weight requirements would be met. The loads due to wind forces and snow forces were calculated for evaluation of the strength of the enclosure. These values were used to perform a windscreen finite element analysis, structural analysis on the telescoping pole, analysis of the aluminum u-channel welds, analysis of the connections between the frame and the telescoping pole, and an analysis of the bolts connected the assembly to the deicing truck bucket. The most critical conditions were found to be drag forces due to wind from the side of the enclosure. These calculations are detailed below. Top and front drag force calculations were also performed, but are excluded from this report as the calculation process was the same. Detailed engineering drawings were produced and the first page of the design package can be seen in Figure 9. To include the whole design package would be too cumbersome.

Drag Forces

The following assumptions were made when calculating the drag force on the windscreens:

1. The drag force is calculated as flow past an immersed body.
2. The air density is assumed to be 0.0897 lb/ft^3. This is the highest air density in which the product will be operated. The temperature, humidity, and elevation were all considered when determining the highest air density.
3. The drag coefficient is that of a three-dimensional flat plate and equal to 1.17 (White, 2009).
4. The maximum wind speed in which the product will be operated in is 40 knots (46 mph).
5. The fluid is assumed to exert a drag force over the cross-sectional area of the windscreen. The cross-sectional area of the support structure is assumed to be negligible.

6. The maximum drag force will occur when the flow is perpendicular to the windscreen surface.

Equation 1 provides the relationship for the drag force, where F_D is the drag force, C_D is the drag coefficient, A is the surface area, v is the fluid velocity, and ρ is the density of the air.

$$F_D = \frac{1}{2}\rho v^2 C_D$$

Equation 1 (White, 2008)

The drag force on the side windscreen is solved using the parameters in Table 5. The front, side, and top drag forces are found to be 49.74 lbf, 35.90 lbf, and 70.11 lbf respectively.

Velocity	ν	67.5124	f/s
Cross-Sectional Area	A	4.833	ft^2
Air Density	ρ	0.0897	lbm/ft^3
Drag Coefficient	C_d	1.17	
Side Drag Force	F_D	35.90	lbf

Table 5. Side Drag Force Calculations

Telescoping Pole

The follow assumptions were made when analyzing the telescoping pole:

1. The telescoping pole is assumed to be an eccentrically loaded column fixed at one end and free at the other.
2. The y-component (longitudinal) of the front drag force is assumed to act with a lever arm equal to the length of the telescoping pole.
3. The displacement caused by the load eccentricity and the deflection due to the y-component of the front drag force are summed to calculate the total deflection when calculating the moment for eccentric loading.
4. The maximum weight of snow build-up on top of the enclosure is 130 pounds.

A buckling analysis on the telescoping pole was required due to its high length to width ratio and compressive loading. For a column fixed at one end and free at the other, the critical load for buckling is given by Equation 2.

$$P_{cr} = \frac{\pi^2 EI}{4L^2}$$

Equation 2 (Gere, 2009)

For the values listed below in Table 6, the critical load is found to be 14,786 lbf.

Young's Modulus	E	10000.00	ksi
Moment of Inertia	I	1.8127	in^4
Length	L	55	in.
Critical Load	P_{cr}	14,786	lbf

Table 6. Critical Load Calculations

The maximum moment for an eccentrically loaded column is given by Equation 3.

$$M_{Max} = P * e * \sec\left(\frac{\pi}{2}\sqrt{\frac{P}{P_{cr}}}\right)$$

Equation 3 (Gere, 2009)

The complex geometry of the cross-section requires the shear stress in the telescoping pole can be solved by finite element analysis. A torque of 666 in-lbs was applied at the top of pole. The bottom of the pole was fixed over the length inside the aluminum U-frame at the poles highest extension. The maximum von Mises stress due to the torsion was found to be 11,130 psi in Figure 6.

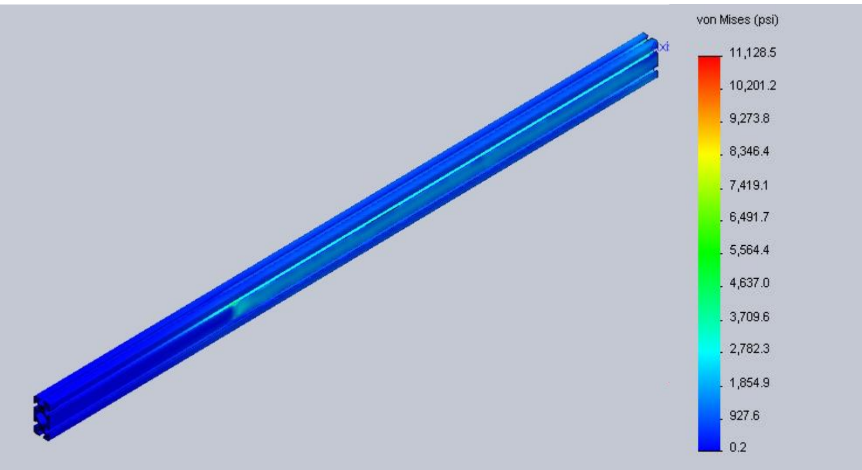


Figure 6. Telescoping Pole FEA

The normal stress due to the bending of the pole is a combination of the normal stress due to the weight and the stress due to bending from the side drag force. The normal stress is given by Equation 4.

$$\sigma = -\frac{F_D L w}{I} + \sigma_{weight}$$

Equation 4 (Budynas, 2009)

The maximum shear stress due to bending is found in Equation 5.

$$\tau_b = \frac{3V}{2A} = \frac{3F_D}{2A}$$

Equation 5 (Budynas, 2009)

The von Mises stress due to the bending is obtained from Equation 6.

