Serco BOWHEAD
Final Report

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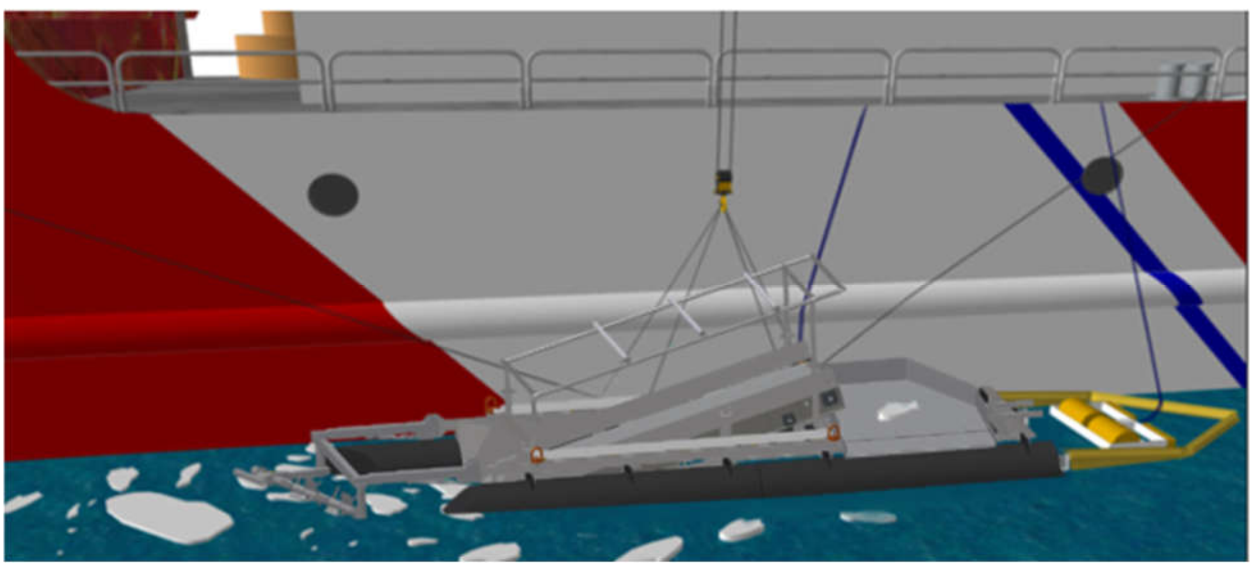
Executive Summary

Oil spill response in Arctic conditions is heavily impacted by ice conditions. Ice is an obstacle to cleaning oil spills from the water surface, and it has an irregular surface that collects oil and must itself be cleaned. Serco, Inc. developed and tested an ice management system, called BOWHEAD, to address the problem of recovering oil in an ice-infested environment. From 1995 to 2002, SINTEF Applied Chemistry™ and other partners performed extensive testing to tackle this problem under the Mechanical Oil Recovery in Ice Infested Waters (MORICE) project[1-7]. In 2019, the Bureau of Safety and Environmental Enforcement (BSEE) contracted with Serco, Inc. to design and test an ice management system based on the experience with MORICE.

Serco designed and tested an ice conveyor system that builds upon the work of the MORICE project but removes unnecessary features while expanding upon that work to create a system that is more operationally ready and easier to deploy and use. Serco designed BOWHEAD to be deployed off the side of a vessel. As the ship moves slowly forward into the areas with the least ice concentration, the oil is captured by pontoons and a boom and guided to a skimmer. Ice and slush that enters between the pontoons is picked up by a conveyor belt and dumped to the side via an ice chute. As the ice and slush moves up the conveyor belt, any oil trapped in the slush or on the ice is washed off and drops through the perforated conveyor belt and between the pontoons where it is guided aft towards the skimmer. BOWHEAD effectively deflects ice in front of the forward moving ice conveyor, and is able to lift ice (as well as small debris, limbs and logs) out of the water so that a standard skimmer can be used to remove the oil from the ice- and debris- free water.



Serco and BSEE tested BOWHEAD at the Ohmsett facility in Leonardo, NJ in January and February 2021. The objective of the testing was to evaluate the performance of the BOWHEAD in simulated arctic environmental conditions including ice and oil. Serco developed test goals to address BSEE's Broad Agency Announcement (BAA) Performance Objectives while handling oil in a scattered 30-70 percent ice coverage area that consisted of small pieces of ice and slush as well as larger pieces of ice (but limited in size).

Testing including a static configuration used to test the oil washing performance as well as get a first look at the ice handling and ice buildup and a dynamic configuration to assess ice handling and oil flow performance. The static tests included oil washing variations and a heater test. The oil washing included two oil types (Hydrocal 300 and Weathered HOOPS); 30, 60, 90 psi water pressure; 1, 2, and 3 spray bars; and tubs and block ice, where the tubs were 31x49x10 inches and the blocks were 40x40x8 inches. For the dynamic tests, the system configuration was fixed with all spray bars in use at 60-90 psi. Ice handling variations included system speed from 0.1 – 1.0 kts, front feeder not in use, and front feeder at 2 different levels.

The major goals and their results were:

- Assess ice handling capability – overall, the system handled ice very well.
    - Blocks of all sizes were able to be picked up and transported aft to the chute as long as the conveyor belt speed was not overly fast.
    - The ice fed into the system without need for the front feeder system as long as the speed of advance was at least 0.8 kts.
    - Front feeder system is a desirable feature for slower speeds of advance and to aid when blocks become jammed together in the opening.
- Assess ice buildup – the system did not suffer from ice build-up during the testing even at temperatures below freezing and with a wind chill.
    - While the spray bars are running, it is unlikely that ice will form inside the enclosure.
    - When the spray bars are not running, the heater system provides sufficient heating to prevent ice buildup.
    - The enclosure worked well; however, the tarps are difficult to secure totally and are blown around in high winds. Fixed panels would be a better alternative.
- Assess oil washing capability – the system worked very well to clean the oil off of the ice.
    - Three spray bars above (plus one below) gave the best performance.
    - 90psi pressure gave the best performance. Performance did not degrade that much at 60psi, especially with the thinner oil. This gives room for adequate system performance with a range of water pump capabilities.
- Assess flow of oil to skimmer.
    - The flow of oil through the system and back to the skimmer was the one area where the system did not perform as well as desired. Some changes to the structure of the system are needed to improve this oil flow.

The report includes recommended changes and improvements for future testing and operational use, all of which could be done as retrofits to the existing system. These changes include improvements to the front feeder system to improve usability, modifications to the framework to improve oil flow, standardization of the flights on the conveyor belt, stainless steel spray bars in place of the PVC, a revised enclosure consisting of metal or composite panels, and replacement of the front half of the outboard pontoon to improve ice deflection.

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1 INTRODUCTION

Oil spill response in Arctic conditions is heavily impacted by ice conditions. Ice is an obstacle to cleaning oil spills from the water surface, and it has an irregular surface that collects oil and must itself be cleaned. Serco's BOWHEAD is a system designed to provide an ice-free zone for skimmers to recover oil under these arctic conditions. Our BOWHEAD design focuses on simplicity, scalability, ease of operation, and deployability, and it can be used with multiple different skimmer configurations.

BOWHEAD was designed to assist oil cleanup endeavors in Artic conditions with up to 70% ice coverage. The system is made almost entirely of stainless steel to withstand the harsh marine and weather conditions. The main body is a large conveyer belt and frame, supported by pontoons. At the forward end of the device is a hydraulic motor-powered front-end feeder that pushes ice towards the conveyer mouth. A spray bar washdown system is set atop a frame over the conveyer belt to clean off the ice as it moves up the conveyer. At the aft end, an ice chute drops the clean ice off to the side and out of the way of the skimmer, which follows behind to collect the oil from the water surface.

Our BOWHEAD design builds on the results of the Mechanical Oil Recovery in Ice Infested Waters (MORICE) project [1-7]. As stated in the MORICE final report "an oil-in-ice spill could involve anything from very light ice conditions, where the presence of ice can be treated as a simple debris problem similar to situations frequently encountered in open water, to heavy ice conditions where the oil is trapped between floes or is intermixed with small ice forms or encapsulated in ice and virtually inaccessible for recovery." Because of this wide range of potential conditions, no one-size-fits-all solution is possible. In designing BOWHEAD, we focused on oil in a scattered 30-70% ice coverage area that could consist of small pieces of ice and slush as well as larger pieces of ice (but limited in size), as described in the Broad Agency Announcement (BAA).

The BOWHEAD design derives from extensive testing performed by SINTEF Applied Chemistry™ and other partners from 1995-2002 to tackle the problem of removing oil in an ice-infested environment. The researchers determined that a conveyor belt type system that lifted the ice momentarily out of the water to be mechanically washed was an effective way of removing oil from the ice. Once the ice is removed from the water, a standard brush style skimmer worked very efficiently to remove the majority of the oil from the water surface. This solution was the end-product of a multi-phase process. The MORICE project started with a literature review and brainstorming sessions to identify solutions that were plausible and could be used in an operational setting. Many of the concepts were tested in the lab and then finally down selected to the three most viable. These concepts, including the mechanical conveyor belt system, were then tested at Ohmsett in January 2002 [6, 7].

As a result of this extensive testing, it was determined that a lifting graded belt (LGB) combined with a brush and drum skimmer system could be extremely effective in removing oil from ice. However, there were many technical factors that had to be overcome during the testing. For example, the MORICE system was designed to be operated independently of other vessels, requiring additional accommodations for propulsion, a human operator, and recovered oil storage. The greatest challenge was building a system that uses a conveyor belt type lifting mechanism, which can be heavy and cumbersome in comparison to the existing oil removal equipment currently deployed operationally in the field.

To create BOWHEAD, we developed a design for a new ice conveyor system that builds upon the work of the MORICE project but removes unnecessary features while expanding on MORICE to create a system that is easier to deploy and use. In developing this concept, we have leveraged our own experience in building and testing systems for oil recovery in ice infested water (ICEHORSE 1 and 2 [8, 9]).

2 SYSTEM CONCEPT

The BOWHEAD system concept of operation is depicted in Figures 1 and 2. The system is designed to be deployed off the side of a vessel (see Figure 1). As the ship moves slowly forward (1 knot or less) into the areas with the least ice concentration, the oil is captured by the pontoons and boom and guided to the skimmer. Ice and slush that enters between the pontoons is picked up by the conveyor belt and dumped to the side via an ice chute. As the ice and slush moves up the conveyor belt, any oil trapped in the slush or on the ice is washed off and drops through the perforated conveyor belt and between the pontoons where it is guided aft towards the skimmer.

Figure 1. BOWHEAD deployed from side of vessel.

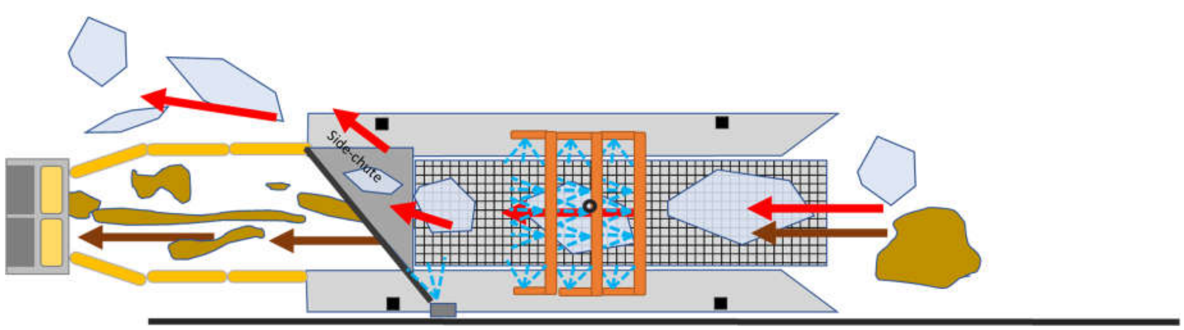

Figure 2. Top view of BOWHEAD and skimmer.

This design effectively deflects ice in front of the forward moving ice conveyor. It is able to lift ice (as well as small debris, limbs and logs) out of the water so that a standard skimmer can be used to remove the oil from the ice and debris free water. It is a "side deployed boom system" and allows the ice-free oil to flow into the boomed area to be skimmed in the traditional manner with a brush or drum skimmer, thus maximizing the oil recovery in the boomed area.

3 SYSTEM DESIGN

Our design for the Brash Ice Oil Management Vessel, nicknamed "BOWHEAD", is a surface-skimming conveyor system mounted on a pontoon vessel designed to operate in arctic waters for the purposes of managing ice during oil spill recovery operations. The vessel has no onboard propulsion and is intended to operate in conjunction with a host vessel to which it is moored alongside. The craft may be lifted by a shipboard crane and placed in the water alongside the host vessel using four wire rope pendants attached to the four dedicated lifting pad eyes, as shown in the rendering of Figure 3. Once in the water, the craft is operated by crew aboard the host ship, who manually operate the BOWHEAD hydraulic power supply system, water washdown system, and heating system. With its primarily stainless steel and composite construction, the BOWHEAD is highly resistant to corrosion. When not in use, the craft may be stowed in the weather on the deck of the host ship.

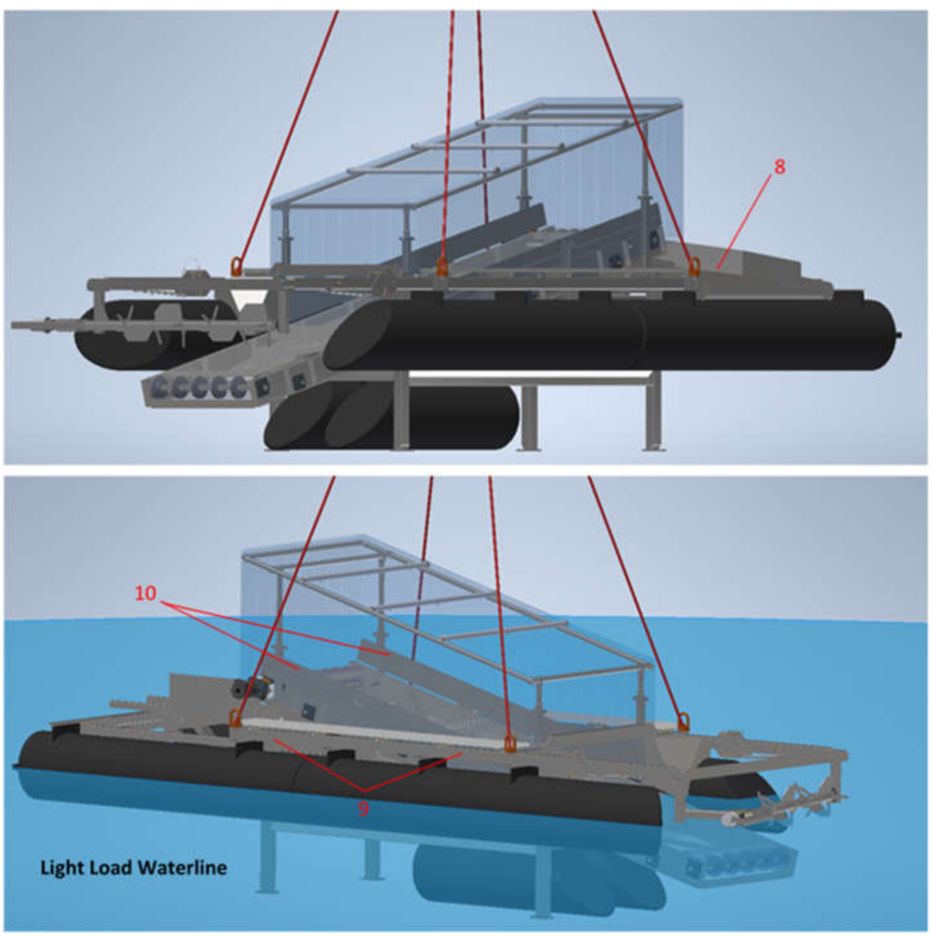

Figure 3. Rendering of the "BOWHEAD" Brash Ice Oil Management Vessel concept.

