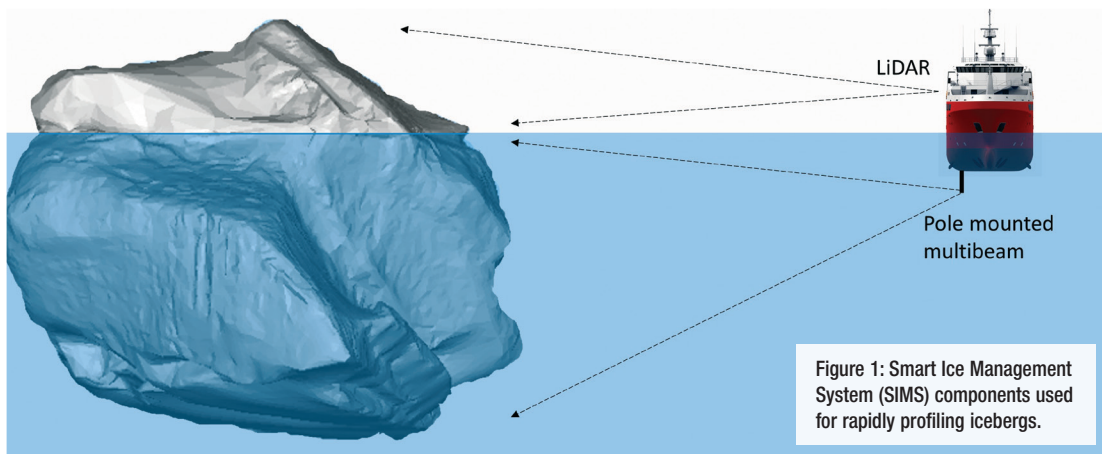


Development of a Decision Support Tool to Aid Iceberg Management Operations

Iceberg photographed during the 2019 field campaign. Using the Smart Ice Management System (SIMS), the iceberg was measured to be 325 m in length at the waterline, 62 m high, 125 m deep with a mass of 6,000,000 tonnes.

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Icebergs present a significant design challenge for oil and gas operations on the Grand Banks of Newfoundland. Icebergs present a risk to surface piercing structures, such as production platforms or moored offshore drilling units, as well as subsea infrastructure, such as pipelines and wellheads. The use of iceberg management (iceberg towing, in particular) significantly reduces the risk of iceberg impacts with offshore structures.

Improvements to iceberg towing success rates have a number of benefits for offshore operations. The primary benefit is the increased safety for those working offshore. Additionally, ISO 19906 permits the risk mitigation effect of iceberg management to be included in the design of offshore structures. Therefore, improvements to iceberg management success rates translate into potential reductions in design loads and the cost of new offshore structures. Towing an iceberg more efficiently, with fewer attempts required to remove the iceberg threat, results in improved vessel utilization and potential reductions in operating costs and emissions.

Iceberg management on the Grand Banks of Newfoundland is currently carried out without knowledge of the underwater shape of the iceberg. A decision support tool (SIMS – Smart Ice Management System) is being developed to integrate the rapid generation of

3D iceberg shape data with tools that utilize the data to improve iceberg management success rates and efficiency.

System Overview

SIMS utilizes a LiDAR and a multibeam sonar to profile the iceberg sail and keel, respectively, as illustrated in Figure 1. The present prototype systems deploy a multibeam over the side of the vessel using a hydraulically actuated pole assembly. The multibeam is mounted to a 90° elbow such that the orientation of the multibeam is sideways looking (looking at the iceberg) rather than in the typical downward orientation (looking at the seabed). A permanent installation would utilize a through-hull pole to avoid impairing the vessel's regular operations and docking capabilities, as well as reducing risk to the multibeam.

The LiDAR system used for the program was a Teledyne Optech Polaris LR, which was paired with an Applanix POS MV Wavemaster inertial navigation system. The multibeam system used for the program was a R2Sonic 2026 sonar, which was paired with the same Applanix POS MV Wavemaster inertial navigation system. The multibeam system was installed on the hydraulically actuated pole assembly, which was used to lower the sonar into the water for profiling operations. The LiDAR and multibeam pole assembly are shown in Figure 2.