$$\sigma' = \frac{1}{\sqrt{2}}\left[\left(\sigma_x - \sigma_y\right)^2 + \left(\sigma_y - \sigma_z\right)^2 + (\sigma_z - \sigma_x)^2 + 6\left(\tau_{xy}^2 + \tau_{yz}^2 + \tau_{zx}^2\right)\right]^{\frac{1}{2}}$$

Equation 6 (Budynas, 2009)

Length	L	55	in.
Moment of Inertia	I	1.8127	in^4
Width	w	1.5	in.
Drag Force	F_D	35.9	lbf
Windscreen CG y distance	y	20.365	in.
Normal Stress Due to Weight	σ_z	**-1,349.040**	psi
Normal Stress Due to Drag Force	σ_z	**-816.944**	psi
Total Normal Stress	σ_z	**-2165.984**	psi
Bending Shear Stress	τ_b	**26.281**	psi
von Mises Stress Due To Bending	σ'_b	**2166.46**	psi
von Mises	σ’	**13296.46**	psi
Safety Factor	n	**2.63**	

Table 7. Stress Due to Weight and Side Drag Calculations

Welding Analysis

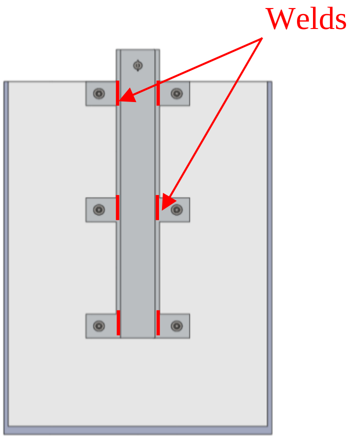


Figure 7. Weld Connection

The area of the double-line weld is given in by Equation 7.

$$A = 1.414hd$$ Equation 7 (Budynas, 2009)

The unit second polar moment of area of the double-line weld is given by Equation 8.

$$J_u = \frac{d(3b^2+d^2)}{6}$$ Equation 8 (Budynas, 2009)

The unit second moments of area of the double-line weld for bending in the YZ plane and for bending in the XZ are given by Equation 9 and Equation 10 respectively.

$$I_u = \frac{d^3}{6}$$ Equation 9 (Budynas, 2009)

$$I_u = \frac{bd^2}{2}$$ Equation 10 (Budynas, 2009)

The total second polar moment of area and the total second moments of area are calculated by Equation 11 and Equation 12 respectively.

$$J = 0.707hJ_u$$ Equation 11 (Budynas, 2009)

$$I = 0.707hI_u$$ Equation 12 (Budynas, 2009)

The weld properties are calculated, and the results are shown in Table 8.

Weld Thickness	h	0.25	in.
Weld Size	b	4	in.
Weld Size	d	9	in.
Weld Strength	τmax	35,000	psi
Maximum distance	rmax	**18.111**	in.
Theta	θ	**0.111**	rad
Weld Area	A	**3.182**	in^2
Unit Second Polar Moment of Area	Ju	**2016**	in^3
Unit Second Moment of Area for Bending in yz Plane	Iu	**121.5**	in^3
Unit Second Moment of Area for Bending in xz Plane	Iu	**72**	in^3
Polar Moment of Area	J	**356.328**	in^4
Second Moment of Area for Bending in yz Plane	I	**21.475125**	in^4
Second Moment of Area for Bending in xz Plane	I	**12.726**	in^4

Table 8. Weld Properties Calculations

The total shear stress in the weld has two components. The primary shear stress is caused by the load itself and is given by Equation 13. The secondary shear stress is caused due to loading away from the weld centroid. Secondary shear stresses can be caused by bending or by torsion and are given for each case in Equation 14 and Equation 15 respectively.

$$\tau' = \frac{V}{A}$$

Equation 13 (Budynas, 2009)

$$\tau" = \frac{M_{max}c}{I}$$

Equation 14 (Budynas, 2009)

$$\tau" = \frac{Mr}{J}$$

Equation 15 (Budynas, 2009)

To calculate the stress on the weld due to the side drag force, the primary shear due to the horizontal and vertical forces was added as vector to the secondary shear caused by torsion and the secondary shear caused by bending. The bending and torsional moments are the same as calculated as for the telescoping pole stress analysis.

Vertical Force	Fz	**-49.74**	lbf
Horizontal Force	Fx	**35.9**	lbf
Maximum Bending Moment	Mmax,yz	**-3060.013222**	lbf-in
Maximum Torsion Moment	Mmax,xy	**1462.207**	lbf-in
Maximum Bending Moment	Mmax,xz	**2620.7**	lbf-in
Primary Shear Stress Due to Vertical Force	$\tau'v$	**15.6341**	psi
Primary Shear Stress Due to Horizontal Force	$\tau'h$	**11.284**	psi
Secondary Shear Stress Due to yz Bending	τ''	**2564.839**	psi
Secondary Shear Stress Due to Torsion	τ''	**74.318**	psi
Secondary Shear Stress Due to xz Bending	τ''	**411.865**	psi
Total Shear Stress	τ	**3063.998**	psi
Safety Factor	n	**11.42298551**	

Table 9. Weld Stress Calculations Due to Weight and Side Drag

Frame Analysis

A finite element analysis was performed on the 80/20 1010 series aluminum tubing in order to ensure that the framing materials would not fail under stress and to estimate total deflection of bars. Two types of tests were performed on a section of 1010 framing of a length of 36 inches, the average length of tubing in the frame section. A value of 125-150% of the maximum operating forces that the frame would experience under normal operating conditions was applied to the sample of frame in order to observe deflection and to calculate factor of safety of the materials yield strength. The minimum safety factor was found to be 2.34.