The craft comprises a stainless-steel frame with composite pontoons. It was initially designed to be transported via a standard ISO container or flatbed truck (i.e. 8.5ft max width), which limited the conveyor width to 4ft. Unfortunately, during detailed design, the size of the pontoons needed for buoyancy increased the width slightly so that they system is slightly too wide for a standard container; although it is still transportable via flatbed on US roads. The system components are listed in Table 1; the numbers listed for each component are used in Figure 3 and Figure 4 to indicate the location of each component.

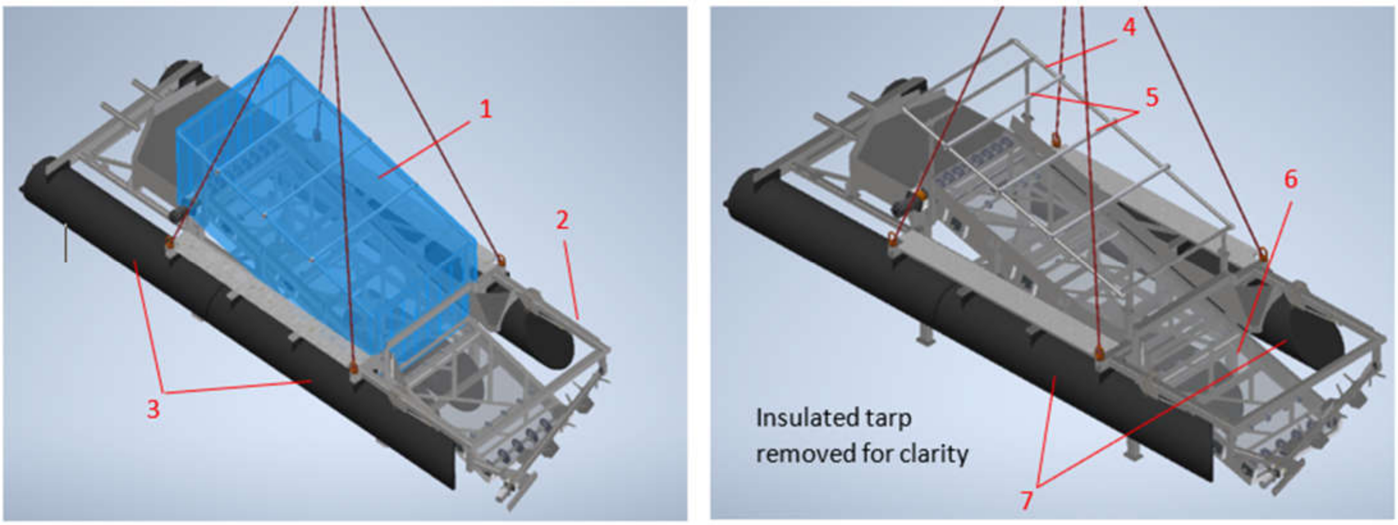

Figure 4: Complete BOWHEAD system.

Table 1. BOWHEAD components

Item #	Component	Item #	Component
1	Heated Tent Enclosure (Detachable)	6	Conveyor
2	Front-End Feeder (Optional)	7	Port/Starboard Pontoons
3	Lifting and Mooring Padeyes	8	Ice Chute (Detachable)
4	Tent Frame	9	BOWHEAD Structural Frame
5	Washdown Nozzle Crossbars	10	Conveyor Ice Guide Rails

3.1 Structural / Frame

All BOWHEAD components are bolted to the welded stainless-steel structural frame assembly. This frame carries all structural loading in operation, when being lifted, and when stowed on deck of the host vessel. Mount plates on the frame feet were added to support the installation of bolt-on casters to improve the ease of BOWHEAD handling, particularly into and out of storage. They are polyurethane wheels with a steel core and have a weight capacity of 2,600-lb each. The casters should be removed when the vessel is resting on the deck of a ship to avoid unsafe, unintended, movements due to ship motion.

3.2 Conveyer System

The ice conveyor is a sprocket-driven, mesh belt, sliding bed-type conveyor, powered by a single hydraulic motor. Conveyor components, including the frame, sprockets, and shafting are stainless steel construction to support corrosion resistance in the arctic marine environment. The conveyor frame is a welded construction with ¼-in welded supports across the length, which is then bolted to the primary stainless-steel frame of the vessel to facilitate easy removal for maintenance if required.

The high-torque/low-speed motor supports greater than 7700 in-lb of torque (at 8 GPM, 3000 PSI hydraulic pressure), which is sufficient to drive the conveyor at 1.5 ft per second while fully covered in 8-inch thick ice, with a factor of safety of two. Due to the relatively high conveyor motor power transmission requirements to the drive sprocket, a stainless-steel hydraulic motor was not available; only standard steel. However, the motor includes a double coating of corrosion resistant paint for extended exposure to sea water.

The conveyor uses a herring bone sliding bed to provide the bulk of support for conveyed ice while distributing wear evenly across the belt over time. Other patterns (run longitudinally or laterally) are easier/cheaper to fabricate but will cause the belt to wear at an accelerated pace in certain places (localized wear). This will cause the belt to "track" (i.e. pull port or starboard, especially when a mass load is applied from conveyed ice) and could eventually cause the belt to 'jump' off of the sprocket. The herring bone pattern enables the belt to function optimally for a longer period of time. Heavy duty stainless steel 8-in diameter drive sprockets are keyed to a standard 2-in stainless steel shaft to support the 909-lb max drive tension when the conveyor is fully loaded with ice. Roller-type catenaries on the underside of the conveyor help to manage the conveyor belt slack and prevent the belt from tracking to either side when loaded and also help keep the belt from sticking to the sprocket teeth under tension. Guide rails along either side of the conveyor keep large ice chunks from falling between the pontoons.

In operation, the conveyor is operated at up to 2.5 feet per second to lift oily brash ice out of the water. This conveyor speed is designed to accommodate 70% ice coverage in conjunction with a host vessel advance speed of about 1 knot. The conveyor is a 1.0 in x 1.0 in steel mesh belt designed to permit oily slush and small ice to pass through the belt and float aft towards the oil recovery unit trailing behind the vessel.

The conveyor was designed with a shallow 15-degree angle, compared to the steeper 45-degree angle of the legacy MORICE LGB. Additionally, the forward end of the conveyor sits approximately 1-foot below the water surface to help scoop ice out of the water. The belt is equipped with flights arranged in a staggered grid pattern to aid in ice gripping. For the Ohmsett tests, one half of the belt length was outfitted with roof-top flights and the other half with pin-up flights (see Figure 5 and Figure 6) to determine which design performed better.

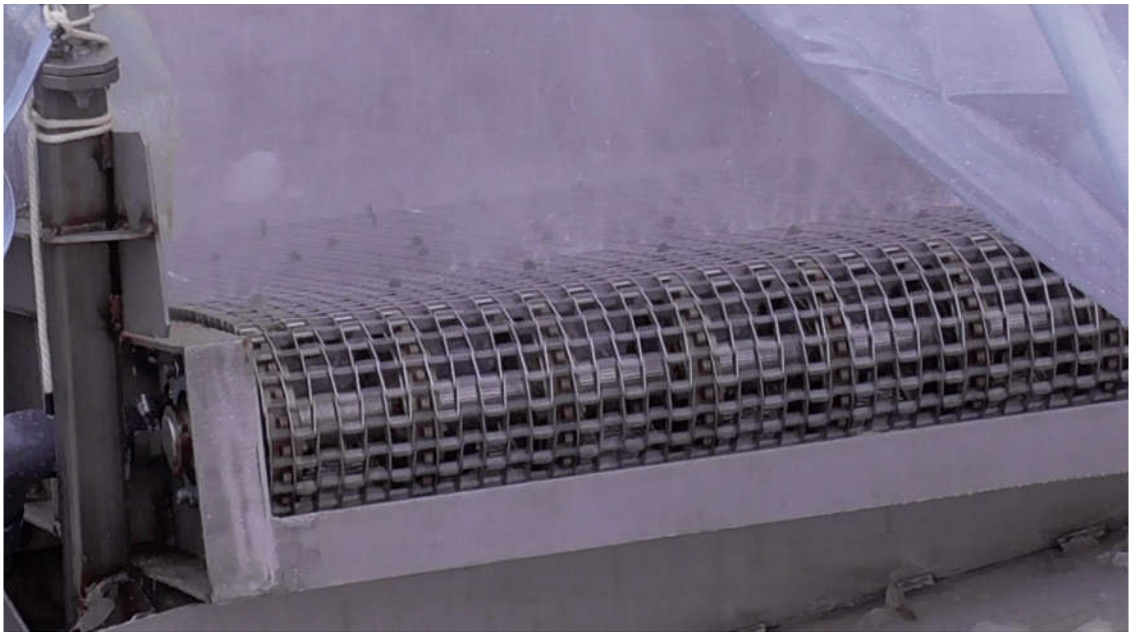

Figure 5. Conveyor belt with both sets of flights visible in the staggered pattern.

Figure 6. Pin-ups (top) and roof tops (bottom).

3.3 Pontoons / Flotation System

The BOWHEAD vessel includes four pontoon assemblies: one each on the port and starboard sides for flotation and stability, and another smaller pair mounted underneath the conveyor along the centerline. These are fully submerged during operation. The centerline pontoons maintain the vessel's center of buoyancy, draft, and even keel. In light load condition, using the actual weight of the BOWHEAD when lifted (~8,000lb), the port and starboard pontoons are roughly 50% submerged, leaving approximately 5,700 lbs of reserve buoyancy for ice loading. The difference between operating in fresh vs. salt water is negligible. In a fully loaded scenario where both the belt and ice chute are 90% loaded with 8" thick ice, the freeboard would only decrease by about 0.05" when operating in fresh water.

The pontoons are constructed of 24-in diameter, ¾-in thick, HDPE (High Density Polyethylene) and are bolted onto the BOWHEAD frame using ¾-in stainless steel bolts. This material is weatherproof, impact and chemical resistant, and has the ability to operate down to –50°C (-58°F) in the arctic. HDPE was chosen for its cost, versatility, and elastic deformation properties in harsh cold temperatures, including well below the service design limit, and will survive down to –70°C (-94°F) without cracking under normal conditions. The port and starboard pontoons are each split into fore and aft sections to reduce size and weight so that they can be lifted and attached to the BOWHEAD frame by 2-3 people. Alternatively, the pontoons may be lifted into place for bolting by one person using a forklift and sling.

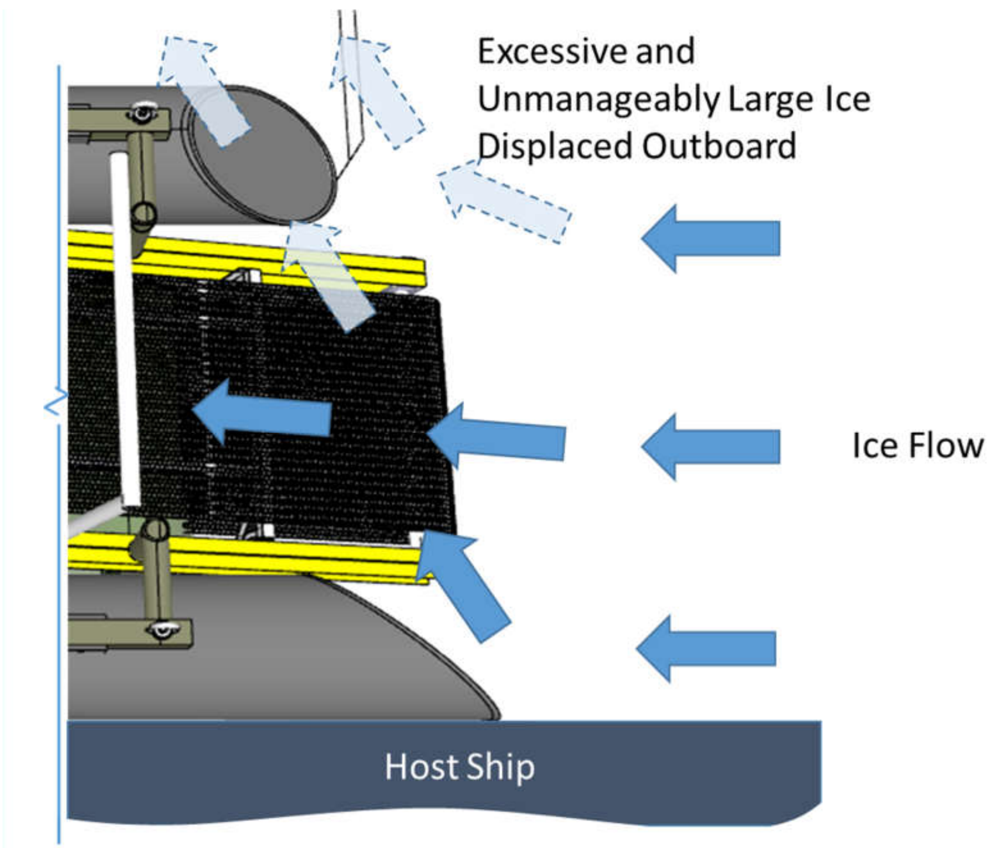

Figure 7. Asymmetric pontoon shape facilitates ice flow.

BOWHEAD has a unique asymmetrical pontoon design. Whereas most pontoon structures are designed for hydrodynamic propulsion efficiency, the bow of BOWHEAD is designed to guide incoming ice that is displaced by the bow of the host vessel into the conveyor opening. The starboard pontoon sits slightly forward of the conveyor and has a 45-degree, horizontal wedge section at the forward end of the pontoon to 'grab' ice and oil that is flowing aft along the skin of the vessel and feed it towards the conveyor. For ice that is too large, the port pontoon sits slightly aft of the conveyor and has a 45-degree, upward-sloped wedge at the forward end of the pontoon which is intended to allow some unmanageable ice to be displaced outboard to prevent ice-jams at the mouth of the conveyor (see Figure 7).

3.4 Ice Feeder System

Based on MORICE lessons learned, a front-end feeder has been included as part of the current system to aid in keeping the front of the conveyor clear of ice that is too large for the conveyor as well as help feed ice onto the conveyor. The feeder level above the water, as well as the forward distance from the conveyor, may be manually adjusted; the design also allows for it to be removed entirely if desired (see Figure 8).

Similar to the legacy MORICE LGB, the feeder's rotating bar includes 6-in steel tines intended to grab floating ice, as well as flat plates intended to aid in directing floating oil and slush into the conveyor. In contrast to the legacy design the BOWHEAD feeder is mounted at an angle, which is intended to help steer ice towards the conveyor when operated forward or away from the conveyor and to the outboard of the craft when operated in reverse.

Figure 8. Front end feeder.

The high-torque/low RPM, reversible, hydraulic motor for the feeder has a low-enough output power to support fully stainless-steel construction. The motor is designed for use in harsh marine environments and may be submerged in water indefinitely without issue. The motor needs to be supplied with 1800 PSI hydraulic pressure.

3.5 Water Washdown System

As ice is being lifted by the conveyor, the high-pressure water washdown system, consisting of multiple spray nozzles oriented along 3 crossbars on top and one underneath, cleans oil off the ice and forces oily slush through the belt. The large chunks of cleaned ice are dumped into the stainless ice chute and slid off the port side of the craft back into the water.

Leveraging MORICE LGB lessons learned, the system includes high-pressure nozzles, spaced evenly to provide an overlapping flat fan spray pattern. The nozzles are arranged in sets of three installed in 2-in PVC pipe forming spray bars (see Figure 9). The center nozzle has an 80-degree fan and the nozzles on either side have 50-degree fans. The nozzles on the outside edges are mounted on adjusters which allow the nozzles to be aimed 45-degrees in any direction. There are three spray bars located above the conveyor; two connected together to be fed by one 1.5-in hose and one separate to be fed by a 1.0-in hose. The three spray bars are attached to the tent frame using hose clamps so that they can be moved during testing (see Figure 10).

