Research and Implications Report

by
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1. Introduction

They say time flies -- and that is especially true for the first two terms of Senior Design. Our team is tasked with designing and fabricating a system that interfaces with an open-source underwater ROV (remotely operated vehicle) and attaches onto an iceberg to perform an analysis of its melting characteristics. The main goals I am responsible for are designing the attachment system and properly enclosing water-sensitive subsystems. My experience so far with this project is unique. Achieving those goals requires a great deal of knowledge in areas that are not closely related to electrical and computer engineering, which I have little. This report will discuss the mechanical challenges that I encountered while working on the project. Additionally, the report will serve as a reference to anyone working on this project in the future.

2. Summary of Expert Topic Areas and Design Challenges

Let's start with some background. I will explain why the goals that I am responsible for are necessary for the success of the entire system and the reasons they prove challenging.

2.1 Waterproofing

First off, the reason why the sensitive components need to be waterproof is somewhat self-explanatory. Since this ROV will be operating submerged in ten meters of water, the waterproof design really needs to be robust. Additionally, since we will carry out missions in the ocean, the water will contain different compounds that are corrosive[1] (but mostly it's salt). This adds additional constraints to our enclosures. The challenges addressing these constraints are listed in Table 1.

Challenge	Research Addressing Challenge
Waterproofing components up to the expected operational depth is non-trivial.	Design, Implementation, and Control of the Underwater Legged Robot AquaShoko for Low-Signature Underwater Exploration Design and Prototyping of a Waterproof Probe Enclosure Handbook of Electrical Insulating Materials for Deep Ocean Applications (this is a good source because the US Military has poured millions into testing things that go deep-sea. Seriously, this is an interesting read).
Operating in seawater poses risks of corrosion on certain materials.	Electroplating for the Amateur (this is a deep find, I found it on an ad in a 1974 issue of Popular Science).

[1] https://iopscience.iop.org/article/10.1088/1755-1315/108/2/022037/pdf

	Handbook of Electrical Insulating Materials for Deep Ocean Applications
Materials should not be able to break off of the structure and risk contaminating the ocean environment.	Talking to June Marion (jmarion.ceoas@gmail.com). She has experience in the field working on harnessing that is approved for use.

Table 1: Waterproofing Challenges

2.2 Iceberg Attachment

Secondly, why do we need to securely attach to an iceberg? In order to maintain a constant proximity to the ice for measurement, we must have some way of rigidly attaching ourselves to it. There are some certain criteria for what would make a good attachment in this situation. A good ROV iceberg attachment method should be:

1.) Able to attach and detach as quickly as possible to maximize the duration of available measurement time,
2.) Robust enough to withstand any water currents exerting a force that would push/pull the iceberg out of configuration,
3.) Energy efficient, such that the power required is reasonable considering all other design constraints,
4.) Cost effective, such that building the device is achievable within the budget constraints imposed on our group,
5.) Time effective, such that one person could conceivably design and build in nine months.

The challenges for meeting these criteria are listed in Table 2.

Challenge	**Research Addressing Challenge**
The clients suggestion of drilling into the ice may prove to fail the speed criteria for being a good attachment method.	- US Patent 3,680,645: Method and Device for Drilling Holes in Ice - US Patent 8,006,780 B2: Method of Attachment of a Towing Anchor to an Iceberg - US Patent 4,223,627: Propulsion Device for Embedding in an Iceberg
The clients suggestion of drilling into the ice may prove to fail the cost effective criteria for being a good attachment method.	^ See above.
The clients suggestion of drilling into the ice may prove to fail the time effective criteria for being a good attachment method.	^ See above.

Table 2: Attachment Method Challenges

Drilling into ice — underwater, nonetheless, poses quite arduous. As described in the patents found in Table 2, high speed drilling creates a large amount of friction, melting the ice surrounding the attachment hole. On the other hand, low speed, high torque drills require a lot of pressure be applied in the direction of drilling, as well as a high torque capability. Motors that satisfy this torque requirement use a gearing system that brings a lot of waterproofing complications with it, and will therefore fail the third criteria in Table 2. Additionally, the ROV does not have a repetitively large forward thrust (19.8 lbf). To get the best of both worlds: motors that provide high torque and are waterproof, would cost far more than we have available [2], failing the second criteria. Due to these limitations of attaching via drilling into ice, another method was chosen and will be discussed in a subsequent section.