Bolt Analysis

The bolts connecting the open-bucket deicing truck enclosure to the bucket required analysis to ensure the connections was strong enough to withstand the applied loads. The selected bolts were 1-1/2” long, ½”-13 UNC threads, 316 stainless steel socket head cap screws. They are arranged as shown in Figure 7. The following assumptions are made:

1. The shear force is carried evenly by all six bolts.
2. The threaded area of the bolt is assumed to be 0.1419 in^2 (Budynas, 2009).

3. When calculating the member stiffness for the fiberglass bucket, the fiberglass behaves according to the general expression for the exponential curve fit with variables A = 0.78952 and B = 0.62914.
4. When calculating the member stiffness for the aluminum mounting plate, the aluminum behaves according to the expression for aluminum for the exponential curve fit with variables A = 0.79670 and B = 0.63816.
5. The bottom of the bucket provides no upward force to support the connection and counter the applied loads.

Bolt Loading

The radial distance from the bolt centroid to the bolt is the same as for welds. The total shear force on the nth bolt is the vector-sum of the primary shear given in Equation 16 and the secondary shear force given in Equation 17.

$$F' = \frac{V}{n}$$

Equation 16 (Budynas, 2009)

$$F_n" = \frac{M_{max} r_n}{r_A^2 + r_B^2 + \cdots}$$

Equation 17 (Budynas, 2009)

In Equation 17, the bending moment M_{max} is bending in the XZ plane. However, bending in the YZ plane adds tension to the bolt. The tension load on the bolts due to this moment is given by Equation 18.

$$P = \frac{M_{max} r}{\sum r_j^2}$$

Equation 18 (Lee, 2011)

Bolt Loading Due to Weight and Side Drag

The primary and secondary shear force and the tension load in the bolt due to the weight and top drag are calculated using the values in Table 10.

Vertical Force (Weight)	Fz	**-49.74**	lbf
Horizontal Force	Fx	**35.9**	lbf
Max. Moment in xz Plane	Mmax,xz	**2620.7**	lbf-in
Max. Moment in yz Plane	Mmax,yz	**-3060.013222**	lbf-in
Max. Moment in xy Plane	Mmax,xy	**1462.207**	lbf-in
Primary Vertical Shear	Fv'	**8.290**	lbf
Primary Horizontal Shear	Fh'	**5.983**	lbf
Secondary Shear at 1	F''	**13.223**	lbf
Secondary Shear at 2	F''	**40.561**	lbf
Total Shear at 1	F	**22.370**	lbf
Total Shear at 2	F	**49.273**	lbf
Tension Load at r1	P1	**22.816**	lbf
Tension Load at r2	P2	**69.991**	lbf

Table 10. Bolt Calculations Due to Weight and Side Drag

Bolt Stiffness

The threaded length, the unthreaded grip length, the threaded grip length, and the unthreaded cross-sectional area are given by Equations 19(a-d).

$$L_T = 2d + \frac{1}{4}$$
$$l_d = L - L_T$$
$$l_t = l - l_d$$
$$A_d = \frac{\pi d^2}{4}$$

Equations 19(a-d) (Budynas, 2009)

The threaded area (A_t) for ½”-13 UNC bolt is 0.1419 in^2 (Shigley’s, Table 8-2). The bolt stiffness is given by Equation 20 and calculated using the values found in Table 11.

$$k_b = \frac{A_d A_t E}{A_d l_t + A_t l_d}$$

Equation 20 (Budynas, 2009)

Diameter	d	0.50	in.
Bolt Length	L	1.25	in.
Aluminum Thickness	l	0.25	in.
Material Thickness	l	0.5	in.
Young's Modulus	E	27.6	Mpsi
Tensile Strength	S_y	70,000	psi
Threaded Length	L_T	**1.25**	in.
Unthreaded Grip	l_d	**0**	in.
Length of Threaded Grip	l_t	**0.75**	in.
Unthreaded Area	A_d	**0.196**	in^2
Threaded Area	A_t	0.1419	in^2
Bolt Stiffness	k_b	**5.22192**	Mlbf/in

Table 11. Bolt Stiffness Calculations

Member Stiffness

The member stiffness is shown in Equation 21. A relationship derived numerically for the individual member stiffness is given in Equation 22. For aluminum, the values for A and B in Equation 22 are 0.79670 and 0.63816 respectively. For the general case, the values for A and B are 0.78952 and 0.62914 respectively. As there are no values given for fiberglass, the values for the general case are used to calculate the member stiffness of the fiberglass (Budynas, 2009). The total member stiffness is calculated using the values in Table 12.

$$\frac{1}{k_m} = \frac{1}{k_1} + \frac{1}{k_2} + \cdots$$

Equation 21 (Budynas, 2009)

$$\frac{k_m}{Ed} = A \exp\left(\frac{Bd}{l}\right)$$

Equation 22 (Budynas, 2009)

Fiberglass Young's Modulus	E	9.9	Mpsi
Constant	A	0.78952	
Constant	B	0.62914	
Fiber Glass Stiffness	k_{m1}	**7.331627**	Mlbf/in
Aluminum Young's Modulus	E	10.4	Mpsi
Constant	A	0.7967	
Constant	B	0.63816	
Aluminum Stiffness	k_{m2}	**14.84557**	Mlbf/in
Total Material Stiffness	k_m	**4.907842**	Mlbf/in

Table 12. Member Stiffness Calculations

Bolt Factors

The load factor is given by Equation 23 and is used in Equation 24 and Equation 25 to calculate the percentage of the tensile load taken by the bolt and the percentage of the load taken by the member in those equations.

$$C = \frac{k_b}{k_b + k_m}$$

Equation 23 (Budynas, 2009)

$$P_b = CP$$

Equation 24 (Budynas, 2009)

$$P_m = (1 - C)P$$

Equation 25 (Budynas, 2009)