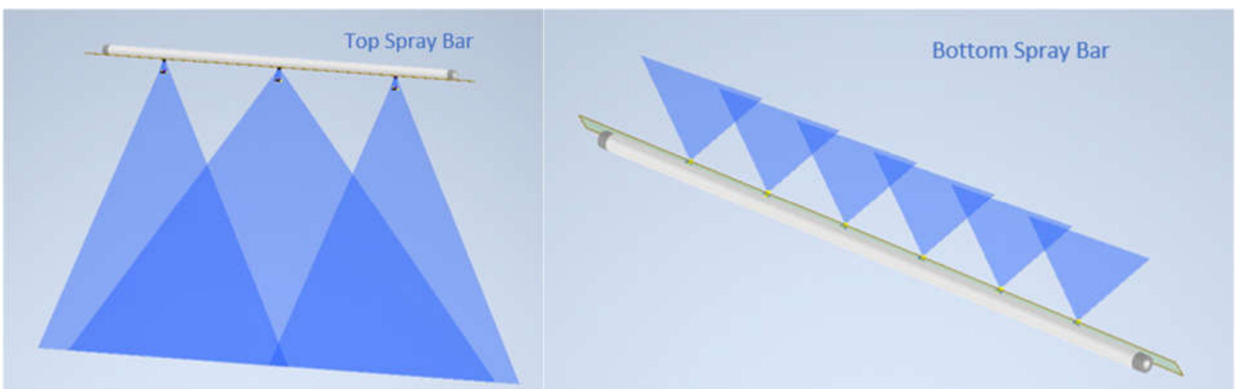

Figure 9. Spray bar design.

A fourth spray bar is used to wash the underside of the ice (dotted gold line in Figure 10). This “bottom” spray bar is positioned on the interior of the conveyer, with nozzles pointing upward, to spray the underside of the ice as it conveys up the conveyor. The bottom spray bar has 6 nozzles with 95-degree fans (see Figure 9 right) to provide coverage over the area, with consideration given to their proximity to the conveyer belt (6-8-in). It is connected to the pump with a 1.0-in hose.

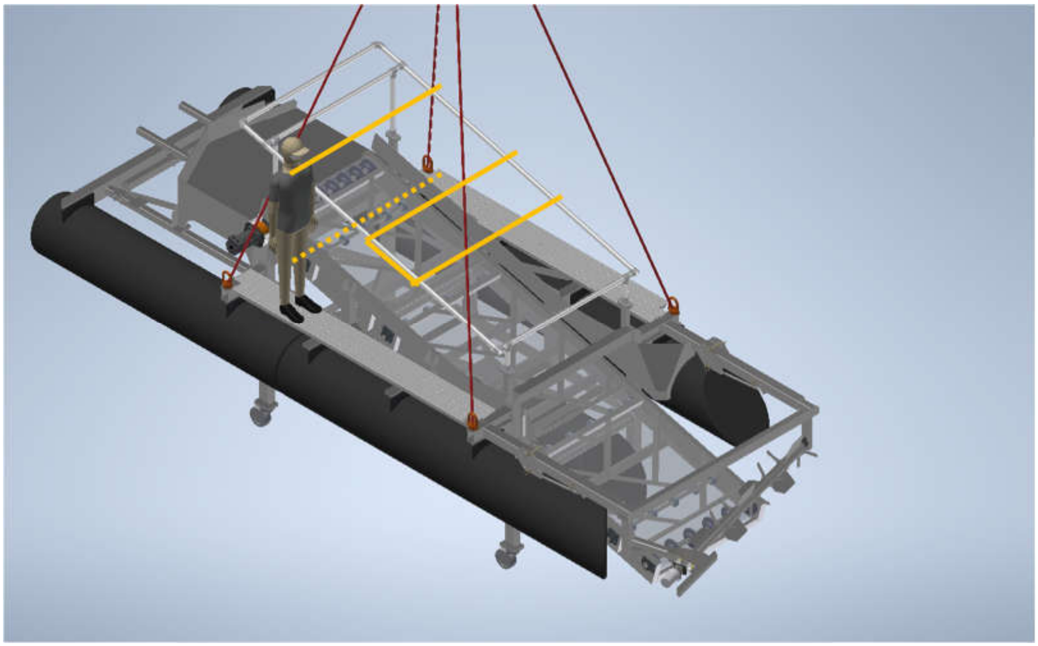

Figure 10. Nominal spray bar locations (gold lines).

The washdown system is operated from the host vessel. A pump taking suction from the sea (or test tank) or a shipboard sea water supply, is used to feed each of the spray bars. At 50 psi, the 12 nozzles use about 90 gpm; at 90 psi this increases to about 120 gpm. Hot water was not used due to the findings of the original MORICE experiments [4]. In this ice wash-down test report, it was found that hot water actually creates divets in the ice instead of washing the oil off of the ice. The recommendation is for high flow rate, low temperature water, which is what was used on BOWHEAD.

3.6 Heating System

Since temperatures in the Arctic can reach -40°C, something is needed to prevent ice-buildup on the system and to enable proper operation. Based on MORICE LGB lessons learned, a heated tent enclosure has been provided, comprised of clear vinyl material to allow visibility of ice handling (see Figure 11). The tent material includes openings at the fore and aft ends to allow ice movement in and out of the tent while keeping warm air in. The tent support frame is welded stainless steel pipe. This frame also supports the upper water washdown crossbars. A 70,000 BTU diesel/kerosene heater was used to force hot air into the enclosure. The heated air within the tent prevents ice accumulation on the conveyor components.

Figure 11. Tent enclosure heating system.

3.7 Design Highlights

Our design has the following advantages/improvements over the LGB designed and tested in the MORICE report:

- By moving the skimmer outside of the LGB there are numerous advantages.
  - The belt does not need to be as high since it does not need to go over the skimmer. This allows for a much shallower angle, which makes it easier for ice to be picked up and moved.
  - The system no longer needs a drip pan – the oil and water can drop directly through the conveyor to the water surface where it is guided by the pontoons and then the booms to the skimmer.
  - Since the skimmer is no longer part of the system, BOWHEAD can be used with ANY recovery skimmer on-hand.
- In lieu of allowing ice to eject directly aft like MORICE, BOWHEAD deflects ice to the side allowing the use of an aft-attached skimmer.
- BOWHEAD has an entire conveyor belt that moves rather than just chains along the edges and a fixed grate in the middle. This facilitates the pick-up and movement of the ice and also allows the system to pick up and move smaller pieces of ice and slush as well as debris such as logs and sticks and kelp.

- BOWHEAD has the front end of the conveyor belt under the water surface to get under the ice pieces and facilitate lifting them.
- By bolting ASTM slide connectors onto the rear of the pontoons, standard oil recovery boom can be easily attached to connect the skimmer system.
- BOWHEAD is designed to be operated from the comfort of the support vessel; there is no need for any personnel on the system (i.e., all steering, propulsion, and weather protection are eliminated).

Our design includes several additional features:

- The conveyor can be reversed to clear up jams.
- The conveyor consists of a commercial off-the-shelf (COTS) belt that can be replaced in whole or in sections if needed. Different designs and configurations are available from the manufacturer (mesh size, flights, etc.).
- In the test model the conveyor angle is fixed. However, future iterations could permit the conveyor to be hinged to lay flat for improved stowage, transport, and handling.
- The system uses COTS hydraulic motors that are easily field-serviceable and replaceable. Hydraulic power will be supplied by the support vessel.
- The ice washer consists of nozzles that can be adjusted in the field to support different ice conditions.
- The ice washer consists of COTS components that are field serviceable and replaceable. Saltwater supply and pumping system will be furnished by the support vessel; either from the ship's firemain system or a stand-alone pump located on deck.
- The system can be transported via commercial carrier using a flatbed truck or towed on a trailer.

4 OHMSETT TESTING

The system was tested at Ohmsett over two weeks in Jan-Feb 2021.

4.1 Test Goals

The objective of the testing was to evaluate the performance of the BOWHEAD in simulated arctic environmental conditions including ice and oil. Test goals were developed (first column of Table 2) to address the BAA Performance Objectives (listed in column 2). The Performance Objectives are included as Appendix A. Two separate test configurations were designed in order to test specific aspects of the system. Test configuration 1, used the first week, was a static configuration used to test the oil washing performance as well as get a first look at the ice handling and ice buildup (see Figure 12). Test configuration 2, used the second week of testing, was a dynamic configuration, where the system was moved down the test lane at speeds up to 1.0 kts (see Figure 13). This was used to assess ice handling and oil flow performance.

Table 2: Test Goals and Assessments.

Test Goal	Perf. Obj.	Assessment	Data Record
#1. Assess ice handling capability	2, 4	Evaluate whether ice larger than 1 in is removed from the path	photo/video record, notes on anomalies
		Evaluate whether blocks that are too large get deflected/not stuck	
#2. Assess ice buildup	6, 7	Evaluate whether ice builds up in the system or whether washdown and heated tent can prevent	photo/video record, measure temperature inside and outside tent, notes on anomalies
#3. Assess oil washing capability	5	Evaluate amount of oil removed from ice	photo/video record, notes on any large amounts of oil not washed
#4. Assess flow of oil to skimmer	3, 12	Evaluate ability of oil to flow to skimmer unimpeded	photo/video record, notes on any large amounts of oil blocked, record amount of oil/water recovered
#5. Assess ability to move debris out of the way	13	Evaluate whether debris is successfully removed from path	photo/video record, notes on any blocks/pieces that get through
#6. Vessel Stability		Evaluate buoyancy and lateral stability under various ice loading conditions	photo/video record, notes on any instability as ice is handled.
# 7. Static assessments	1, 8, 10	Total system size and weight	Weigh system, record dimensions as-built and as packed for shipping.
	9, 11	Operator Handling: Ease of set-up and use	take notes during testing on ease of set-up and operation

Figure 12. Static configuration.

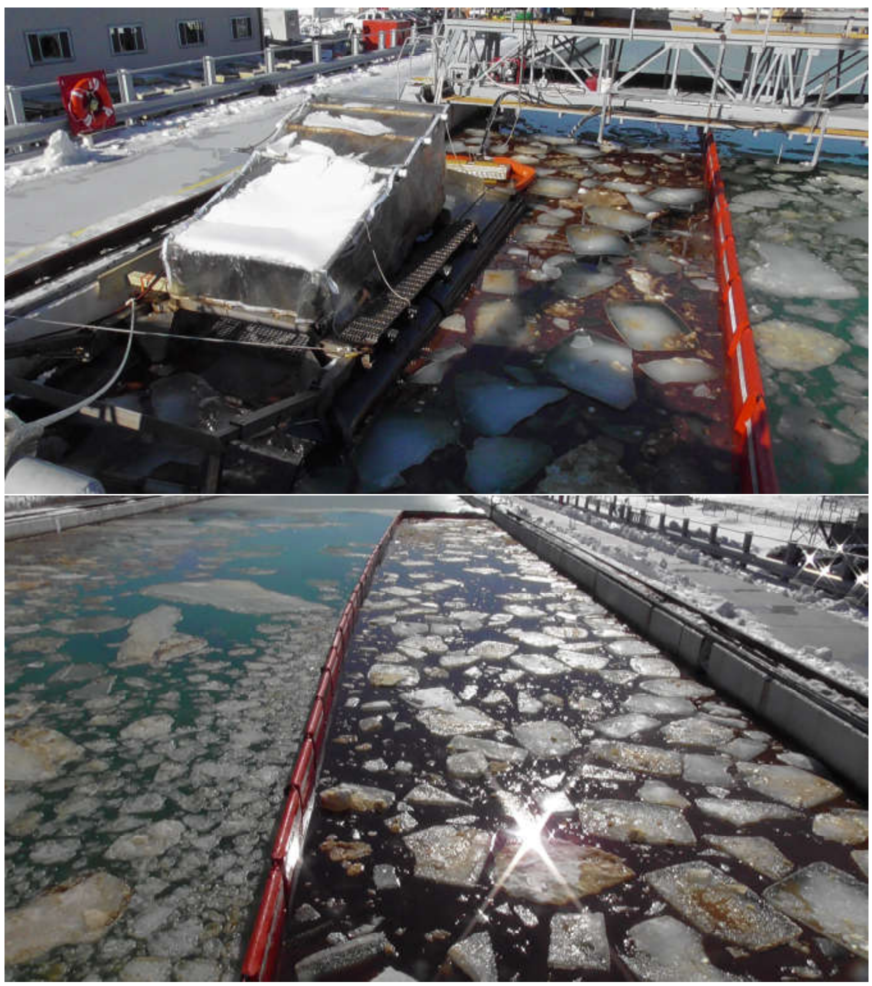

Figure 13. Test configuration 2 - dynamic.

4.2 Tests Conducted

4.2.1 Static Tests

The series of static tests conducted is listed in Table 3. All of the static tests were conducted with the feeder in the raised position. Three large blocks and three tubs of ice were used for each test. The plastic tubs created ice blocks that was roughly 31x49x10inchs and the wooden frames created large blocks that were roughly 40x40x8inches (see Figure 14). Some of the ice blocks were broken up before or while putting them into the tank. Once the oil was added, we split each test into two parts – first with the tubs and then with the blocks. Test start times are estimated from video footage times.

Figure 14. Tubs of ice (left) and blocks of ice (right) staged to be loaded into the tank at Ohmsett.

4.2.2 Dynamic Tests

The series of dynamic tests conducted is listed in Table 4. Each test consisted of a run down the tank. After the run the system was dragged back to the start. Some the dynamic tests were conducted with the feeder in the raised position and some with it lowered and in operation. The test lane in the tank was loaded to an estimated 70% ice concentration using a combination of blocks and tubs of ice; some of which were broken up before or while putting them into the tank. Test start times are estimated from video footage times. Hydrocal 300 was dispensed into the tank during the first 4 runs.

Table 3: Static Test Matrix.

#	Test	Date	Start	Configuration	Notes
1	Initial test of system	1/26/21	1015	Ice, no oil	Conveyor set to ~1.5 fps
2	Heater test	1/26/21	1030	Test run of heater to look at performance	Ran heater and took video with IR camera. IR camera did not record properly.
3a	Oil washing	1/26/21	1114	Tub ice, Hydrocal 300, 90 psi water pressure	Started at ~1.5 fps then slowed down. Started with 3 spray bars then 2 then 1.
3b	Oil washing	1/26/21	1139	Block ice, Hydrocal 300, 90 psi water pressure	Started at slower speed then increased at end. 3 then 2 then 1 spray bar
4a	Oil washing	1/26/21	1339	Tub ice, Hydrocal 300, 30 psi water pressure	Started at ~1 fps, 1 then 2, then 3 spray bars
4b	Oil washing	1/26/21	1400	Block ice, Hydrocal 300, 30 psi water pressure	Started at ~1 fps, 1 then 2, then 3 spray bars
5a	Oil washing	1/26/21	1458	Tub ice, Hydrocal 300, 60 psi water pressure	Started at ~1 fps, 1 then 2, then 3 spray bars
5b	Oil washing	1/26/21	1512	Block ice, Hydrocal 300, 60 psi water pressure	Started at ~1 fps, 1 then 2, then 3 spray bars
6a	Oil washing	1/27/21	0911	Tub ice, Weathered HOOPS, 90 psi water pressure	Started at ~1 fps, 1 then 2, then 3 spray bars
6b	Oil washing	1/27/21	0928	Block ice, Weathered HOOPS, 90 psi water pressure	Started at ~1 fps, 1 then 2, then 3 spray bars
2b	Heater test	1/27/21	0937	Quick test of heater to ensure IR camera is recording	
7a	Oil washing	1/27/21	1019	Tub ice, Weathered HOOPS, 60 psi water pressure	slowspeed, 1 then 2, then 3 spray bars (dropped bottom single not top single by mistake)
7b	Oil washing	1/27/21	1054	Block ice, Weathered HOOPS, 60 psi water pressure	faster speed, 1 then 2, then 3 spray bars (dropped bottom single not top single by mistake)
8a	Oil washing	1/27/21	1112	Tub ice, Weathered HOOPS, 30 psi water pressure	faster speed, 1 then 2, then 3 spray bars
8b	Oil washing	1/27/21	1130	Block ice, Weathered HOOPS, 30 psi water pressure	slowspeed, 1 then 2, then 3 spray bars
6c	Oil washing	1/27/21	1240	Tub ice, Weathered HOOPS, 90 psi water pressure	Started at ~1 fps, 1 then 2, then 3 spray bars

6d	Oil washing	1/27/21	1253	Block ice, Weathered HOOPS, 90 psi water pressure	Started at ~1 fps, 1 then 2, then 3 spray bars
2c	Heater test	1/27/21	1404	Ran heater, started cold, turned heater on, adjusted hose for better airflow, turned off	Recorded IR video and stills, took temps during test

Table 4: Dynamic Test Matrix.