2.3 Design Challenge Drivers

To tie the two challenges on a single thread, I must stress how interconnected they are. For example, a design limitation on the waterproofing side may drive a design decision for the attachment system and vice versa. This made accomplishing many of the challenges very time intensive and some were not able to be solved as of yet.

3. Challenge One: Waterproof Enclosure Design

Now that we have some background on the specifics of the requirements and challenges faced during the design, lets dive a little bit into the chosen design solutions. For the waterproofing challenge, it was clear from the extensive research done by Eric Lindqvist and Nikolaj Grondahl[3] to find the "perfect" water-proof seal, that an O-ring solution would maximize performance and cost effectiveness in our situation. In addition, it would allow us to seal and reseal the enclosure multiple times for access to the components inside. Similarly to their enclosure, I chose to create a design with a double O-ring seal. I designed a CAD model with these features in mind which can be seen in Figure 2. The enclosure will be made out of polyurethane, or more specifically ultra-high-molecular-weight polyethylene (UHWP), which was chosen for:

1.) Its low cost[4] and machinability[5],
2.) Its resistance to the corrosive environment found in the ocean[6] as further indicated by Figure 1.

The enclosure will be sent off as a CAD file to June Marion to fabricate in the OSU Buoy Lab Machine Shop. She has access to a CNC mill that can accurately produce the desired components.

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[2] Hydraulic Motor
[3] Design and Prototyping of a Waterproof Probe Enclosure
[4] Polyurethane Material Purchase
[5] Machining Polyurethanes
[6] Polyurethane Chemical Properties

Technical Handbook

Chemical Resistance Table

Chemical or Material Conveyed	Butyl	CPE	EPDM	CSM	TPC-ET	Natural	Neoprene	Nitrile	Nylon	SBR	TPV	PTFE	UHMW	Urethane	FKM	XLPE
SODIUM ACETATE	E		E	C		E	G	G	G	X		E	E	X	X	E
SODIUM ALUMINATE	E		E	E		G	E	E	G	G		E	E		E	E
SODIUM BICARBONATE	E		E	E	G	E	E	E	E	E		E	E	E	E	E
SODIUM BISULFATE	E	X	E	E	C	E	E	G	C	G		E	E	E	E	E
SODIUM BISULFITE	E		E	E	G	E	E	E	E	G		E	E	E	E	C
SODIUM BORATE	E		E	E	G	E	E	E	E	E		E	E	G	E	E
SODIUM CARBONATE 10 % – 15 %	G	G	E	E	G	E	E	E	G	E		E	E	G	E	E
SODIUM CHLORATE			E												E	
SODIUM CHLORIDE	G	G	E	E	E	E	E	E	G	E	C	E	E	E	E	E
SODIUM CYANIDE	E	G	E	E	G	E	E	E	E	E		E	E	G	E	E
SODIUM DICHROMATE	E		C	G		X	C	E	G	G		E	E	G	C	G
SODIUM FLUORIDE			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SODIUM HYDRATE	E	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SODIUM HYDROCHLORITE	G	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SODIUM HYDROXIDE (CAUSTIC SODA)	E	C	E	E	C	E	G	C	G	G	C	E	E	C	G	E
SODIUM HYPOCHLORITE	G	X	G	G	C	X	C	X	X	C	C	E	E	C	C	G
SODIUM METAPHOSPHATE	G		E	G		E	G	E	E	E		E	E	G	E	E
SODIUM NITRATE	E	G	E	E	G	G	G	G	E	G		E	E	G	E	E
SODIUM PERBORATE	E	X	E	G	G	G	G	G	E	G		E	E	G	E	E
SODIUM PEROXIDE	E	X	E	G	G	G	G	G	X	G		E	E	X	E	E
SODIUM PHOSPHATE	E		E	E	G	E	C	E	C	E		E	E	E	E	E
SODIUM SILICATE	E	G	E	E	G	E	E	E	E	E		E	E	G	E	
SODIUM SULFATE	E	G	E	E	G	G	E	E	E	G		E	E	E	E	E

E = excellent; G = good; C = conditional; X = unsatisfactory

E = excellent; G = good; C = conditional; X = unsatisfactory

* compounds not in catalogue. Ask Parker for right solution

TH30

Catalogue 4401/UK

Figure 1: The chemical resistance of UHWP.