Figure 2: Iceberg profiling equipment – the LiDAR (left) and multibeam attached to hydraulically actuated pole assembly (right).

Data Collection and Processing

A vessel equipped with the profiling system circumnavigates an iceberg twice to collect the iceberg shape data, while maintaining a safe standoff distance from the iceberg. This process typically takes approximately 15-30 minutes, depending on vessel mobility and iceberg size.

The data acquisition is achieved by using commercially available surveying software. The software is complex and is generally operated by those with a surveying background. As part of SIMS development, a simplified pared-back user interface was developed for operating the system, with complex setup work done when the system is installed on the vessel, making it possible for the system to be operated by trained vessel crew as opposed to surveyors.

Drifting icebergs have three translational and three rotational degrees of freedom. Iceberg translation and yawing are the most significant movements during the profiling process. An iceberg travelling at a speed of 0.5 m/s can move approximately 600 m in 20 minutes. The iceberg may undergo significant rotation during this time also. Therefore, the point clouds collected during profiling will appear to be skewed and have to be corrected

for drift and rotation. The data must also be processed to remove noise. Noise is any registered point that does not belong to the iceberg surface.

C-CORE uses algorithms to automatically correct for drift and de-noise the profile data. A graphical user interface has been developed which allows the user to inspect the output data from the automated correction and cleaning algorithms to ensure that they have been applied appropriately. The user interface also allows one to do fine-tuning of the drift and noise correction, if required.

Iceberg Profile Data

Iceberg profiling field programs took place in both 2018 and 2019 off the coast of Newfoundland and Labrador. The 2018 program took place on an anchor handling supply tug vessel and had a duration of nine days. During this program, 18 icebergs were profiled and the field team was able to identify a number of opportunities for future development and improvements to the system. In 2019, an additional field program was carried out on board a 30 m long fishing vessel and had a total duration of 42 days, carried out over three two-week long voyages. The 2019 program resulted in an additional 132 icebergs profiled,

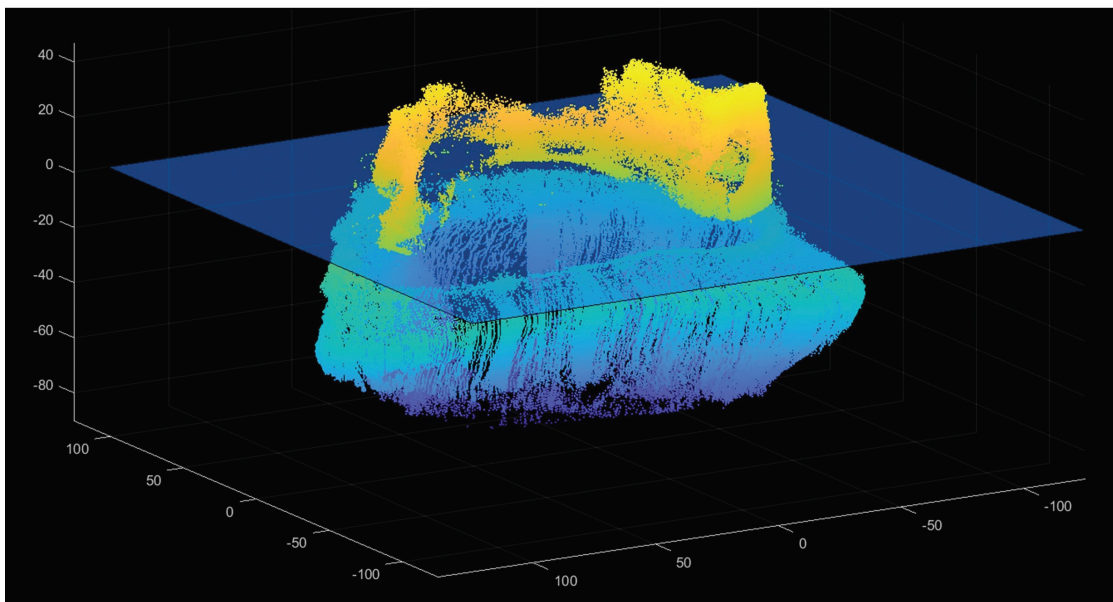


Figure 3: Iceberg profiled using the Smart Ice Management System (SIMS).