#	Test	Date	Start	Configuration	Speed	Feeder	Notes
1	Ice handling underway	2/3/21	1534	No spray bars	0.1 – 0.2	N	256 gal oil dispensed. Water pump OOC. Had to stop a couple of times due to bridge getting hung up on the boom. A couple of big blocks had difficulty.
2		2/3/21	1545	No spray bars	0.3 kts	N	143 gal oil dispensed. Conveyor ran as slow as possible while still keeping up with ice. Had a blockage with 4 blocks lined up across the pontoons. Moving BOWHEAD side to side (ship course changes) probably would have broken it free.
3		2/3/21	1607	No spray bars	0.4 kts	N	176 gal oil dispensed. Conveyor ran as slow as possible while still keeping up with ice.
4		2/3/21	1626	No spray bars	0.5 kts	N	Total of 677 gal oil dispensed. Conveyor ran as slow as possible while still keeping up with ice. Worked better at higher speed.
5		2/4/21	1107	all spray bars at 60-90 psi	0.25 kts	Manual	Delayed start while waiting for pump to be repaired and re-rigged, skimmer to be rigged, and some ice loaded. Used person with boat hook as a manual feeder. Ended up with a big jam, unable to clear as person could not reach.
6		2/4/21	1135	all spray bars at 60-90 psi	0.5 kts	Manual	Re-arranged to bring main bridge closer to front of BOWHEAD. System worked better at higher speeds.
7		2/4/21	1146	all spray bars at 60-90 psi	0.6 kts	Manual	System worked better at higher speeds.
8		2/4/21	1155	all spray bars at 60-90 psi	0.8 kts	Manual	System worked better at higher speeds.
9		2/4/21	1202	all spray bars at 60-90 psi	1.0 kts	Manual	System worked better at higher speeds.
10		2/4/21	1349	all spray bars at 60-90 psi	1.0 kts	N	All spray on - 60 psi. No manual feeder
11		2/4/21		all spray bars at 60-90 psi	1.0 kts	N	Sprayers off

12		2/4/21	1406	all spray bars at 60-90 psi	1.0 kts	N	Aft facing spray bar only - faster drum on skimmer
13		2/4/21	1421	all spray bars at 60-90 psi	1.0 kts	N	fire monitor
14		2/5/21	1046	No spray bars	0.5 kts	Y	Removed skimmer, boom, water pump, and hoses. Used crane to lift BOWHEAD out - pulled pins on feeder. Used bridge crane to support and adjust the front feeder. Moved BOWHEAD back towards aux bridge to get better view of front. Feeder adjusted just at surface.
15		2/5/21	1102	No spray bars	0.5 kts	Y	repeat
16		2/5/21	1111	No spray bars	0.5 kts	Y	Slightly lower on feeder
17		2/5/21	1119	No spray bars	0.5 kts	Y	Slower feeder rotation

5 SYSTEM PERFORMANCE

5.1 Goal #1. Assess ice handling capability (perf obj. 2, 4)

Evaluate whether ice larger than 1-inch is removed from the path. Evaluate whether blocks that are too large get deflected/not stuck.

This goal was assessed initially in a static mode during the first test week and then in a dynamic mode in the second week.

During static testing the ice chunks were pushed into the system manually. There was initial concern that the ~4x4ft square ice blocks could get wedged between the sidewalls and pontoons, so the forward edges of the sidewalls were "chamfered" to help mitigate this risk (see Figure 15). During static testing several 4x4ft ice blocks were fed into the conveyor. The blocks appeared to orient themselves well and were lifted by the conveyor with relative ease. A few of the larger ice blocks took more time to become fully gripped by the conveyor belt flights. Smaller ice blocks and pieces seemed to be lifted up by the belt with ease. The belt is designed to prevent ice larger than 1x1inch from passing through and this appeared to be the case.

Figure 15. Front view of BOWHEAD in static configuration pool of weathered HOOPS. Chamfered sidewalls are circled.

During the dynamic testing week, the system was moved down the ice-filled lane (see Figure 16) at speeds from 0.1 to 1.0 kts. At the slower speeds, the ice did not move into the conveyor area. Once the speed was above 0.5 kts, the ice moved readily to the belt. At speeds of 0.8-1.0 kts there was not a need for the feeder system as the ice either moved up onto the belt or was deflected to the side (see Figure 17).

Figure 16. Looking South down the tank in the direction of travel. Boomed off ice/oil lane visible.

Figure 17. Ice moving on the belt and up into the system.

Once the ice was on the belt it was typically managed well; blocks of all sizes were lifted out of the water and moved aft to the chute. However, if the belt was run too fast, then the belt would just move under the ice with the flights just digging grooves into the ice. Sometimes if the blocks were picked up, but the belt was moving too fast, the larger blocks of ice would lose traction on the belt and slide back down. The flights on the belts were too small to prevent this from happening once the larger blocks gained momentum. Initially there did not seem to be much difference in performance between the pins and the roof top flights on the belt, but after several tests it was clear that many of the roof top flights had become bent by the ice (probably when blocks slid down the belt) – see Figure 18 .

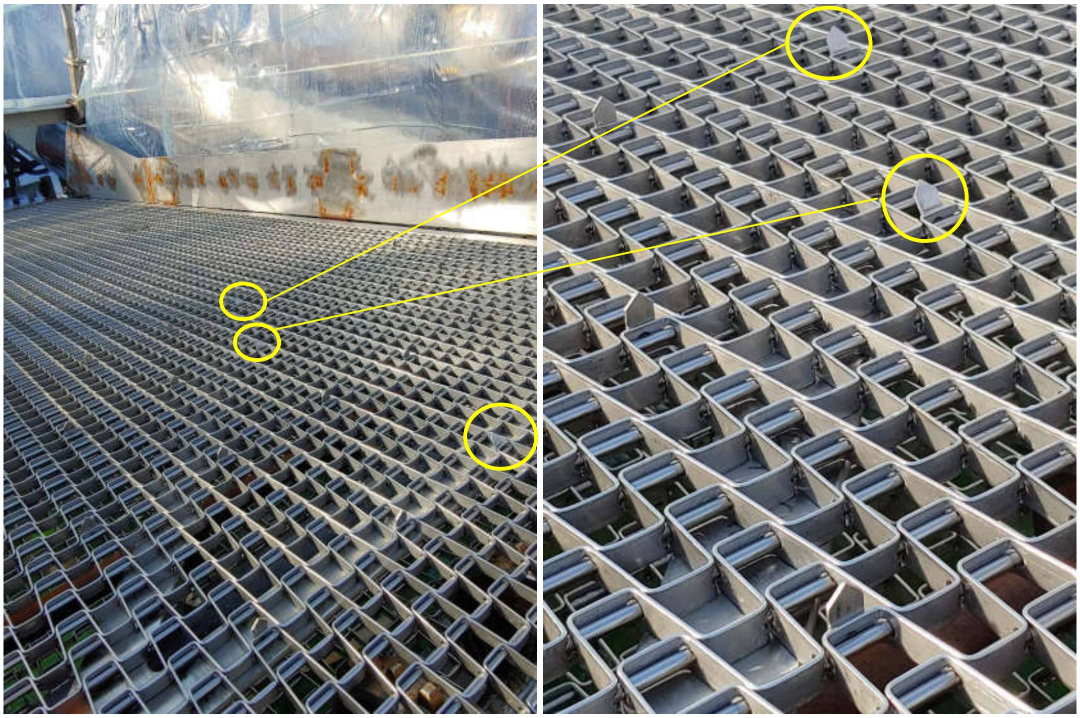

Figure 18. Roof top flights bent during testing.

The feeder system (see Figure 19 and also refer back to Figure 8) was tested on the final day. When adjusted to the correct level (tips just below the water surface) and run at slow speed, it did assist in getting ice to the belt and clearing jams (when run in reverse).

Figure 19. Ice feeder in use.

5.2 Goal#2. Assess ice buildup (perf obj. 6, 7)

Evaluate whether ice builds up in the system or whether washdown and heated tent can prevent this.

There was no observable ice buildup in/on the system during operation. During the first test week there was a combination of snow, hail, and sleet on the first test day and over the weekend between the two test weeks there was a major storm that dropped 8 inches or more of snow on the facility (see Figure 20). This made for a snow-covered system (see Figure 21), but it did not impact performance. Temperatures during the first test week ranged from a low of -10° at night to a high of 3° C during the day. In the gap between testing, temperatures were uniformly below 0° C day and night. During the second set of tests, temperatures increased each day, to reach a maximum of 9° C on the final day.

Figure 20. Snow clearing at Ohmsett on 1 Feb 2021.

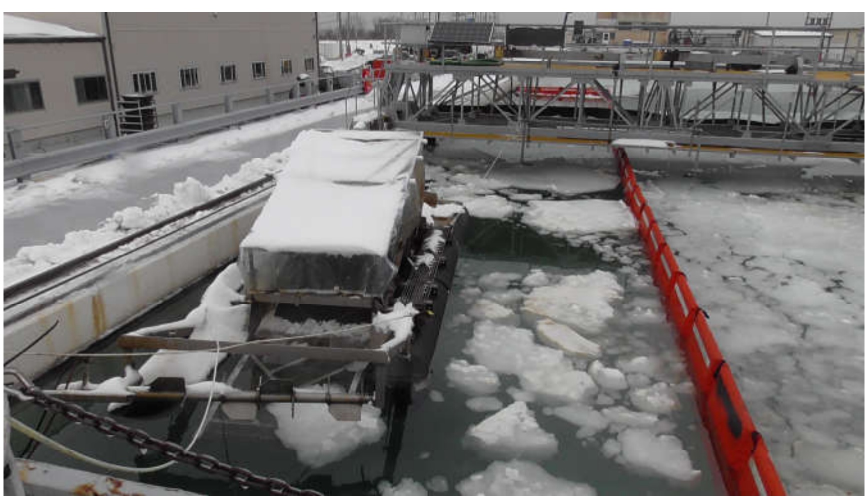

Figure 21. BOWHEAD after the storm.

The tank temperature was just below 0° C (cooling maintained by the chiller unit in combination with the cold night-time temperatures). The water spray did not freeze or allow ice buildup inside the tent. During the heater test, an infra-red camera was used to track the heat flow and an IR thermometer was used to take surface temperatures at various locations on the tent. Starting from cold conditions the heater raised the temperature inside the tent from ~ -1° C to 21° C at the heater end and 4.2° C at the far end. Once the spray bars were turned on (~ -0.5° C water) the temperature in the tent dropped to 3.3° C at the upper end and 1.4° C at the lower end. Figure 22 shows an IR picture of the BOWHEAD enclosure during the heater test. Figure 23 shows the same location with the sprayers on and the resulting drop in temperature (resulting in a darker blue color).

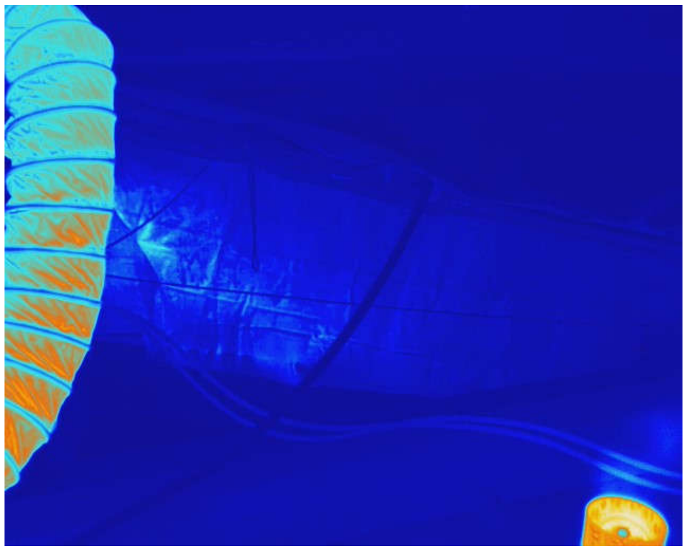

Figure 22. IR picture of BOWHEAD enclosure during the heater test. Heater duct is on the left (heater exhaust is lower right corner).

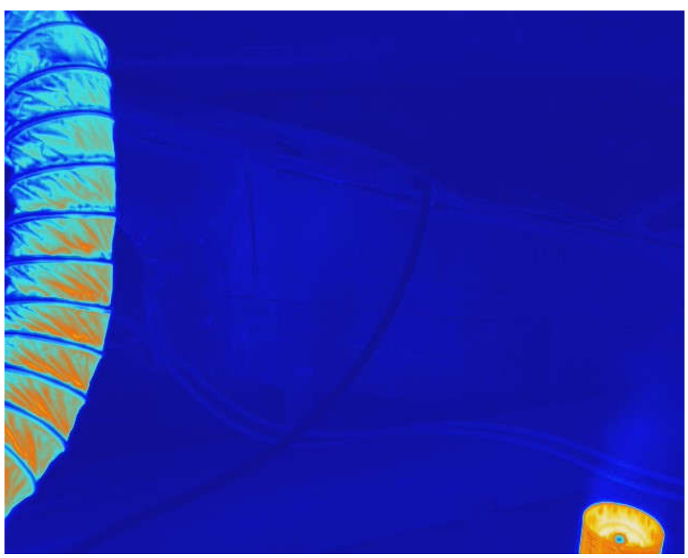

Figure 23. IR picture of the BOWHEAD enclosure with the sprayers on; note that temperature has dropped in the enclosure as compared to the previous picture.

It is not possible to heat up all of the cold water flowing into the enclosure. However, while the water is flowing there should be no ice buildup. The heater seems to be more than sufficient for keeping the system from freezing when it is not in use.

5.3 Goal#3. Assess oil washing capability (perf obj. 5)

Evaluate amount of oil removed from ice.

This goal was primarily assessed during the static testing in week one (with two different oils) but was also evaluated during the second (dynamic) test week. Three different pump pressures were used: 30, 60, and 90 psi. The pump used could deliver the capacity of water for the nozzles as listed in Table 5. Various combinations of the spray bars (1, 2, or 3 on top) were also tested. Typically, the bottom spray bar was always on.

Table 5. Sprayer nozzle capacities.

Nozzle	Qty	GPM at 30 psi	GPM at 60 psi	GPM at 90 psi
base nozzles 95°	6	2.6	3.7	4.4
top middle nozzles 80°	3	6.1	8.6	10.5
top side nozzles 50°	6	6.1	8.6	10.5
Total GPM		**70.5**	**99.6**	**120.9**

Overall, the spray bar system proved highly effective at most pressure/flow and nozzle quantity variances and seemed to perform well at washing the oil from the ice blocks. It was observed that the sides of ice facing the forward end of the BOWHEAD were not getting as clean as the remaining sides of the ice. To remedy this, for day two, the forward-most spray bar was angled ~10 degrees aft (relative to the normal, downward axis). This appeared to be the most successful orientation for cleaning the ice.

After some tests the upper set of spray bars was also moved slightly forward so that the uppermost spray did not intersect with the spray from the bottom spray bar.

The water flow at 30 psi was insufficient for good washing. The nozzles used are intended for higher pressure so at 30 psi the amount of water flowing is probably too low – also the spray patterns are reduced. As can be seen in Table 5, the total volume of water delivered at 30 psi is quite a bit lower than that at 60 or 90 psi. In general, higher flow rates and pressure did seem to have relatively improved ice cleaning capacity. However, the improvements between 60PSI pressure/flow and 90PSI appeared to be marginal.

The belt speed had a large effect on the ability to clean the ice, especially for heavier oil. The slower the ice moved through the water spray, the more effective the washing; so slower belt speeds improved washing. Belt speeds of approximately 20% of the rated speed of 1.7fps appeared to give the system sufficient time to remove the majority of oil from the ice.

We should note however, that the washing of the ice is not the prime objective; the main objective is to get the ice out of the skimmer's path so it can recover oil. The ice cleaning feature enhances oil recovery because oil that is cleaned off of the ice flows into the boomed area for skimmer collection.