The clear, top and bottom parts of the enclosure will be made out of polycarbonate. This material was chosen to create a viewing window for the enclosure as well as its chemical and price similarities to (UHWP). Polycarbonate is a stronger type of plastic and therefore can be thinner than UHWP while still withstanding a comparable amount of compressive force (polycarbonate is used to make bullet-proof windows[7]). The polycarbonate will be permanently epoxied to the O-ring seal component in order to provide a robust seal. One part of the design that diverges from Eric Lindqvist and Nikolaj Grondahl's work is that the O-rings in my enclosure will be further compressed by bolting the components together, as illustrated in Figure 2. This will be required for our operation as the compression achieved by the mechanical fit in Lindqvist and Grondahl's work is only rated to be submerged to one and a half meters. Bolting the enclosure together will ensure that the proper compression can be achieved[8]. An additional detail on the O-rings: they are placed inwards relative to the bolts to extra work sealing off the holes that the bolts are placed in. Now, back to the bolts. Metal, threaded inserts[9] will be placed into the UHWP components in order to avoid stripping out the plastic when a high amount of torque is exerted when compressing the O-rings.

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[7] [Polycarbonate Pricing and Properties]
[8] [O-ring Basic]
[9] [Metal Threaded Inserts]

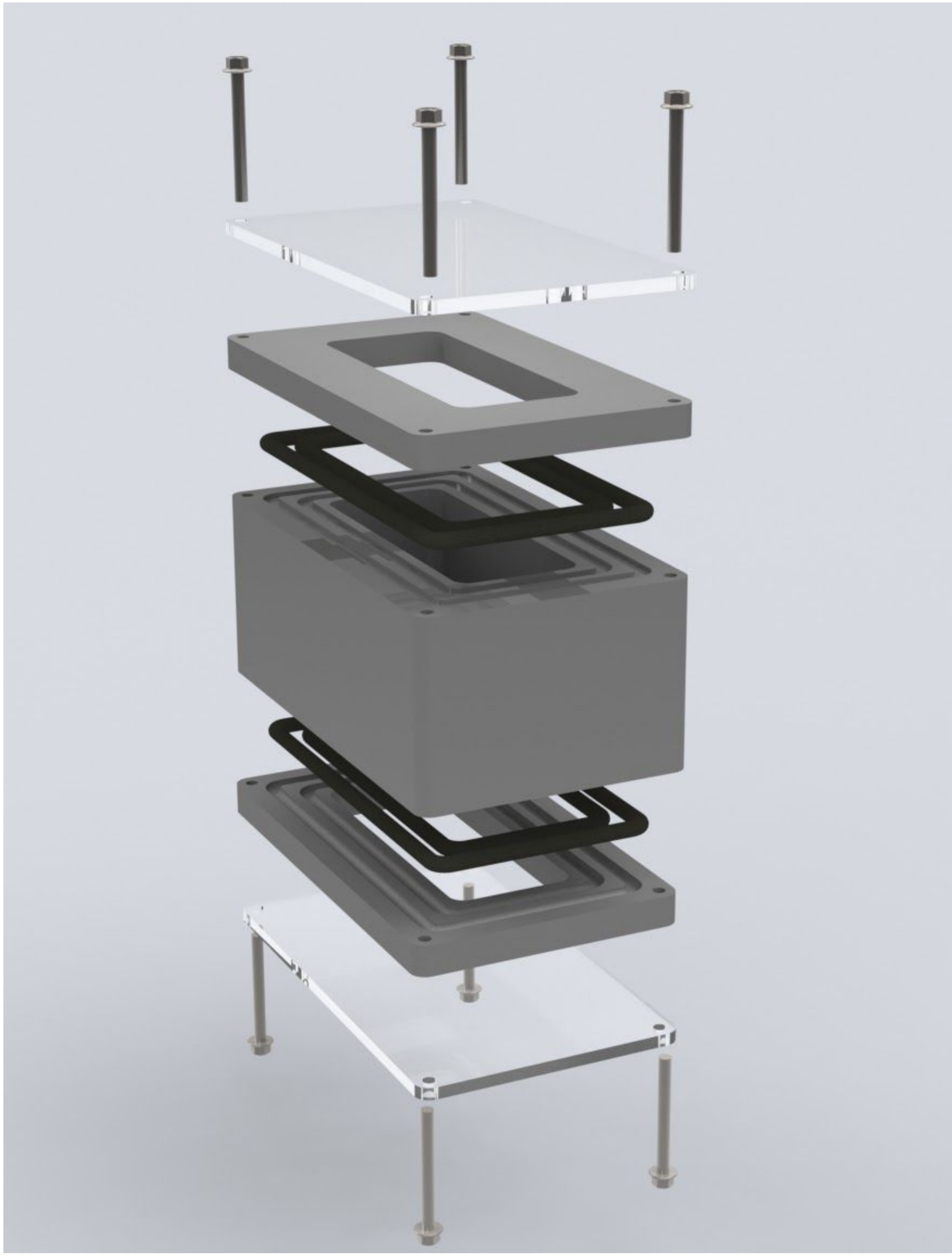

Figure 2: Waterproof Enclosure Prototype

3.1 Methods to Test the Enclosure Design

The effectiveness of this enclosure can be simulated or tested. I've looked into simulation software provided by OSU such as ANSYS Workbench and SOLIDWORKS (what I used to design the CAD model of the enclosure on). I have concluded that the simulation method, while nice in theory, would be disadvantageous due to the large amount of time it would take. First, I would need to learn the proper way to simulate the properties of my enclosure, which most likely entails a term of studying. Secondly, how accurate will the simulations be? I have no empirical analysis to add here, but there's anecdotal evidence from SOLIDWORKS users that cast doubt on the possibility realistically achieving an accurate simulation, even if I was moderately experienced[10],[11]. As one user eloquently put it, we probably don't need to simulate this "unless [we] are designing a space shuttle for NASA." Testing now enters the docket. Conducting a representative test is difficult as well, but it is, in fact, feasible. There is a pressure testing device in the OSU Buoy Lab (that I just got access to as of December 3rd, 2019) which can serve as a great simulation for what the enclosure will experience as it descends to its maximum depth of ten meters.

3.2 Waterproof Enclosure Decision

In order to speed up the development of the overall system, we have decided to order pre-made enclosures[12] sold by the same company that manufactures the ROV we're using for the project. These enclosures already have been tested and are rated to depths of 150 meters with acrylic tubing and 400 meters with an aluminum tubing and end caps.