The proof strength of the bolt is the product of the tensile area and the proof strength. It is given in Equation 26. The proof strength for stainless steel is not provided directly by Shigley's, however the general formula given in Equation 27 is used to calculate the proof strength.

$$F_p = A_t S_p$$

Equation 26 (Budynas, 2009)

$$S_p = 0.85 S_y$$

Equation 27 (Budynas, 2009)

The preload in the bolt is given by Equation 28, which is the recommendation from Shigley's for permanent connections. The total force taken by the bolt is the sum of the preload and the applied load taken by the bolt. This is given in Equation 29. The stress in the bolt is given in Equation 30.

$$F_i = 0.90 F_p$$

Equation 28 (Budynas, 2009)

$$F_b = F_i + P_b$$

Equation 29 (Budynas, 2009)

$$\sigma_b = \frac{F_b}{A_t}$$

Equation 30 (Budynas, 2009)

The yielding factor, the load factor, and the joint separation factor for this connection are calculated with Equation 31, Equation 32, and Equation 33 using the values found with the above equations. The calculated values are shown in Table 13.

$$n_p = \frac{S_p}{\sigma_b}$$

Equation 31 (Budynas, 2009)

$$n_L = \frac{S_p A_t - F_i}{CP}$$

Equation 32 (Budynas, 2009)

$$n_o = \frac{F_i}{P(1 - C)}$$

Equation 33 (Budynas, 2009)

Load Fraction	C	**0.516**	
Load Taken by Bolt	Pb	**78.906**	lbf
Load Taken by Member	Pm	**74.160**	lbf
Proof Strength	Sp	**59500**	psi
Proof Force	Fp	**8443.05**	lbf
Preload	Fi	**7598.745**	lbf
Bolt Force	Fb	**7677.651**	lbf
Member Force	Fm	**-7524.585**	lbf
Bolt Tensile Stress	σb	**54106.06**	psi
Yielding Factor	np	**1.099692**	
Load Factor	nL	**10.7002**	
Joint Separation	n0	**102.4647**	
Bolt Shear Stress	τ	**347.2363**	psi
Shear Strength	τmax	**38990**	psi
Safety Factor	n	**112.2867**	

Table 13. Bolt Factor Calculations

The yielding factor was calculated to be 1.09. The load factor was found to be 10.70 and the joint separation factor was found to be 112.29.

Bolt Shear Stress

The maximum shear stress in the bolt was calculated by taking the highest resolved shear force and dividing by the threaded area. The safety factor was found to be 84.34. The details of the calculations are provided in Table 14.

Bolt Shear Stress	τ	**462.2549**	psi
Shear Strength	τ_{max}	**38990**	psi
Safety Factor	n	**84.3474**	

Table 14. Bolt Shear Stress Calculations

Connections Analysis

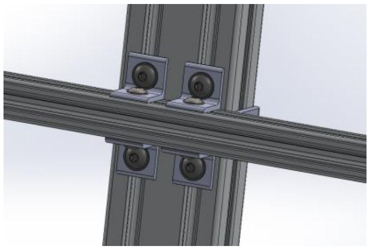


Figure 8. Connection Assembly

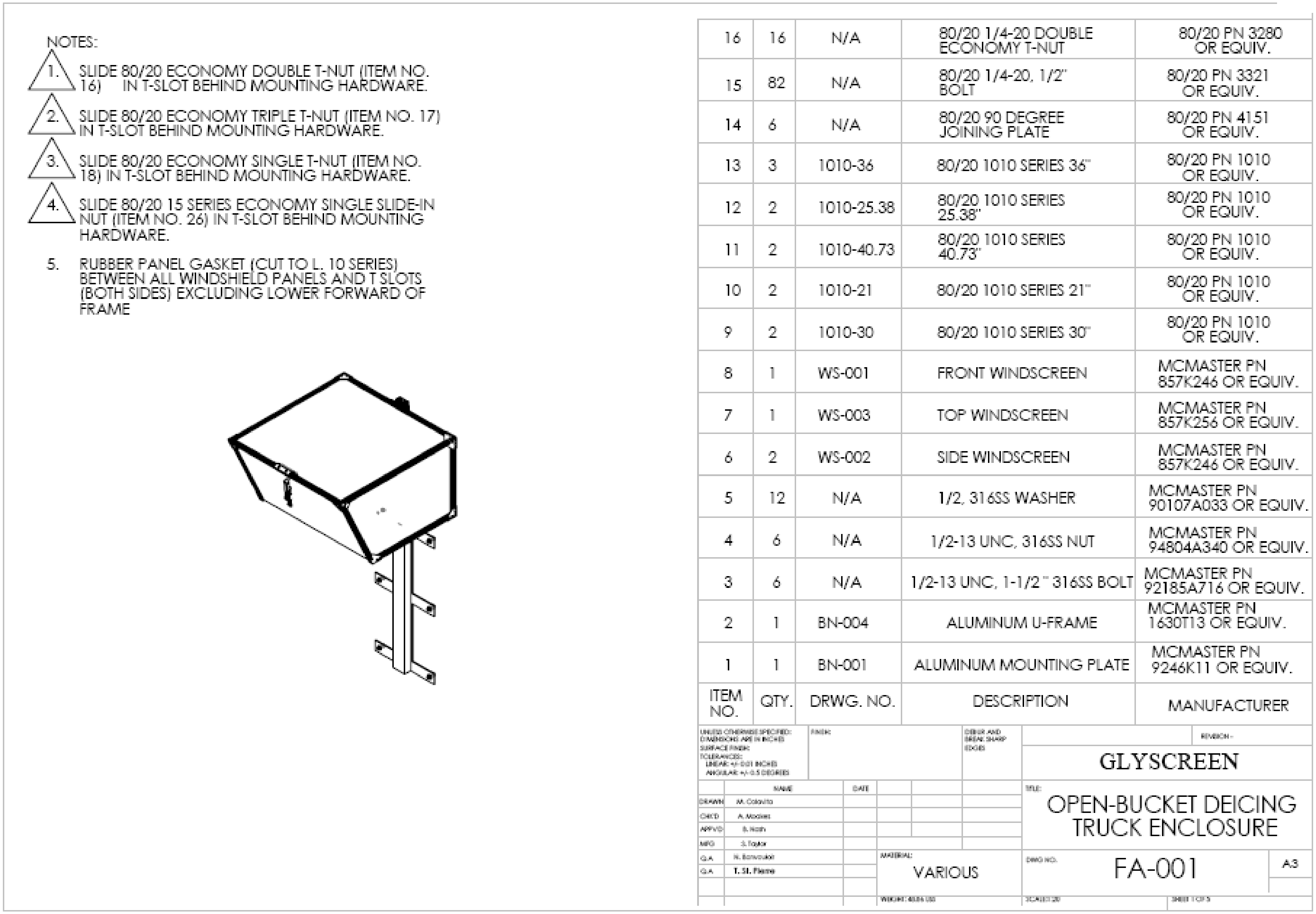
Two groupings of connections attach the enclosure frame to the telescoping pole as shown in Figure 8. Due to the varying orientations of the corner gussets in the designed connection assembly, their behavior and strengths in their coordinate system needs to be converted to the strength they provide the assembly in its coordinate system. When analyzing the force at the joint, all of the joints provide the same strength. Therefore, the total strength of the joint for vertical forces can be found by multiplying the individual strength by the total number of gusset corners. When analyzing the bending moment (in the YZ plane) of the enclosure, the corner gussets aligned vertically are stressed as a moment, and the corner gussets aligned horizontally are stressed in torsion. When analyzing the torsion (in the XY plane) of the enclosure, the corner gussets aligned vertically are in stressed in torsion and the corner gussets aligned horizontally are stressed in bending. These interactions produce strength results as shown in Table 15.