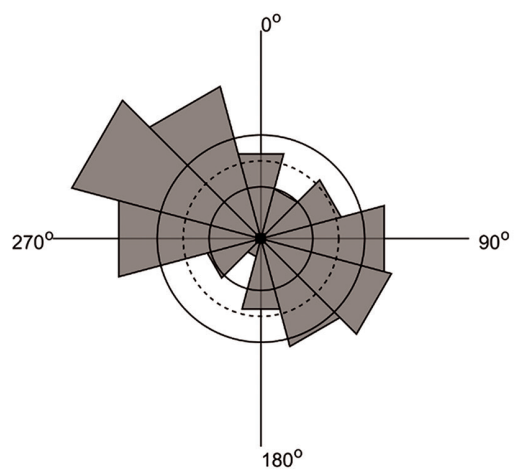
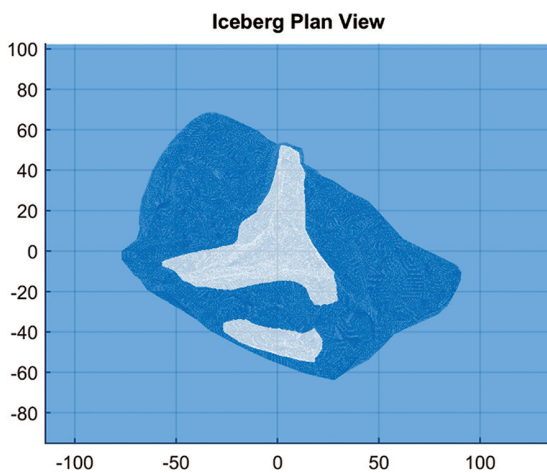


Figure 4: Stability tool output applied to an example 3D iceberg profile. The plot on the right provides the relative magnitude of the directional stability of the iceberg. Directions with larger slices of pie represent directions with higher relative stability for the profiled shape.

representing a significant increase in the database of available high quality 3D iceberg profiles. An iceberg profiled using SIMS is shown in Figure 3 with a photograph for comparison purposes.

Decision Support Tools for Ice Management

A decision support system is being developed as part of SIMS to assist with iceberg management operations. SIMS integrates the rapid generation of 3D iceberg shape data with a collection of tools that process the data to provide products that will allow operators to carry out more informed decision making, improving iceberg management effectiveness. These tools detailed in the following sections include Iceberg Stability, Net Fit, Iceberg Impact Assessment, and Iceberg Drift Forecast.

Iceberg Stability and Net Fit Tools

A review of the Program of Energy Research and Development Comprehensive Iceberg Management Database has indicated that 38% of iceberg tow attempts result in rope slippage events, and 10% result in iceberg rolling events. Note that this does not mean that 48% of icebergs are un-towable; rather, it means that these icebergs require multiple attempts to tow the iceberg successfully. Both rope or net slippage and iceberg rolling events result in significant down time in order to retrieve, untangle, and re-deploy the rope or net (on the order of hours). The tools that have been developed as part of this work aim to reduce the likelihood of both iceberg rolling and net slippage events.

The iceberg stability tool uses the profiled 3D iceberg shape and identifies the directions that are most stable in which to tow the iceberg in order to reduce the frequency of iceberg rolling events. Figure 4 is an example of the stability tool applied to a profiled shape, where the plot on the right shows the directional relative stability of the iceberg. The vessel operator would ideally try to tow the iceberg in the directions corresponding to higher relative stability (directions with larger pieces of pie) to avoid rolling the iceberg.

The towing net fit tool provides a simple visual comparison of the iceberg shape relative to the shape of the iceberg net. The tool is intended to help identify underwater rams or unfavourable iceberg slopes to be avoided to decrease the likelihood of net slippage. The tool can be configured such that it uses the output from the stability tool to show the relative net fit for the most stable towing directions as shown in Figure 5(left) so that the user can consider both net fit and stability. Further development of this tool has focused on using finite element methods to model the way in which the towing net wraps around the iceberg in three dimensions as shown in Figure 5(right). Given the complex geometry of an iceberg, it is challenging to keep the processing time down to an acceptable level to make this efficient enough for operational usage. Efforts are underway to improve the speed of the analysis for this option.