4. Challenge Two: Melting Into Ice

Next, we will move on to the next challenge, which is creating a new design for an attachment system alternative to drilling into ice. Initially, I thought of horror stories when you were a kid and people warned you not to lick a pole when it was freezing outside or your tongue would get stuck to it. Why not just melt into ice and let it refreeze so it gets stuck? After looking for other ideas out there and coming across the patents listed in Table 2, melting into ice started to seem like an idea that wasn't really all that far fetched. My decision flow chart is shown in Figure 6. My method would differ from the patents listed in that there would be no drilling into the ice, just melting and refreezing. This was due to the drawbacks of motors as previously discussed. This is also ideal as heating elements are not expensive (around $25), there are no moving parts to waterproof, and the OSU Buoy Lab has many batteries available for power. After discussing the idea with the client, I got the green light to do some experimenting.

4.1 Initial Melting Tests

Initially, I started testing the concept with a spare soldering iron. I froze a large bucket of ice, turned on a soldering iron, melted in, shut the power off, and waited to see if it would refreeze. To my surprise, the soldering iron effortlessly melted into the ice and was refrozen rather quickly. After presenting this evidence to our client, we hypothesized that the ice would not refreeze around the heating element since the operating environment is not conducive to do so: the ambient temperature of the water is 3-7 degrees Celsius and the surface of the ice is at 0 Celsius, while the ice I tested on was most likely somewhere from -3 degrees to -10 degrees. The next idea was to create some sort of mechanical device on the heating element that could spring up and stick into the ice after we have melted in, but first, I needed to develop a larger scale prototype that was more robust than a soldering iron.

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[10] https://forum.solidworks.com/thread/83726
[11] https://forum.solidworks.com/thread/45277
[12] Watertight Enclosure for ROV/AUV (3″ Series)

4.2 Prototype One

The design that I came up with is a fairly high powered (300W) heating element that would be encased in a sealed copper tube, which is visualized in Figure 3. Copper was chosen due to its very low specific heat. This means that compared to other materials and most metals, lowering (or raising) the temperature of a certain mass of copper takes less energy. This is ideal as it would act as a good heat sink to distribute the heat from the heating element, who's shape is not a regular geometry, to the ice. Additionally, the end of the tube should be sharpened to provide a high pressure point that will aid in the melting of the ice. Part of me still suspects that the heating element will still have the melted water around it freeze as inner-iceberg temperature can reach -15 to -20 degrees Celsius[13] and is aided by the high thermal conductivity of the enclosure and Newton's Law of Cooling[14] (hot things in cold environments cool faster).