Connection Assembly	Load at Joint (lbs)	Moment (in-lbs)	Torsion (in-lbs)
Strength	3900	9520	3580
Applied Load/Moment	120	2487.6	670
Safety Factor	32.50	3.83	5.34

Table 15. Connection Assembly Strength and Safety Factors

Ball Lock Pin Analysis

The ball lock pin is a 3/8 inch diameter, 2 inch long, 17-4 precipitation hardened stainless steel ball lock pin. It is rated at 18,400 pounds. The maximum force the ball lock pin will experience is 170 pounds. This provides a safety factor of 108.



NOTES:

1. SLIDE 80/20 ECONOMY DOUBLE T-NUT (ITEM NO. 16) IN T-SLOT BEHIND MOUNTING HARDWARE.
2. SLIDE 80/20 ECONOMY TRIPLE T-NUT (ITEM NO. 17) IN T-SLOT BEHIND MOUNTING HARDWARE.
3. SLIDE 80/20 ECONOMY SINGLE T-NUT (ITEM NO. 18) IN T-SLOT BEHIND MOUNTING HARDWARE.
4. SLIDE 80/20 15 SERIES ECONOMY SINGLE SLIDE-IN NUT (ITEM NO. 26) IN T-SLOT BEHIND MOUNTING HARDWARE.
5. RUBBER PANEL GASKET (CUT TO L. 10 SERIES) BETWEEN ALL WINDSHIELD PANELS AND T SLOTS (BOTH SIDES) EXCLUDING LOWER FORWARD OF FRAME

ITEM NO.	QTY.	DRWG. NO.	DESCRIPTION	MANUFACTURER
16	16	N/A	80/20 1/4-20 DOUBLE ECONOMY T-NUT	80/20 PN 3280 OR EQUIV.
15	82	N/A	80/20 1/4-20, 1/2" BOLT	80/20 PN 3321 OR EQUIV.
14	6	N/A	80/20 90 DEGREE JOINING PLATE	80/20 PN 4151 OR EQUIV.
13	3	1010-36	80/20 1010 SERIES 36"	80/20 PN 1010 OR EQUIV.
12	2	1010-25.38	80/20 1010 SERIES 25.38"	80/20 PN 1010 OR EQUIV.
11	2	1010-40.73	80/20 1010 SERIES 40.73"	80/20 PN 1010 OR EQUIV.
10	2	1010-21	80/20 1010 SERIES 21"	80/20 PN 1010 OR EQUIV.
9	2	1010-30	80/20 1010 SERIES 30"	80/20 PN 1010 OR EQUIV.
8	1	WS-001	FRONT WINDSCREEN	MCMASTER PN 857K246 OR EQUIV.
7	1	WS-003	TOP WINDSCREEN	MCMASTER PN 857K256 OR EQUIV.
6	2	WS-002	SIDE WINDSCREEN	MCMASTER PN 857K246 OR EQUIV.
5	12	N/A	1/2, 316SS WASHER	MCMASTER PN 90107A033 OR EQUIV.
4	6	N/A	1/2-13 UNC, 316SS NUT	MCMASTER PN 94804A340 OR EQUIV.
3	6	N/A	1/2-13 UNC, 1-1/2" 316SS BOLT	MCMASTER PN 92185A716 OR EQUIV.
2	1	BN-004	ALUMINUM U-FRAME	MCMASTER PN 1630T13 OR EQUIV.
1	1	BN-001	ALUMINUM MOUNTING PLATE	MCMASTER PN 9246K11 OR EQUIV.