The bottom bar (within the conveyor belt, pointing up) appeared effective at cleaning the underside of ice. During initial test runs, this bar had tilted such that the nozzles were angled forward due to the nozzle bar pipe clamp not being tight enough. The spray pattern was observed to lack coverage across the width of the belt. The bar was restored to the ideal angle (perpendicular to the belt plane), drastically improving the spray pattern and hence ice cleaning capacity.

The bottom bar does tend to spray some oil up into the air. This oil is trapped by the tent roof/walls, then drips back down into the area between the pontoons to be recovered by the trailing boom. So, the tent serves an oil recovery role in addition to retaining heat.

A typical test is shown in Figure 24 with before and after pictures of the same ice block (it has broken into 3 pieces from being dropped into the ice chute). Figure 25, Figure 26, and Figure 27 show performance at various pressures and numbers of spray bars using weathered HOOPS oil.

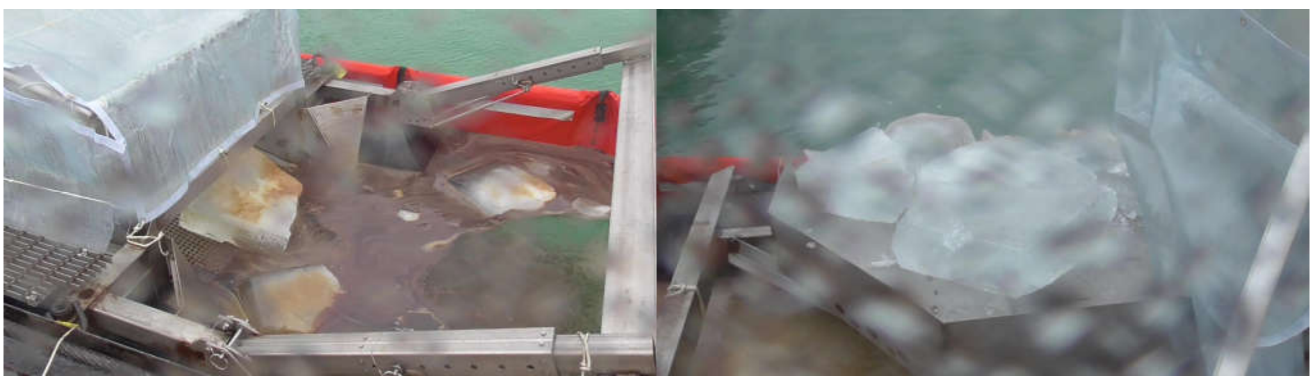

Figure 24. This shows an example of one oil washing test on the first day; 60 psi water pressure on Hydrocal 300. Before is on the left and after on the right. The images are a little blurry due to the precipitation during the testing.

Figure 25. 90 psi spray test – 1 top spray bar on left, 3 on right.

Figure 26. 60 psi spray test – 1 top spray bar on left, 3 on right.

Figure 27. 30 psi spray test – 1 top spray bar on left, 3 on right.

5.4 Goal#4. Assess flow of oil to skimmer (perf. Obj. 3, 12)

Evaluate ability of oil to flow to skimmer unimpeded.

This goal was assessed during both the static and dynamic tests, but primarily during the dynamic tests in week 2.

During the static tests, the oil seemed to move through the belt into the skimmer pocket without difficulty. There was, however, a great deal of emulsification due to the motion of the belt and the spray pressure. We noticed after the first test with Hydrocal (90 psi) that the oil formed an emulsion in back of the device (see Figure 28). We discussed the possibility of it being caused by the sprayers, the belt, or a combination of the two. Ohmsett personnel cleaned the emulsion out of the boom so we were starting clear with the afternoon tests. The 30 psi tests still had some emulsion, but not as much. Also, there was some emulsion forward of the belt, which could either have been from the belt or could have drifted froward from the emulsion accumulated aft of the system. The tests with crude on Wednesday appeared to produce some emulsion, but it was much darker in color (see Figure 29). Further testing was conducted during the dynamic test week with just the belt on (no sprayers). The results of this seemed to show that the emulsification was caused by both the belt and the sprayers.

Figure 28. Hydrocal emulsion after 90 psi (left) and 30 psi (right) January 26.

Figure 29. Crude emulsion at end of day January 27.

Originally, there was uncertainty as to how well the oil would be able to pass through the belt and back into the trailing boom. There was concern that the returning length (underside) of the conveyor belt might return oil that was “scooped up” by the belt and also washed off the ice, back to the front of the system. However, during this static test, oil was observed to pass through relatively well, even without forward movement.

As noticed in a preliminary operational test in Mystic, CT the top of the conveyor belt moving aft creates a slight current towards the belt close to the belt. Farther forward, at the submerged end of the conveyor, there is an area of upwelling and outward current due to the underside of the belt moving forward. This tends to push ice away and create a clear oil-free spot (see Figure 30). At one point the belt was run in reverse as a test – this cleared ice out very well. No ice made it past the system into the pocket behind (where the skimmer would be). Some small pieces made it onto the belt but were either melted or pushed out the chute.

Figure 30. A very mild high-pressure zone is created when the conveyor is operating in the forward mode (right) compared to conveyor off (left).

During the dynamic tests, some oil was observed to flow back to the skimmer, but it did not flow as well as we would like it to (see Figure 31). The conveyor belt and parts of the frame that are at the waterline tend to act as an oil boom and block the flow of oil.

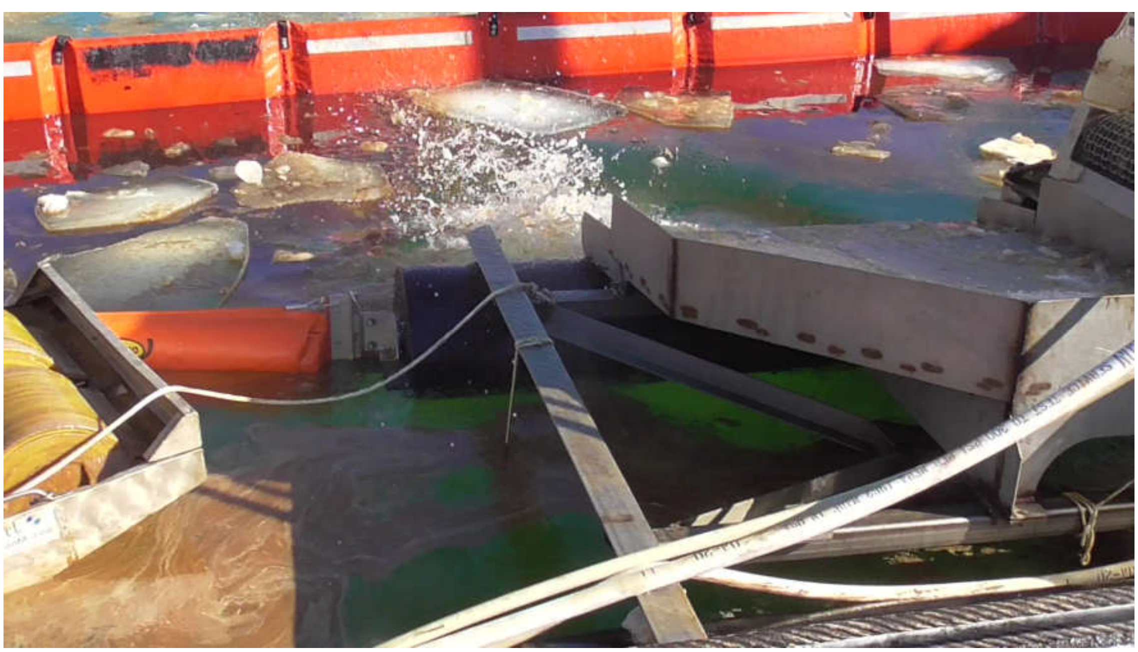

Figure 31. Oil flow under BOWHEAD to skimmer, during dynamic testing.

5.5 Goal#5. Assess ability to move debris out of the way (perf. Obj.13)

Evaluate whether debris is successfully removed from path.

The BOWHEAD system was highly successful at removing any and all ice and debris from the path. This was observed during both static and dynamic tests with ice at Ohmsett and in static tests with wood debris in Mystic, CT.

5.6 Goal#6. Vessel Stability

Evaluate buoyancy and lateral stability under various ice loading conditions.

The BOWHEAD system is very stable with considerable reserve buoyancy. It was designed to be able to handle the weight of ice entirely covering the conveyor belt. Since it is impossible to cover the entire belt, there is a lot of room for extra weight to be added. During testing up to three people were on the system at various times with no adverse impacts to stability noted. During the dynamic testing, the system was able to be pulled easily in either direction and did not exhibit any instabilities as ice was picked up with the belt and dropped out the chute.

5.7 Goal# 7. Static assessments (perf obj. 1, 8, 9, 10, 11)

Total system size and weight. Operator Handling: Ease of set-up and use.

During testing it was noted that the final weight of the BOWHEAD was ~8,000 lb (accurate to a couple hundred pounds) according to the crane scale. The final model file weight used was 6,700 lbs. A breakdown of the BOWHEAD parts between the model file and shipping weights, was utilized to resolve the discrepancy between these weight totals. Upon direct comparison it was found that there was 600 lb unaccounted for between the pontoons and the conveyer belt. In addition, the fabricated pieces, particularly the conveyer assembly, feeder assembly, and craft frame weldment, were heavier than the model properties found them to be. This could be for a number of reasons, but most likely due to the fabricated/stock item pieces being slightly thicker or larger than the model designs accounted for. The hardware and welds make up another couple hundred pounds having been unaccounted for in the model file. Overall although the difference in weights seems quite large, it is distributed between all the components and allows the BOWHEAD to function as anticipated with the waterline falling directly halfway up the pontoons which is where it was designed to be under light load, and where it remained throughout testing.

The system is not difficult to set-up; it just requires the hoses and hydraulic lines to be attached. Some additional set-up was required for the first-time use. Attaching the spray bars and tarps took about an hour. A production system could have permanently attached spray bars of stainless steel and the top area could be enclosed with fixed panels rather than tarping.

The system is very easy to use. The main control during operation is to adjust the belt speed (and direction) depending upon conditions. We experimented with different spray bar configurations and pump pressures for research purposes but for operational uses neither of these would be changed. Although a stand-alone water pump was used for the testing, in operational usage, it would be much easier to use the support ship’s firemain pump to provide the water. A pressure of 90psi would be ideal, but if the fire main could provide at least 60 psi, that would be sufficient.

The catwalks on the sides of the system are essential for set-up. However, there is currently no grating on the aft end of the system, which would be highly beneficial for crossing over between the port and starboard sides of the system. Crossing the ice chute is particularly cumbersome and somewhat hazardous after covered in oil. During operation, this is less of an issue as there shouldn't be a need to board the system in the water.

The current front end feeder system is not operationally friendly. It is difficult to manually raise and lower it, even with the air spring system. This needs to be modified to be hydraulically controlled from the support ship in order to be usable in an operational environment.

6 OPERATIONAL USAGE

Our system is designed to be operated alongside a support vessel. The current design is for it to operate off the port side. Future variants could be designed to allow field changes to the system to enable starboard side operation. When operating in the field, the equipment listed in Table 6 is needed.

Table 6. Host vessel requirements.

Host Ship Service	Parameter	For	Details	Notes
Salt water supply	Up to 120 gpm at 90 psi	Water washdown system	A manifold and hoses are needed to provide water to the four spray bars	If the ship's firemain service cannot supply this amount of water than the stand-alone gasoline pump can be used.
Diesel Fuel	1.41 gal/hr	BOWHEAD HPU	The BOWHEAD diesel-powered HPU, supplying 1800-3000PSI, 12GPM oil to the vessel. The HPU powers the conveyor and front-end feeder motors.	If the support vessel has an HPU that meets the supply requirements that can be used instead of loading the supplied HPU.
10W40 Hydraulic Oil	30ga; capacity, top-off as needed	BOWHEAD HPU		
Diesel Fuel	0.53 gal/hr	BOWHEAD Heater	The BOWHEAD includes a tent heater to supply 70,000 BTU, 900 cfm.	

Host Ship Service	Parameter	For	Details	Notes
Electric power	120 VAC, 60Hz	Bowhead heater and HPU	Electric power is needed for the fan on the heater and for the hydraulic tank heater and block heater on the HPU	
Skimmer system		Oil Skimmer	BOWHEAD is designed to be used with any oil skimmer.	The support vessel must supply the oil skimmer and whatever is needed to power the skimmer (hydraulic typically for the drum).
Oil recovery system		Oil pump, hoses, storage tanks	BOWHEAD is designed to be used with standard oil recovery systems.	The support vessel must supply the oil recovery pump (typically hydraulic) which is typically mounted at the back of the skimmer. Discharge hose and storage tanks must also be provided for the recovered oil/water.

7 CONCLUSIONS/RECOMMENDATIONS

Overall, the system handled ice very well. Blocks of all sizes were able to be picked up and transported aft to the chute as long as the conveyor belt speed was not overly fast. The ice fed into the system without need for the front feeder system as long as the speed of advance was at least 0.8 kts. However, the front feeder system is a desirable feature for slower speeds of advance and to aid when blocks become jammed together in the opening. Some jamming can be eliminated by reversing the conveyor belt, but to allow the most flexibility for operational use, the feeder system should be kept. In order for a feeder system to be used in an operational setting, the feeder needs to be able to be lifted remotely using hydraulics.

The system did not suffer from ice build-up during the testing even at temperatures below freezing and with a wind chill. While the spray bars are running, it is unlikely that ice will form inside the enclosure. When the spray bars are not running, the heater system provides sufficient heating to prevent ice buildup. The enclosure worked well; however, the tarps are difficult to secure totally and are blown around in high winds. Fixed panels would be a better alternative. The system should not be operated without the tarps, even in warmer weather, as the oil tends to get spattered around – the enclosure keeps this in and directs it down to the surface to be recovered. Fixed panels would also be easier to clean/decontaminate. A lightweight material could be used – perhaps aluminum or plastic or a composite in order to minimize the increase in the topside weight.

The system worked very well to clean the oil off of the ice. Three spray bars above (plus one below) gave the best performance. Using only two spray bars above did not reduce performance that much so would be acceptable; however, having three spray bars provides some excess capacity in case of system degradation during operations. The 90psi pressure gave the best performance; however, the performance did not degrade that much at 60psi, especially with the thinner oil. This gives room for adequate system performance with a range of water pump capabilities. The spray bars for the testing were separate PVC pieces so that they could be moved and adjusted during testing. For operational usage, these should be replaced with fixed, stainless steel bars for more robustness. This would also allow the system to be fed with a single fire hose, instead of three, reducing complexity.

The flow of oil through the system and back to the skimmer was the one area where the system did not perform as well as desired. It appeared that there was too much of the system framework blocking the oil flow at the waterline. In addition, all of the water from the spray bars hitting the surface of the water under the conveyor belt impeded the oil flow as well. Some changes to the structure of the system are needed to improve this oil flow.

8 RECOMMENDED SYSTEM CHANGES

The following changes are recommended to the existing BOWHEAD system. Some rough estimates for costs have been provided; however, note that these do not include costs for hardware or for Serco's time to complete the detailed design/plans and oversee the execution of the changes. All of these changes can be made to the existing system; however, it would need to be shipped back to the fabricator so there would also be shipping and crane expenses.