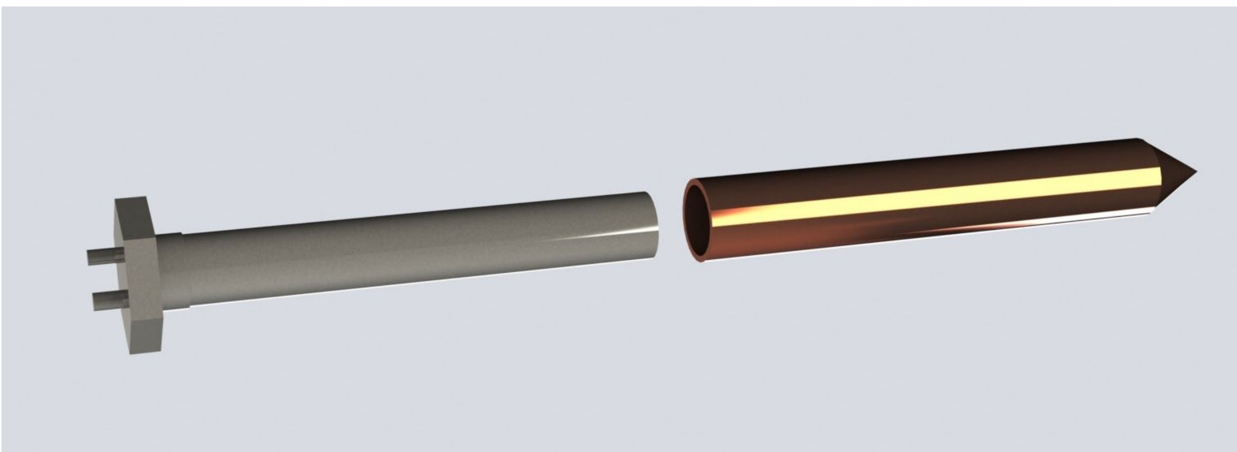

Figure 3: CAD Model of the Iceberg Melting Attachment. Note: The heating element on the left looks different than pictured; there is a pair of heating tubes rather than a cylinder[15].

4.3 Prototype One Results

The first iteration of the prototype, seen in Figure 4, was not successful. This was mostly due to a large air gap between the end of the end of the heating element and the tip of the copper tube, which caused heat to mostly dissipate from contact points with the heating element before it reached the tip.

4.4 Prototype Two

The second prototype, pictured in Figure 5, addressed this main concern and the tip gets piping hot now, around 230 degrees Celsius. Now, the goal is to create an accurate environment to test the prototype in. Since using a household freezer won't recreate the

[13] Iceberg Facts
[14] Newton's Law of Cooling
[15] DERNORD 12V 300W Immersion Heater

operating environment, the plan is to use the controllable freezer at the OSU Buoy Lab to get ice right at its freezing point and create a buffer layer of water (simulating the water around the iceberg) that is at -5 degrees Celsius. We should be able to begin testing at the start of Winter Term. I'm looking forward to seeing how it will perform in a realistic scenario.

4.5 Prototype Two Results

Unfortunately, the second prototype did not perform much better. While more heat was concentrated to the tip of the heating enclosure, the amount of energy wasted by not contacting the ice was also significant. In order to melt into the ice, a lot of pressure had to be exerted downwards, forcing the tip into the ice. This high-pressure is needed because the cross-sectional area of the device is relatively large.

4.6 Design for Prototype Three

The third design takes into account that the volume of ice, and therefore, energy, needed to melt a section of ice is exponentially proportional to the diameter of the cross-section of the heating element. Considering this, we are shifting our design to use a much smaller heater[16] and a stronger, carbon fiber, material for the arms to compensate for the reduced strength of the heating element. The heating elements have arrived at our lab on 2/05/20 and we will begin building a prototype within the week. Another design choice that was made is to switch from a low-voltage, high-current heater to a high-voltage, low-current one. Before, we were supplying 12V at 25A -- now, with the new heater, we will supply 120V at 0.2A. This will reduce power loss along the wire as we will be transmitting power to the heater over at least 1m of wire. Since the resistance of a wire is proportional to its length, and power loss along the wire, I^2R, is proportional to the square of the current passing through that wire. Therefore, by reducing our current to $1/125^{th}$ the current in the second prototype, we can achieve a power loss 15625 times less than before.

[16] 25W Insertion Heater with Standard Wire Lead Covering

Figure 4: 1st Prototype of the heating element

Figure 5: 2nd prototype of the heating element. It is 1.5 inches shorter and has a different tip that makes better contact with the heating element inside.