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
SURFACE FINISH:
TOLERANCES:
LINEAR: +/- 0.01 INCHES
ANGULAR: +/- 0.5 DEGREES

FINISH:

DEBUR AND BREAK SHARP EDGES

	NAME	DATE
DRAWN	M. Colavito	
CHK'D	A. Morales	
APPV'D	B. Nash	
MFG	J. Taylor	
Q.A	N. Bonvouloir	
Q.A	T. St. Pierre	

MATERIAL: VARIOUS

WEIGHT: 40.86 LBS

REVISION -

GLYSCREEN

TITLE: OPEN-BUCKET DEICING TRUCK ENCLOSURE

DWG NO. FA-001

A3

SCALE 1:20

SHEET 1 OF 5

Figure 9. Drawing Package Cover Page

Airport Operator and Industry Expert Interactions

In an effort to seek an understanding of the airport deicing process and FAA regulations, the team engaged in demonstrative and informational meetings with several aviation and engineering professionals. Each of these individuals had an immense impact on the design, prototyping, and testing processes involved in the creation and implementation of the open-bucket enclosure system.

Rhode Island Airport Corporation (RIAC), a semiautonomous subsidiary of the former Rhode Island Port Authority (now known as the Rhode Island Economic Development Corporation), sponsored the design team. RIAC is responsible for the design, construction, operation, and maintenance of Rhode Island’s state-owned airports. They also supervise all civil airports including landing areas, navigation facilities, and air schools. Jay Brolin, RIAC Environmental Manager, James Warcup, RIAC Aeronautics Inspector, and Daniel Porter, RIAC Airport Planner, were all involved in an initial consultation with RIAC. During this meeting, problems and preliminary design concepts were presented by the team on a range of issues from snow handling to airport personnel situational awareness. RIAC provided feedback and guidance on these topics, and also introduced other topics to be considered, including reducing glycol consumption during deicing operations. Their guidance was paramount in selecting this topic. Mr. Brolin served as the team’s primary point of contact at RIAC. After the initial problem definition meeting, Mr. Brolin and Mr. Porter provided an on-site tour of T.F. Green State Airport (PVD), RIAC’s busiest airport, focusing primarily on deicing operations, equipment, maintenance, and relevant logistic concerns. During this visit, several informal interviews with airport operations specialists and glycol farm operators and supervisors. This site visit provided critical information used when evaluating the design concepts, and ultimately led to the selection of the open-bucket deicing truck enclosure as the chosen concept. Information was also collected during this visit for use during redesign and optimization of the product. Mr. Brolin provided the cost differential between closed and open bucket systems as approximately $20,000 for an original equipment manufacturer (OEM) truck. This information was a key factor in affirming the benefits of a retrofit open bucket enclosure product. Throughout the semester, Mr. Brolin and RIAC were contacted in regards to several questions or concerns as they related to the project. They were also regularly updated with the group's progress and invited to several presentations of concept, design, and redesign.

Premier Engineering & Manufacturing, Inc. (Premier), a large deicing truck manufacturer, provided instructional details relevant to the operation of their deicing trucks. Mr. Jerry Derusha, Premier, Inc. President, was the main point of contact. Various emails and phone calls were exchanged with Mr. Derusha throughout the design process between October and February. The information gathered from Premier was paramount to initial design concerns, especially as they related to a universal retrofit. The dimensions of several truck buckets and their construction material were obtained during these interactions. Premier also provided valuable insight about the structure of bottom structure of currently available truck buckets. This was especially helpful in determining whether the design should account for grated or solid bottom buckets. The information provided was also used in designing a connection that could fit the maximum number of bucket variations with minimal increase in difficulty and cost of installation. Mr. Derusha also provided details on the electrical connections available in the bucket and his recommendations to include a windshield wiper led the team to follow this path. During redesign and testing, Mr. Derusha provided critical insight regarding the windscreens, leading to an upgrade to scratch and ultraviolet resistant polycarbonate.

Impacts

The open-bucket deicing truck enclosure is in alignment with the FAA’s Destination 2025 vision. Most notably, the enclosure offers increased safety, one of the cornerstones of Destination 2025, through improved deicing truck operator visibility and protection. The design helps achieve the FAA’s desired outcomes for no accident-related fatalities by mitigating the risk of icing-related incidents. The design process also effectively applies the tools and principles of the FAA’s Safety Management Systems Manual to provide a safe product to both passengers and ground operators. As a low cost option, the enclosure can be used at smaller general aviation airports, helping the FAA to achieve its goal of reducing general aviation accidents to no more than 1 fatal accident per 100,000 flight hours. Furthermore, the enclosure reduces the environmental impact of deicing operations by providing glycol consumption savings. The enclosure can play a role in achieving environmental sustainability, another fundamental cornerstone of Destination 2025, and its strategy to eliminate impacts on water-quality in communities near airports.

During the market research stage it became clear that there have been attempts at a similar product, but none that are currently successful in North America. A retrofit enclosure for deicing trucks would be very useful at most North American airports, but has yet to be as successful as the versions available in Europe which have displayed moderate success due to its marketability and relative affordability. This project also offers the potential to further increase awareness of FAA goals, specifically as they relate to environmental preservation and general airport operations. Environmental sustainability is one of the cornerstones of Destination 2025, and one of the specific strategies is “to eliminate water-quality impacts.” The open-bucket deicing truck enclosure helps the FAA strive to achieve this goal.

This project has the potential to increase the efficiency of deicing operations at airports experiencing medium to heavy precipitation. These goals will be accomplished largely through an increase in visibility. This increase of visibility will provide a direct increase to efficiency of glycol application. This efficiency increase will lead to quicker application and hence shorter lead times on takeoff preparation for planes. Additional benefits would include cost reduction in deicing operations and through reduced volume dispensation, decreased environmental impact.

The commercial potential of this product has been demonstrated empirically through market success in similar markets that are not in direct competition. This commercial potential is also obvious through quantitative analysis of current market conditions. The smallest differential currently available between deicing trucks with similar qualities except enclosure status is approximately $20,000. The estimated cost for prototype assembly begins at approximately $1,500, but will range upwards depending on level of quality applied during further redesign cycles. Even with a generous increase in production and assembly cost, this product has outstanding potential for maintaining profit margins without unethical gouging of the available customer base.