8.1 Front Feeder System

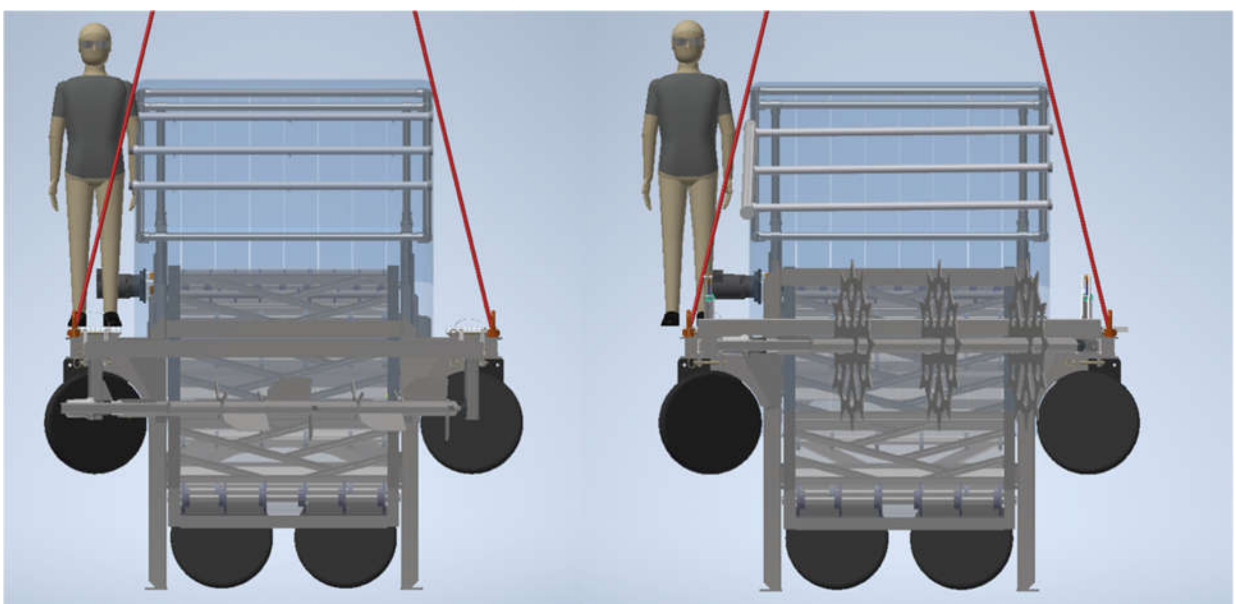

Figure 32. Redesigned front feeder system on right, current system on left.

8.1.1 Feeder Design Change

To improve the current design, we've moved the rotating arm and driving motor further up away from the water; this provides more protection for the motor from ice and allows for larger diameter spiked wheels (see Figure 32). The paddles/spikes previously attached are replaced with larger spiked wheels which will be able to grip the ice better and either pull it towards the conveyer mouth or move it away preventing ice blockage at the conveyer mouth. The larger diameter wheels allow for longer contact with the ice. The cost estimate from our fabricator, J Steel, is $12,600 in material and labor. We will also need to transport the device to his shop for the work to be accomplished.

8.1.2 Hydraulic Lift for Feeder System

The downside to the current feeder design is the inability to adjust the height while it's in use; we suggest changing the current design to a hydraulic actuator solution which would allow the user to adjust the height while in use, raising and lowering it as needed to accommodate variations in the ice height (see Figure 33). In addition to the hydraulics, we suggest raising the support bar across the conveyer. Where it sits on the as-built model is quite low, which although not an issue with any of the man-made ice blocks, could cause issues when dealing with ice of varying sizes in the wild. In the image on the right of Figure 34, the bar is raised allowing for ice size variation. The cost estimate to update the feeder is a 3-part cost. The actuators themselves cost $1,300. The adjustment to the HPU in order to run another hydraulic line to power lifting and lowering the feeder will be $930 for parts and labor. And finally the cost for the fabricator to build the hinge device is $12,000.

Figure 33. Proposed hydraulic actuator system on right, existing configuration on left.

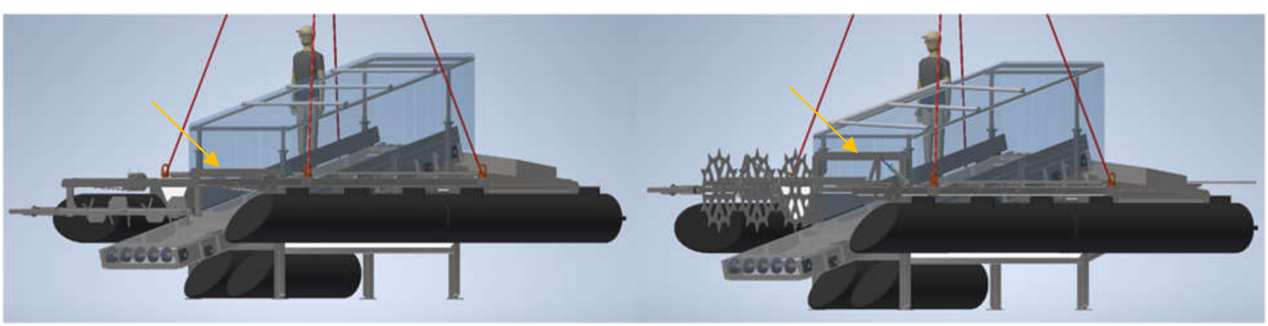

Figure 34. Angled view of front feeder system, current on left and proposed new version on right. Arrows indicate the crossbar to be raised.

8.2 Ice Chute

8.2.1 Ice Chute Slots

The ice chute became covered in ice and oil throughout testing, and this oil was dumped off to the side. In order to recover this oil that would otherwise be lost, we recommend cutting slots on the angled decline of the chute. This will allow the oil that is coming off the ice to drop through to be recovered (see Figure 35).

8.2.2 Additional Catwalk

We suggest adding a catwalk behind the ice chute to provide a safe way to reach the far side of the system while it is in the water (see Figure 35). Although there is still a gap in the walkway between the stern catwalk and the port side catwalk, the height of the catwalks relative to the ice chute is such that a plank could be placed across the ice chute between the catwalks to enable a safe way to get all the way around the system. The cost for both of these changes is estimated to be less than $1000.

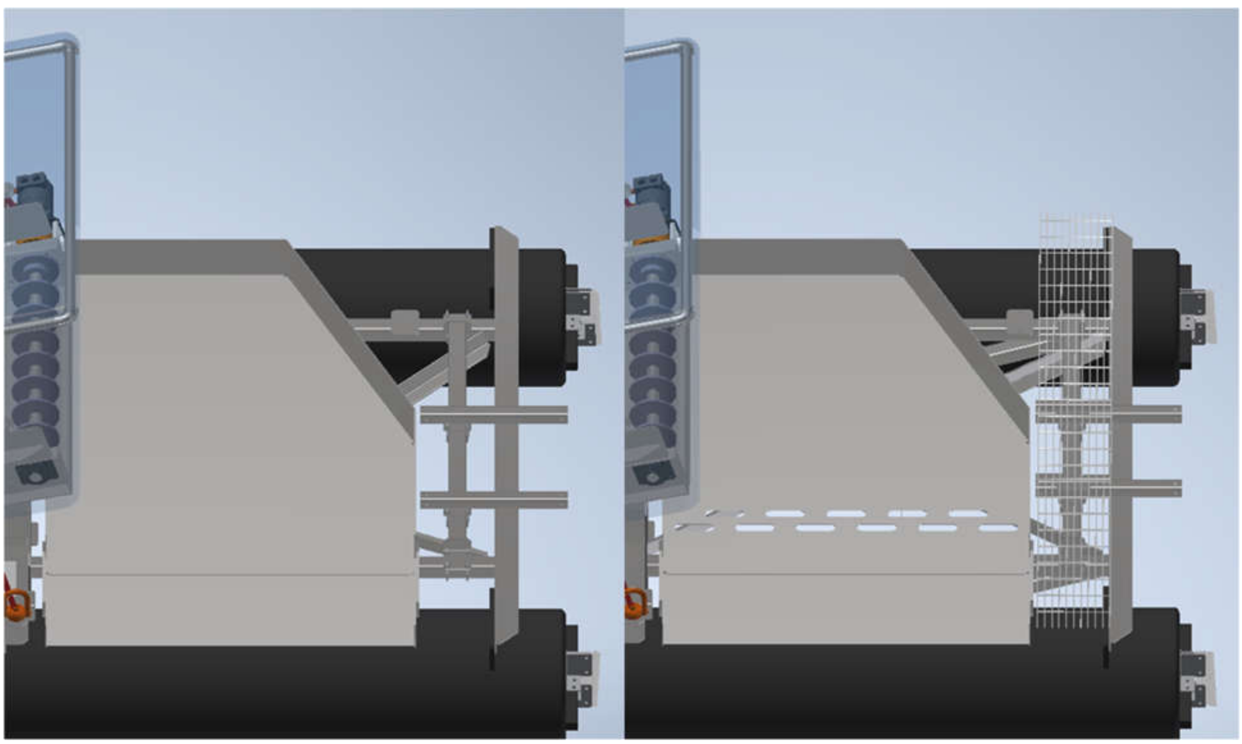

Figure 35. Ice chute and stern of BOWHEAD as-built (left) and suggested updates (right).

8.3 Framework

8.3.1 Framework at Waterline

During testing it became apparent that the supporting framework at the waterline was blocking oil from traveling back to the skimmer. Adjustments to the framework, as shown in the comparison in Figure 36, would allow for increased water and oil flow beneath the system.

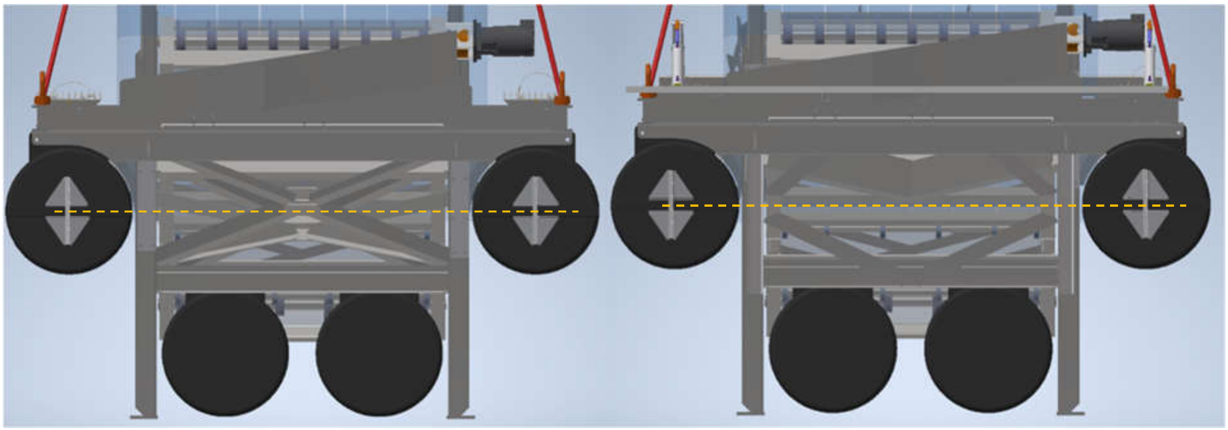

Figure 36. Framework cleanup at the waterline before (left) and after (right); view from astern looking forward, waterline indicates by dashed lines.

8.3.2 Spray Shield

The spray from the spray bars, although very effective at cleaning off the ice, create a water wall disrupting the path of the oil underneath the conveyor. The addition of a spray shield, shown in Figure 37, will block the high-powered spray and allow the oil and water to be distributed downward in a less forceful manner. The cost estimate for material and labor for both of these changes is $700.

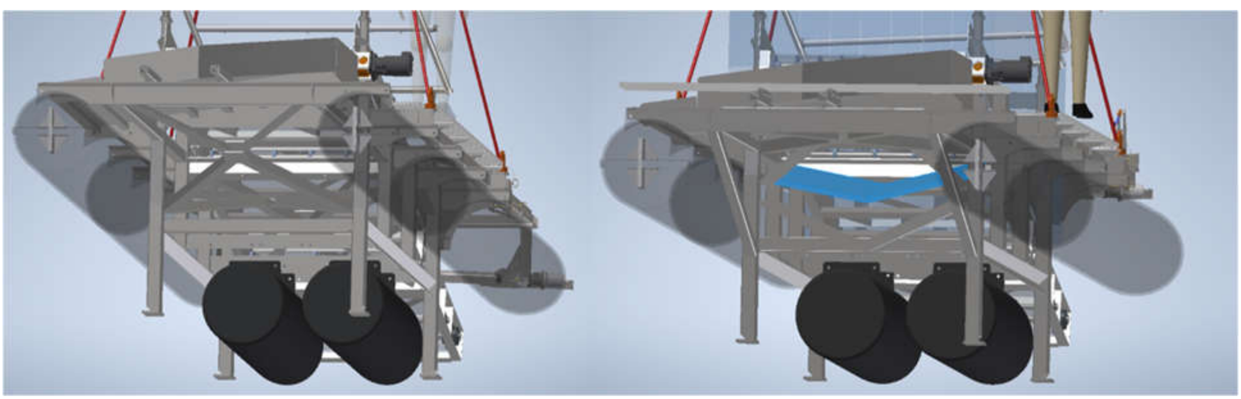

Figure 37. Framework cleanup at the waterline before (left) and after (right), as well as highlighted spray shield (blue); view from below, astern looking up and forward.

8.4 Conveyor belt

The roof top flights were not strong enough and need to be replaced. Since the pins worked effectively, we recommend replacing the half of the belt that has the roof top flights with a new belt section that has the pin up flights. Additionally, it might help to add at the beginning and end of this half-belt section a row of taller pins or even just a solid piece of angle-iron. This would provide a shelf to catch a block of ice that slips down the belt. To replace half the belt with the pin up flights will cost ~$2,0000 + shipping.

8.5 Spray bars

Post testing, we realized the ideal placement of the spray bars is higher up on the frame so that the water spray can be captured by the new spray shield. It would also be better to have more spray bars directed aft rather than forward to ensure deflection of the oil and water aft. The new configuration would be the two forward spray bars angled slightly aft and the third, aftmost, spray bar angled slightly forward. This coupled with the side nozzles angled in provides water coverage on all sides of the ice blocks while directing the water flow into the spray shield. In addition, for increased robustness, the individual PVC spray bars should be replaced with stainless steel pipes that are permanently mounted to the frame. This also allows all four spray bars to be piped together with a single 2- or 3-inch hose connection (instead of three separate hoses). The cost estimate for the material and labor is $1,000.

8.6 Enclosure covering

The enclosure could be made more insulated and more secure against the wind by replacing much of the tarping with permanent metal or composite panels. This could be done on the front, the upper section of the back, the sides, and part of the top leaving tarping just over the spray bars. The solid panels could be attached to the frame with screws so that the enclosure would be more secure against the wind, but the panels could still be removed if necessary. Solid panels would also be easier to wash and decontaminate. As part of this change, a better attachment point for the heating duct could be fabricated to allow for easier attachment and removal. The cost estimate for encasing the frame will vary based on the material chosen, a metal enclosure is estimated to be $4,000 for materials and labor.

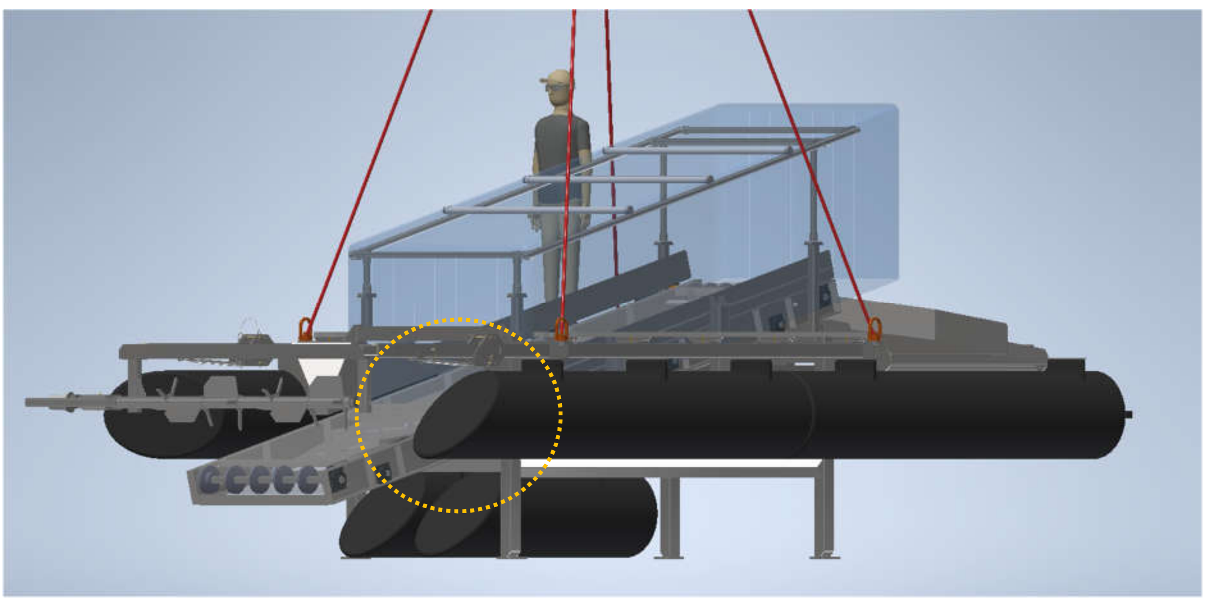

Figure 38. Angled view of BOWHEAD with outboard pontoon end circled.