5. Implementation and Discussion

In conclusion, there was a significant amount of progress getting the starting points for my goals up and running and overcoming some initial challenges. However, there does exist a large amount of uncertainty on how the ice attachment prototypes will perform in testing. The first two ice melting prototypes show that there are a lot of variables to consider to meet all of its requirements. There still remains large uncertainty about the effect of heat loss due to dissipation to the surrounding ice and water near attachment points. The iterative prototyping to eventually get the components to perform under operational conditions has resulted in improvements each time and suggests that, at this rate, being able to at least melt into ice with the ROV is an achievable goal.

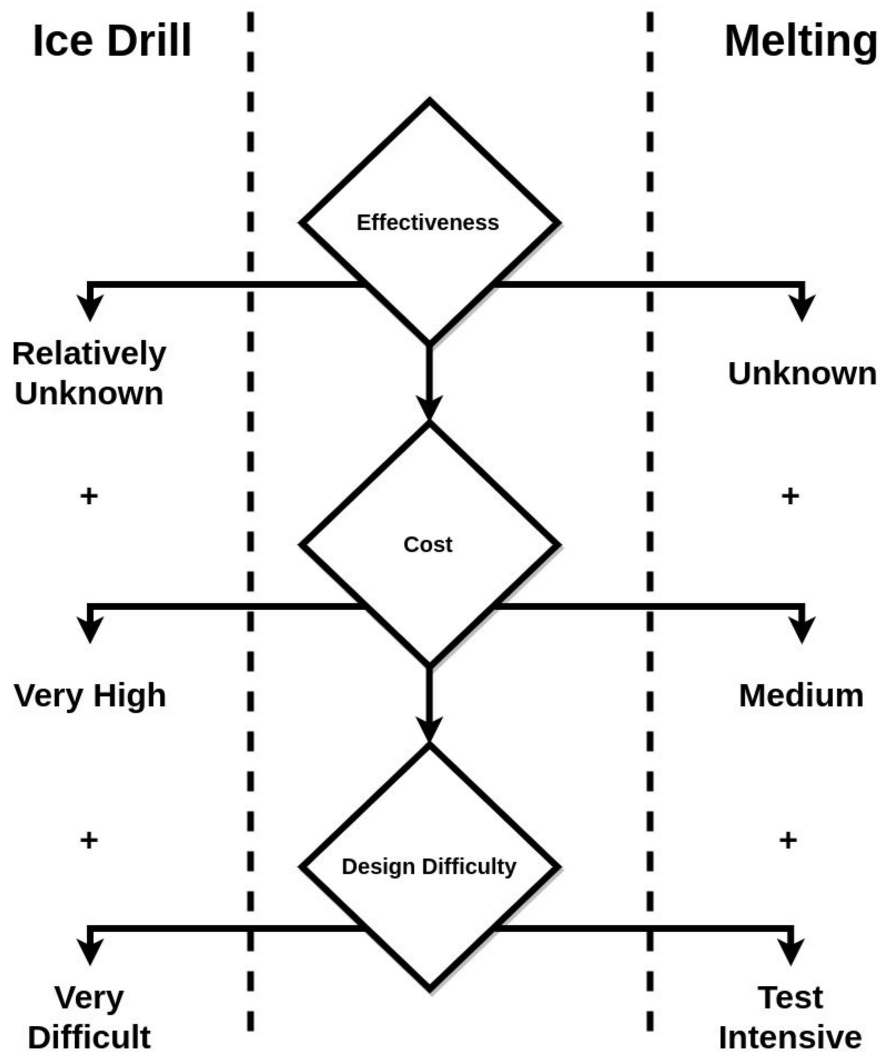

Figure 6: Decision Flowchart for Ice Drill vs. Ice Melt for Attachment System

6. References

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[11] Alberto Perez Nunez ; Matko Orsag ; Daniel M. Lofaro, “Design, Implementation, and Control of the Underwater Legged Robot AquaShoko for Low-Signature Underwater

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7. Revision Table

Change Description	**Date**
Adding Section Headings	2/06/20
Adding Table of Contents	2/06/20
Adding Title Page	2/06/20
Update for 2nd heating element prototype test results	2/06/20
Add design rationale for 3rd heating element prototype	2/06/20
Various wording changes to include 2nd quarter work done	2/06/20
Added rationale for waterproof enclosure purchase	2/06/20