Due to economic constraints, the design prototype has been significantly scaled back. Before the product reaches market, there are various specific alterations, improvements, and adjustments to be made. Such adjustments will be made to the polycarbonate, the windshield wiper, the ball lock pin, and the overhang distance. Each of these components has been redesigned for the prototype to be more economically and ergonomically friendly. The production method will also be scaled down because the team is only creating one prototype assembly, whereas when the assembly goes to market, it will be done via mass production.

The polycarbonate panels should be replaced with DOT 2 polycarbonate or an equivalent abrasion and impact resistant low density material. If a material is chosen which has significantly different mechanical attributes from typical impact-resistant polycarbonates, failure analysis of the material must be rerun. The addition of this abrasion resistance to current specifications will prolong the service life cycles of panels, increasing long term visibility and reducing customer maintenance costs. This abrasion resistance is absolutely necessary if the windshield wiper assembly is mounted on the enclosure.

The use of a windshield wiper will greatly increase functional visibility during inclement weather conditions, but will have the adverse effect of greatly increasing the frequency of abrasive forces acting on the windshield. This is in large part related to the unpredictable and uncontrollable nature of outdoor equipment operation and cannot be directly prevented. With the alteration of the previously mentioned panels to include abrasion resistance, the effects of this environment should be mitigated.

Ergonomic concerns in the current prototype include the ball lock pin and the overhang distance. The ball lock pin was purchased with a primary concern of safety followed directly by cost. In the final version of this product the ball lock pin should be switched for a slightly more expensive but more aesthetically pleasing and functional model. This will result in a two-fold benefit of professional appearance and an indirect increase in both actual and perceived functionality due to operator comfort and ease of use. It is important to note that the changes made to the prototype have been effectively incorporated into the design and are factored into the cost-benefit analysis below. Future efforts related to these design aspects are related purely to manufacturing and production.

The last potential improvement of this design was related to the production method. With respect to the resources available during the design and production of an initial prototype it was economically advisable to use off the shelf components provided by 80/20. If this product was to be mass produced it should be noted that overall costs could be reduced by investing initially in an extrusion die and cutting equipment for production of the aluminum cross bar extrusions. Due to the simplistic nature of the custom cuts and drilling, the long term savings of this initial investment could potentially be high. However, it should be noted that it is unclear whether the polycarbonate could be produced in reasonable quantities while maintaining an increased profit margin. Therefore, it is advisable to avoid uninformed investment in extrusion or molding equipment for these panels.

Ongoing work at this time is focused on decisively proving benefits through rigorous testing. The key marketable benefits of this design project are centered largely on socio-economic concerns. This enclosure will mimic the behavior of close bucket systems, already shown by the EPA to reduce glycol use by nearly 30% through more accurate and effective application of the fluid. During initial analysis of this enclosure, it was determined that increased visibility was the dominant factor in this reduction.

This enclosure’s behavior should lead to a reduction in glycol use during inclement weather of up to 30%. Aside from the benefit of not harming the environment (the worth of which is beyond the scope of this project) there is a marked decrease in operation cost at airports using similar products. Glycol costs range between $6 and $8 per gallon depending on the volume purchased wholesale and is consumed at a rate of 500-1000 gallons per application at airports experiencing subfreezing climate conditions. This leads to an average cost ranging from $3000 to $8000 per application within the regions of interest. This cost does not include labor of the employees which was estimated, with the help of Mr. Brolin from RIAC, to be $400-$500 dollars per day.

While the open-bucket deicing truck enclosure does not provide the operator with the same level of protection and comfort as the closed-bucket variants, it is difficult to extrapolate the effectiveness of the enclosure, but it is clear that the reduction of back spray and improvement of ergonomics will be mimicked to a degree that will create at least a five percent reduction in glycol use. This is a low-end estimate due to the inconclusively of any tests at this time and has the potential to range as high as fifteen percent in ideal situations. These glycol reduction percentages are based solely on empirical evidence from the current prototype build. If the low end estimate of five percent is applied to daily glycol operation costs, the cost per day will drop from between $3400 and $8500 to between $3250 and $7600. This savings of $150 to $900 per a day is a statistically significant number as the current build cost is $1500 and the cost differential between open and closed bucket trucks is $20,000. This leaves room for a healthy profit margin while still maintaining strong customer returns per cost. It is important to note that the product cost will shrink as markets of scale are approached. Current costs are based on single item purchases through off the shelf vendors and may be reduced through production within the company itself or by bulk purchases.

Appendix A – Contact Information

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Appendix B – University Description

University of Rhode Island

The University of Rhode Island, founded in 1892, is Rhode Island's public, learner-centered research university, holding accreditation from the New England Association of Schools and Colleges (NEASC). It is the only public institution in the state offering undergraduate, graduate, and professional students the distinctive educational opportunities of a major research university. The main campus is on 1,200 acres in Kingston, Rhode Island with three satellite campuses: Feinstein Providence Campus, Narragansett Bay Campus, and the W. Alton Jones Campus. As of this past fall, there are 13,398 undergraduate students and 3,053 graduate students, of those students, 9,882 are in-state residents and 6,569 are from out-of-state or international. There are over 80 majors offered at the university from eight degree granting colleges: Arts and Sciences, Business Administration, Continuing Education, Engineering, Environmental and Life Sciences, Human Science and Services, Nursing, and Pharmacy.