8.7 Outboard pontoon.

The existing outboard (port) pontoon has a wedge shape (see Figure 38). The thought was that this would allow ice that was too big for the opening to ride up the pontoon and be shunted to the side. However, in practice, with the front feeder system in place, this wedge just creates a choke point where ice can get wedged (see Figure 39). Angling the front end to match the inboard (starboard) pontoon would alleviate this and allow ice to be directed either into the opening or shunted to the side (see Figure 40). Since the pontoon is in sections, this would require just the replacement of the front half of the port pontoon. The quote for this pontoon from the manufacturer, Pipefusion, is $1,750.00 plus shipping.

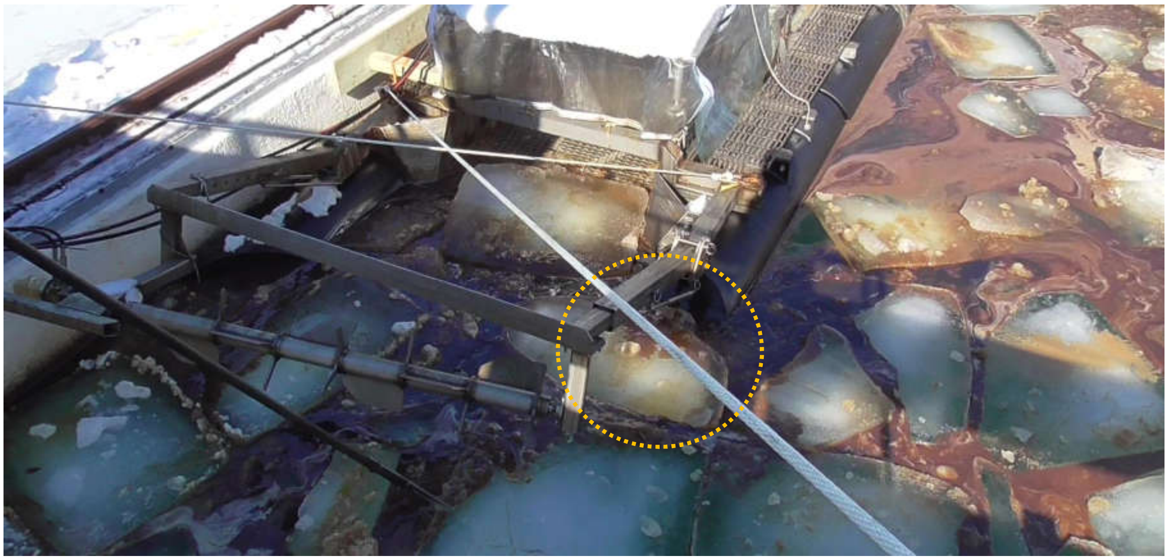

Figure 39. BOWHEAD in action with an ice block caught on the front end of the pontoon (circled).

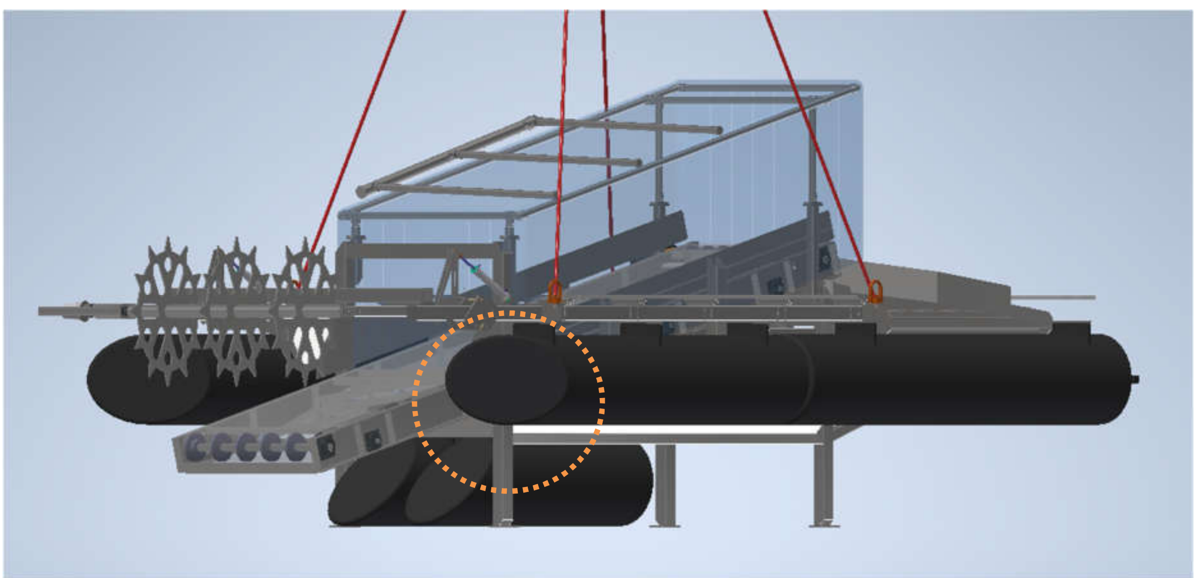

Figure 40. Angled view of BOWHEAD with outboard pontoon suggested change (circled).

8.8 Summary of Changes

The rough cost estimates for each of the proposed changes are listed in Table 7, with estimated hardware costs included. In order to compare the costs of retrofitting these changes to the cost of fabricating a new system with the changes, the estimated shipping costs are listed as well. It appears to be significantly cheaper to retrofit the existing system than fabricate a new one.

Table 7. Cost Summary for Proposed Changes.

Item	Est. Cost
Front Feeder System	$28K
Ice Chute	$2K
Framework	$1K
Conveyor Belt	$3K
Spray Bars	$2K
Enclosure	$5K
Outboard pontoon	$3K
Shipping (2) and crane services (4)	7K
Total	**$51K**
Vs est. New System Cost	**$115K**

9 REFERENCES

[1] B. O. Johannessen, H. Jensen, L. Solsberg, and T. Lorenzo, "Mechanical Oil Recovery in Ice Infested Waters (MORICE) - Phase 1," SINTEF, Trondheim, Norway, BSEE Report 310aa, 23 July 1996.

[2] B. O. Johannessen, T. Lorenzo, H. Jensen, and L. Solsberg, "Mechanical Oil Recovery in Ice Infested Waters (MORICE) - Phase 2," SINTEF, Trondheim, Norway, BSEE Report 310ab, 28 February 1998.

[3] H. Jensen, T. Lorenzo, and L. Solsberg, "Mechanical Oil Recovery in Ice Infested Waters (MORICE) - Phase 3," SINTEF, Trondheim, Norway, BSEE Report 310ac, 7 July 1999.

[4] H. Jensen and L. Solsberg, "Mechanical Oil Recovery in Ice Infested Waters (MORICE) - Phase 4," SINTEF, Trondheim, Norway, BSEE Report 310ad, 18 September 2000.

[5] H. Jensen and L. Solsberg, "Mechanical Oil Recovery in Ice Infested Waters (MORICE) - Phase 5," SINTEF, Trondheim, Norway, BSEE Report 310ae, 15 June 2001.

[6] H. Jensen and L. Solsberg, "Mechanical Oil Recovery in Ice Infested Waters (MORICE) - Phase 6 - Final testing in Oil and Ice," SINTEF, Trondheim, Norway, BSEE Report 310af, 11 December 2002.

[7] H. Jensen and J. Mullin, "MORICE––new technology for mechanical oil recovery in ice infested waters," ***Marine Pollution Bulletin,*** **vol. 47, no. 9-12, Sep - Dec 2003.**

[8] G. W. Johnson, C. Grayson, K. Dykstra, and M. Fitzpatrick, "Methods for Mechanical Removal of Surface Oil in Ice Infested Waters (ICEHORSE I)," Alion Science and Technology, New London, CT, ICEHORSE Final Report Deliverable 7, 9 May 2016.

[9] G. W. Johnson, C. Grayson, K. Dykstra, and M. Fitzpatrick, "ICEHORSE II Development and Testing," Alion Science and Technology, New London, CT, ICEHORSE Final Report Deliverable 7, 31 July 2018.

APPENDIX A. PERFORMANCE OBJECTIVES

Our system concept meets all of BSEE's design goals (in blue):

1. Be able to be used with an existing vessel mounted side skimming system. This could include USCG vessels such as the USCG Ice Breaker Healy or the USCG Juniper class buoy tenders that operate in Alaska. It could also include vessels that respond in the Alaska area including Cook Inlet or the Prince William Sound. As described in the concept, our system can be easily deployed over the side from a vessel such as the HEALY or JUNIPER class buoy tender using the vessel's crane. It is designed to work with any existing skimmer system, which would be towed behind our system using standard oil recovery boom, connected by industry-standard American Society for Testing and Materials (ASTM) slide connectors.
2. Minimize ice accumulation within a boomed recovery area as vessel moves through an area of ice and oil (targeted 30%-70% ice field and 1 knot travel speed). Our system will virtually eliminate any ice being presented to the skimmer. All ice pieces larger than 1-inch square will be lifted out of the way by the conveyor belt. Any ice or slush that does not melt on the way up the conveyor will be dumped off to the side. Previous Serco and USCG testing has demonstrated that anything smaller than 1-inch will not adversely impact the skimming operations.
3. Maximize oil flow into the boomed recovery area. This will require the ice to be rotated or tumbled at the system interface to allow oil between ice chunks to flow to the recovery area. The ice will be lifted out of the path of the skimmer while oil will flow through the mesh of the conveyor belt. The conveyor belt is long enough to allow oil lifted with the ice to drip through the conveyor before the ice is pushed off to the side. Any oil on the ice or mixed with slush will be washed using multiple variable pressure & flow rate saltwater spray nozzles.
4. Consider different sizes of ice that may need to be deflected. The system has a 4-ft wide conveyor and the pontoons will prevent ice any larger than that from getting to the conveyor. Part of the testing at Ohmsett will be to evaluate the system and whether it needs to be scaled up any larger for operational use – there is a trade-off between size and operational usability. There will always be a maximum size of ice block that can be handled by the system and the ship will need to maneuver to avoid these larger pieces (as noted in the MORICE report) – focusing on areas that have the most oil. The ice feeder mechanism at the front of the system, can also be run in reverse to push too-large chunks of ice out of the way.
5. Include capability to spray ice at the interface area to remove oil that adheres to the ice. As mentioned above, any oil on the ice or mixed with slush will be washed using multiple spray nozzles. Some of the spray nozzles mounts are adjustable so that their pointing can be optimized during testing. Several combinations of water pressure, flow rate, and number of nozzles can be used (low pressure, high flow rate non-heated water was shown to be most effective on ice embedded in the ice blocks in MORICE project). Pre-determined combinations of washdown parameters will be tested at Ohmsett.
6. Deflect the ice and prevent buildup of ice along the system interface. As the host vessel advances and ice concentration increases, the conveyor belt rate can be increased to process ice more quickly to prevent build-up in front of the conveyor. Additionally, high

pressure water spray will aid in preventing ice buildup on the system itself. If necessary, a spray nozzle can be directed into the ice chute to keep the ice moving and prevent accumulation.

7. Operate in conditions as would be found in an arctic environment such as temperature extremes, exposure to saltwater, and UV exposure. The system is designed with commercial off the shelf (COTS) components that can handle the arctic marine environment. The design incorporates a “tent” around the conveyor and wash-down area that will be heated to reduce ide build-up. The system is also designed to be as simple as possible so that there are fewer parts that could fail.
8. Minimize storage requirements. The system will fit into a standard 40-foot container for storage and shipping. It can sit on the deck of the ship prior to deployment. Future iterations of the design can permit the conveyor to virtually ‘lay-flat’ for reduced storage.
9. Minimize system complexity. The system is designed to be as simple as possible. It requires water and hydraulic connections, which if the ship or test facility does not have, can be provided by a small unit placed on deck. Aboard ship, high pressure saltwater is typically available through a firemain connection. Any adjustment of water flow or conveyor speed can be done from on deck of the ship.
10. Minimize Deck Space required for operation. During operation, the only deck space needed is for the Hydraulic Power Unit (HPU) and water pump and heater. Even this space is not needed if the support vessel already has the capability and connections to supply water and hydraulics.
11. Consider ease of setup. System set-up is very easy and similar to that of existing oil recovery systems. The ice conveyor is lifted over the side and placed in the water by the ship’s crane and then tied up alongside. It is then connected to the skimmer using standard oil recovery boom with ASTM slide connectors; this may be able to be done prior to putting the system over the side. The water and hydraulic connections can be made prior to putting the system over the side.
12. Not impede ability of skimmer to be moved in and out of the recovery area. Since the skimmer is towed behind our system, it can be removed, swapped out, or heads changed as desired. Our system does not obstruct the skimmer system in any way.
13. The ability to handle debris such as logs, twigs, kelp is desired for use in other than ice conditions. Our conveyor belt system, since the entire belt moves (not just chains along the edge like the MORICE system) will be able to lift debris such as logs, twigs, and kelp and dump it over the side (after being washed).

APPENDIX B. MAJOR PARTS LIST

Item	Cost	Source
Pontoons	$ 9,590	Pipe Fusion
Conveyor Belt	$ 6,375	Keystone
Hydraulic Motors	$ 3,095	RG Group
Misc hardware, castors, motor couplings, gas springs	$ 4,390	McMaster Carr, Northern Tool
Boom, slide connectors	$ 445	Abasco
Fabrication and assembly	$ 59,850	J Steele
HPU, hoses, couplers, hydraulic fluid	$ 22,600	HydraTech
Water Pump	$ 1,995	Absolute Pumps
Spray bars and fittings	$ 500	J Steele
Nozzles	$ 665	BEX
Hoses (two 1in, one 1.5in, 2in suction) and strainer	$ 560	FireHose Direct
Air heater, heater duct, adapter	$ 1,540	Smokey Mtn Emporium
Clear vinyl tarping	$ 400	
Total	**$ 112,005**	

APPENDIX C. DETAILED DRAWINGS

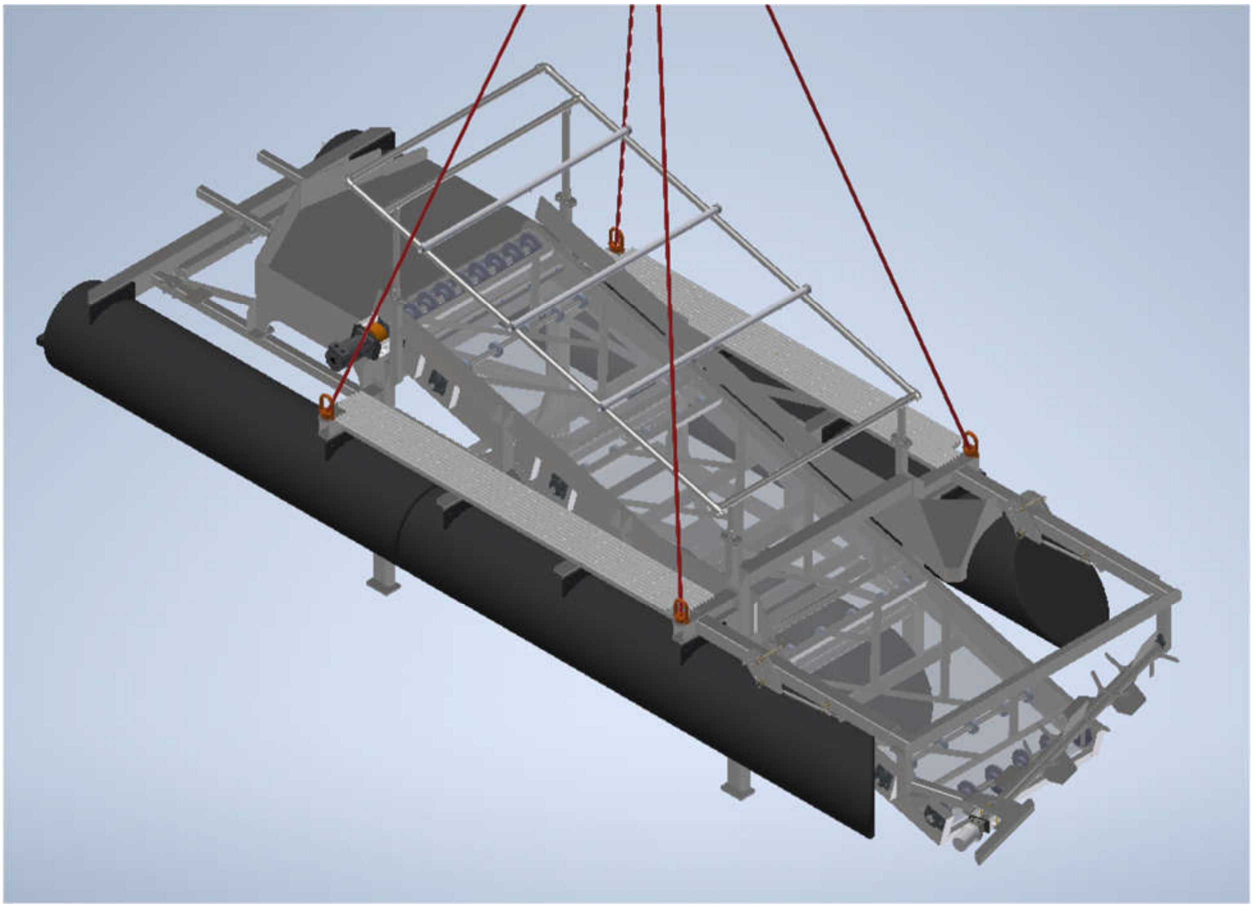

Figure 41. Isometric view.