College of Engineering

The College of Engineering at the University of Rhode Island has the vision to be "a global leader in engineering education and research." Their diverse community of scholars, students, and professional staff is devoted to the development and application of advanced methods and technologies. The college offers eight different engineering programs to its undergraduates: Biomedical, Chemical, Civil, Computer, Electrical, Industrial and Systems, Mechanical, and Ocean. The college, accredited by the Accreditation Board for Engineering and Technology (ABET) educates all focuses to be creative problem solvers, innovators, inventors, and entrepreneurs and to utilize those skills in the advancement of our society's knowledge.

Appendix C – Non-University Partner Descriptions

Rhode Island Airport Corporation

The Rhode Island Airport Corporation (RIAC) was formed on December 9, 1992 as a semiautonomous subsidiary of the then Rhode Island Port Authority, now the Rhode Island Economic Development Corporation, to operate and maintain the state's airport system. The powers of the corporation are vested in its seven-member Board of Directors, six appointed by the Governor, and one appointed by the Mayor of the City of Warwick. RIAC is responsible for the design, construction, operation and maintenance of the six state-owned airports, and the supervision of all civil airports, landing areas, navigation facilities, air school, and flying clubs. In addition to T.F. Green Airport, RIAC is responsible for five general aviation airports throughout the state: Block Island, Newport, North Central, Quonset, and Westerly.

Premier Engineering & Manufacturing, Inc.

Premier Engineering & Manufacturing, Inc. (Premier) entered the deicing arena in 1991 in Marquette, Michigan as a service and support company for existing aircraft deicers. After relocating to Marinette, WI in 1992, the company began to boom with their primary focuses on creating solutions to existing problems and guaranteeing customer satisfaction. It now operates from a 23,000 square foot production facility where some of the most extreme weather in the country takes place to accommodate for a prime testing ground. Premier has utilized state of the art technology with innovative solutions to create a robust deicer with a low cost of operation for customer appeal.

Air Inc.

Air Inc. is New England’s leading distributor of pneumatic automation components, controls and accessories. Entering the world of distribution in 1946, the company has built a reputation by maintaining large inventories of the superior product lines they distribute. One line in particular that they distribute is 80/20 Inc.

80/20 Inc.

80/20 Inc. was formed in 1989 as the first Industrial Erector Set. Starting off as a small company with the philosophy from an ancient Chinese proverb, “there is a main in the world who will never be turned down…he is the man who delivers the goods,” the company has grown significantly. Today, the company produces and sells over 6,500 products ranging anywhere from T-slot framing to linear bearings to T-nuts. The company works on an “80/20 attitude” meaning 80% of their results come from 20% of their efforts, which directly reflects in their service to their customers as well as the decades of industry experience, and willingness to do what it takes to get the job done.

Appendix E – Evaluations

Student Evaluation

The FAA Design Competition provided a meaningful learning experience for the design team. The competition offered the team an opportunity to utilize the skills and knowledge gained over many years of academic and professional study. This application of these skills helped the team hone and refine these skills as well gain additional understanding and perspective regarding engineering principles and the engineering design process. The team faced a handful of challenges, as does any design team, when developing the open-bucket deicing truck enclosure. The biggest challenge was being denied a research grant from the University to sponsor the project and the associated scheduling delays associated with the lack of funding. The team overcame this challenge by proposing funding from the Department of Mechanical, Industrial, and Systems Engineering and the College of Engineering. The team also developed a scaled back prototype to adequately build and examine the design without incurring unnecessary costs. The team developed the hypothesis after consulting with the Rhode Island Airport Corporation and conducting industry research. The EPA's 2000 report on deicing operations provided important information regarding deicing operations as an environmental problem as well as validating the effectiveness of improving operator protection. Participation from industry, including the Rhode Island Airport Corporation (RIAC) and Premier Manufacturing and Engineering, Inc was incredibly important to the design process. RIAC provided important background knowledge and guidance during topic selection and concept generation. Premier provided outstanding technical information to help the design team generate design specifications and evaluate the design at different points in the process.

This project helped the team learn and further refine technical skills regarding both solid mechanics and fluid dynamics as well as the use of computer-based solvers such as finite element analysis and the computer-aided drafting and design program Solidworks. The team also learned and refined systems engineering techniques include developing and utilizing Gantt charts, decision matrices, and detailed design specifications. These skills will help the team be successful in the workplace as it gives the members additional experience in the same processes and practices that will be utilized as a full-time engineer.

Advisor Evaluation

To: FAA Design Competition

This was the fourth year that our university and engineering program participated in the FAA design competition. I selected this competition as one of the projects for my senior capstone design course in mechanical, industrial, and systems engineering because the program description and particularly timeline was an excellent match for my project requirements. Our senior capstone design sequence starts in the fall of the senior year and concludes in the following spring semester.

The value of the educational experience for students participating was excellent. In particular, interactions with our local Rhode Island Airport Corporation (RIAC) were outstanding and we received tremendous support from the engineering staff there. The students conducted a broad and comprehensive search through the problem space outlined by the FAA design competition and identified a problem of significance to RIAC that is also of significant interest nationally (and perhaps internationally).

The most significant challenge for the students at the beginning was to identify, define, and research the problem(s) of interest. This search was conducted over a period of two months which delayed them somewhat during the fall semester. This delay was necessary because of the broad scope definition of problems provided by the FAA design competition and the necessary interaction time with the state airport corporation staff.

The student team has done an excellent job in thoroughly exploring their problem (improving safety and operations during aircraft deicing). They have designed a practical and economical solution. They have prototyped their solution and have obtained reasonable results to pursue the creation of an engineered product. This is exactly the type of process and experience that we expect for our students on design projects. I am very pleased with the competition process, project solicitation, and organization of the FAA design competition. I will definitely use this competition again in the future if it will be continued.

If you have any questions or need additional information, please contact me.

Sincerely,

Bahram Nassersharif

Bahram Nassersharif, Ph.D.

Distinguished University Professor

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