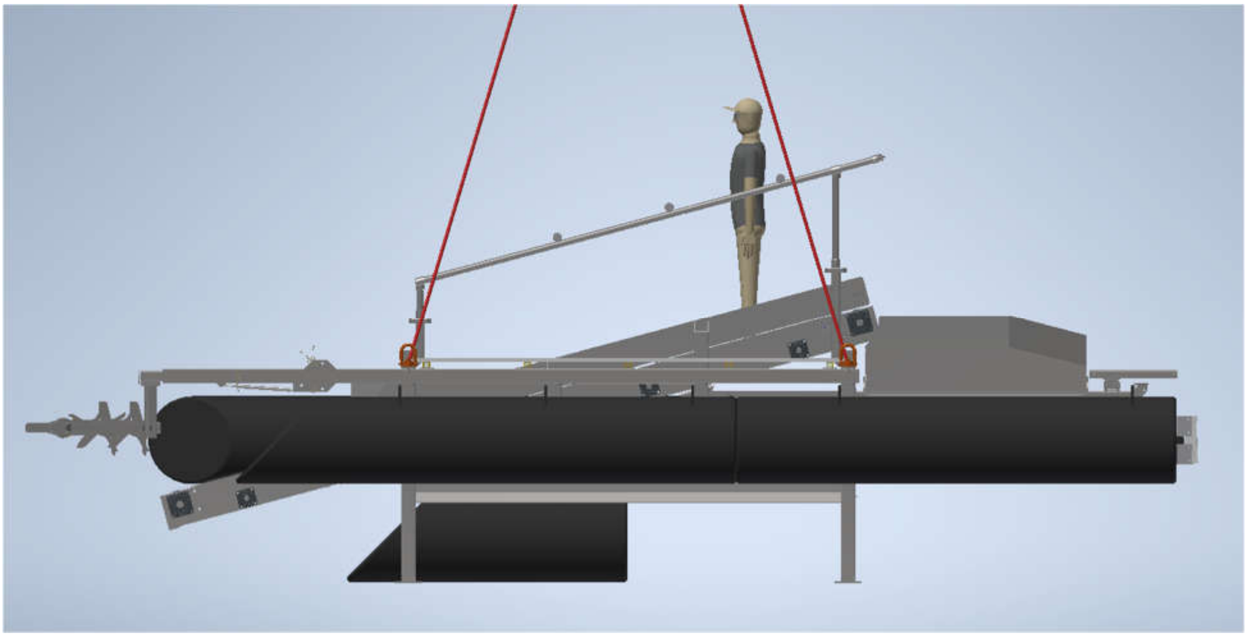

Figure 42. Port side view.

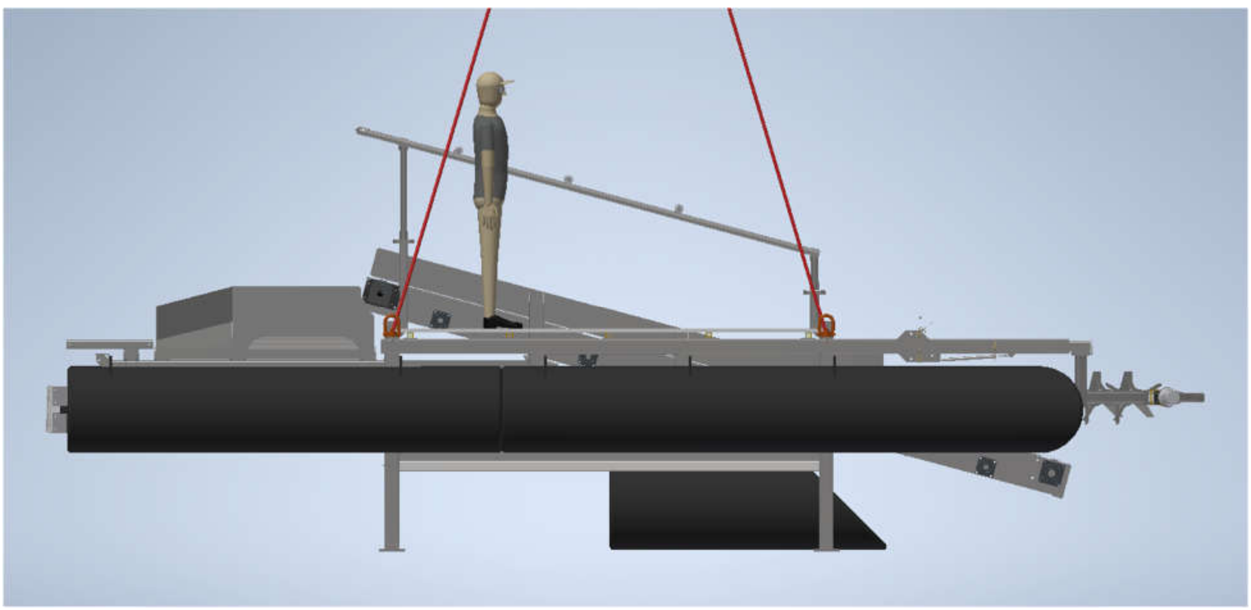

Figure 43. Starboard side view.

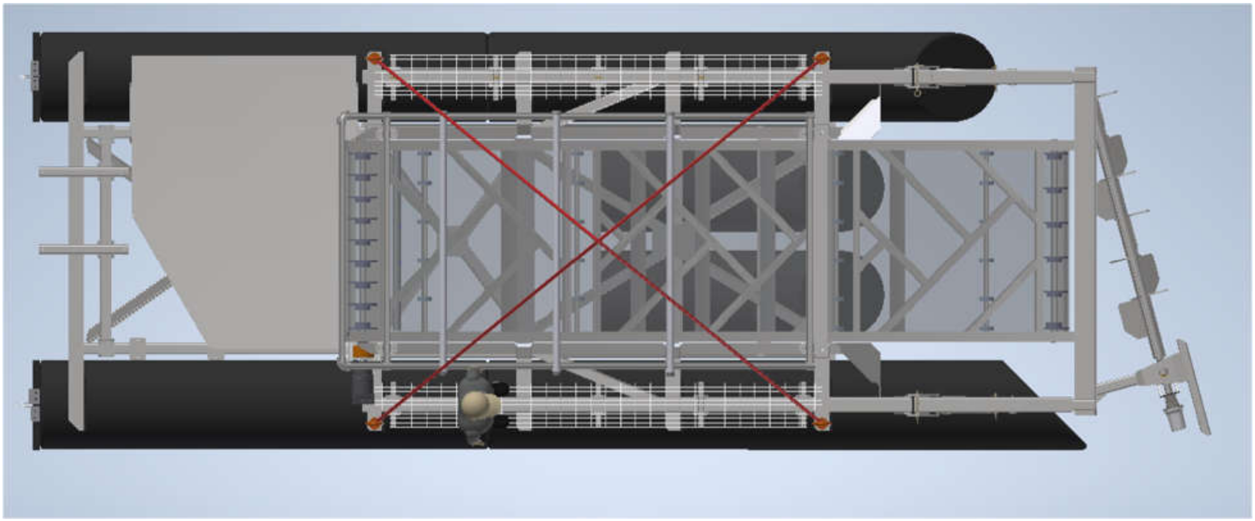

Figure 44. Top view.

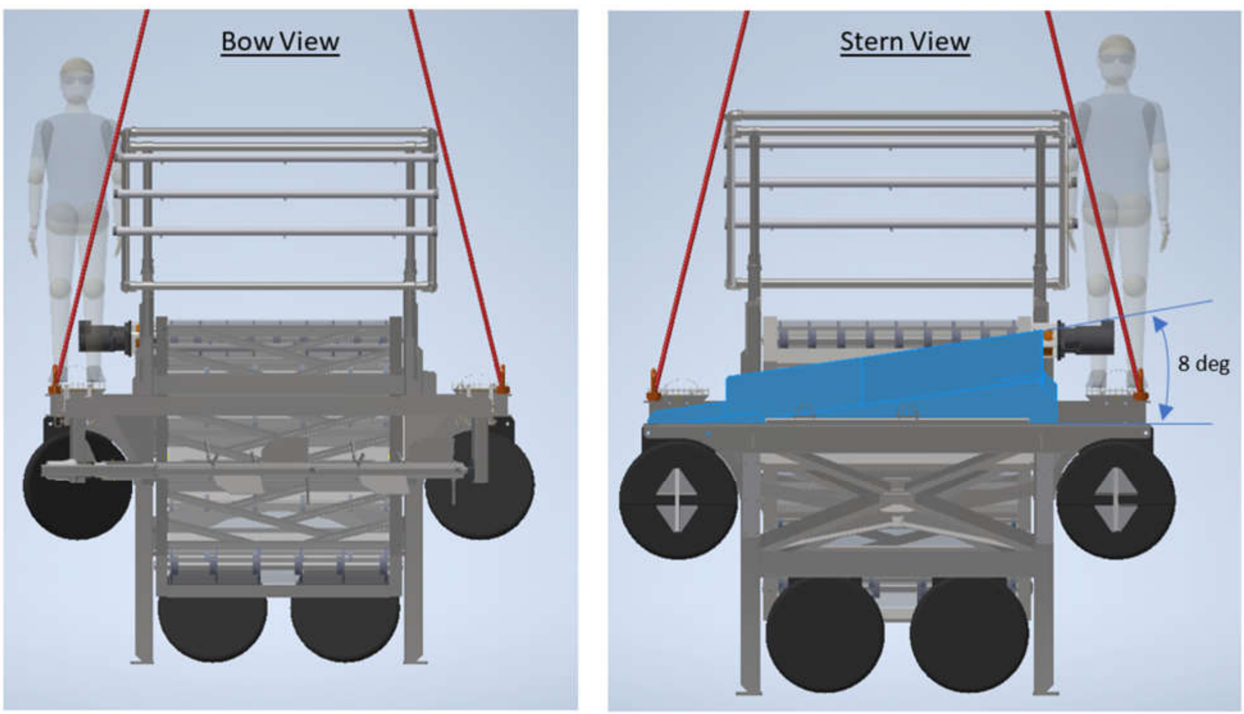

Figure 45. Bow (left) and stern (right) views.

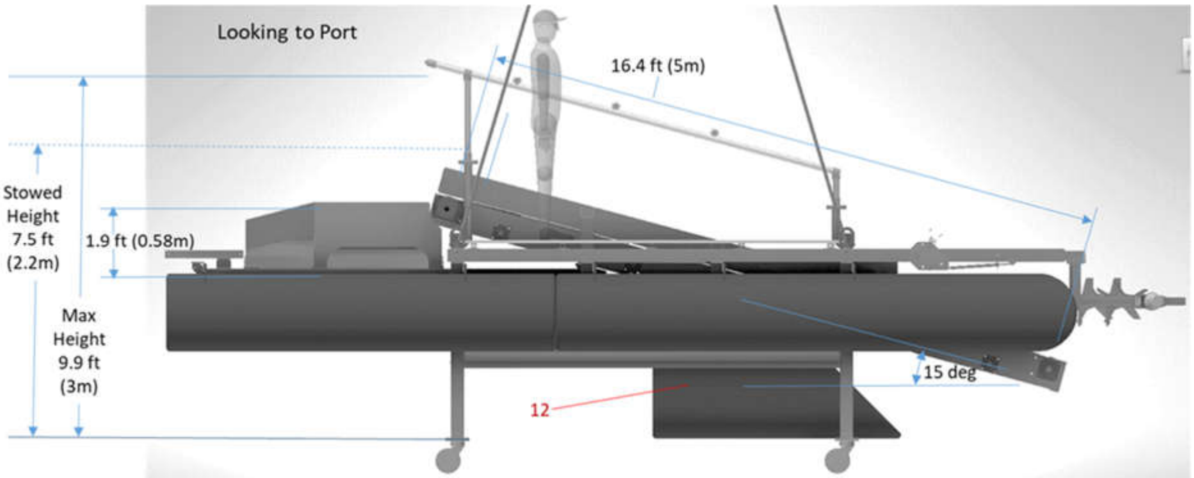

Figure 46. Dimensioned side view.

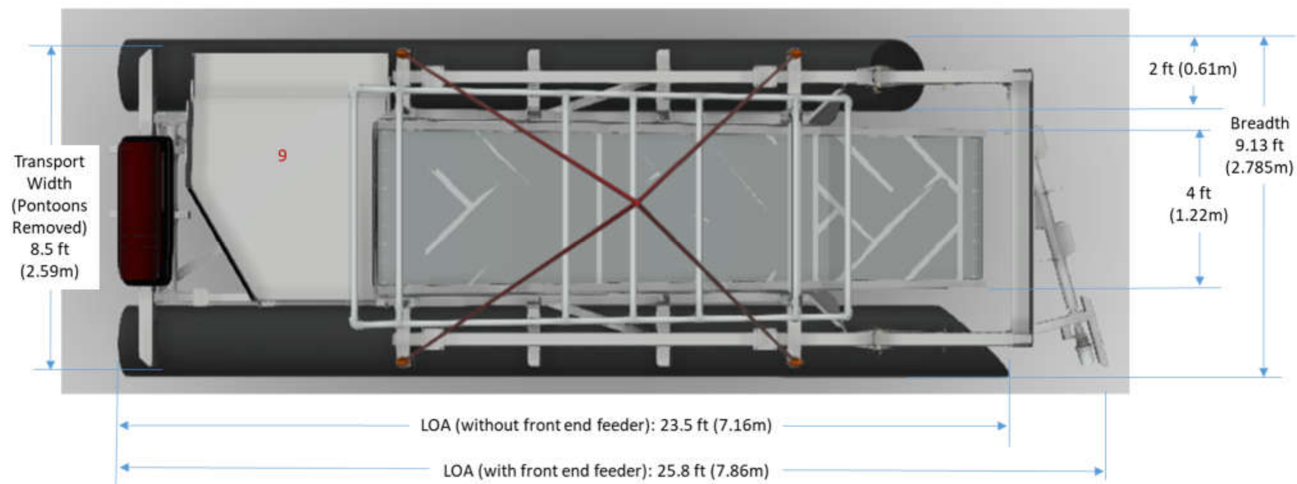

Figure 47. Dimensioned top view.