Iceberg Impact Load Assessment Tool

There is a need to be able to assess the threat from approaching icebergs quickly and accurately. Presently, to assess the threat, ice management personnel rely on estimates of above water iceberg dimensions which are typically scaled from photographs, measured from radar display, or visually approximated. Other parameters, such as mass and draft, are estimated using established relationships. Without any information on the below water geometry, it is difficult to determine the contact location on the structure (e.g., shaft or caisson for a stepped shape gravity-based structure) should an impact occur. Estimating impact actions based on limited iceberg size and shape data will result in added uncertainty, potentially unnecessary conservatism, and unnecessary shutdown events.

An Iceberg Impact Load Assessment tool has been developed to utilize the actual profiled shape to estimate a distribution of iceberg impact forces as a result of a specific iceberg impacting a given structure for defined

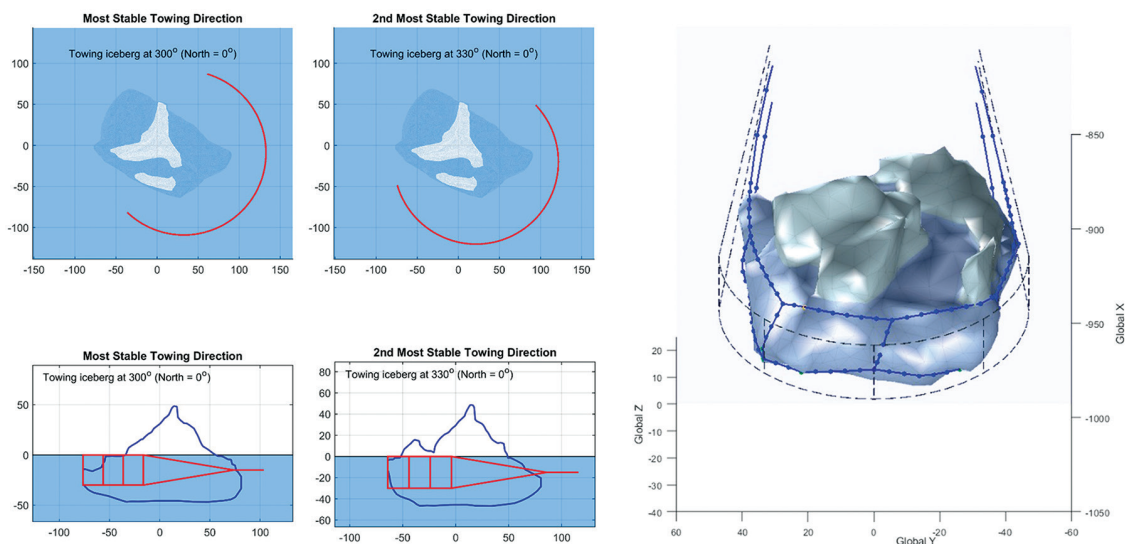


Figure 5: Towing net fit tool (left) is a simplistic 2D comparison of shapes while (right) is a more complex 3D finite element model.

metocean conditions. This tool will assist operators in identifying the threat level that the specific iceberg poses to a given platform, and may reduce unnecessary facility down manning or disconnection of floating facilities. This may be particularly useful if there are multiple icebergs in the vicinity of the platform allowing the operators to prioritize the management of the most threatening icebergs.

The tool was developed using components of the Monte Carlo simulation module of the C-CORE Iceberg Load Software. Loads related to an iceberg impact with a platform will be a function of the iceberg shape and size; the environmental conditions, which influence the impact velocity; the offset and orientation of the iceberg at the time of impact; and the ice crushing strength. In most cases, the iceberg will be observed at some distance from the platform. Any parameters that have not been measured will be treated as random parameters with distributions selected based on distributions and relationships from the general population of icebergs. It is not possible to predict exactly how the iceberg will impact the platform (in terms of wave-induced velocity,

impact offset, and iceberg orientation). These parameters, and ice strength, are always treated as random. A graphical user interface (Figure 6) has been developed to allow the end user to assess the interaction of each profiled iceberg with the structure including the distribution of potential loads which could occur as a result of an impact.

Iceberg Drift Forecast Tool

Tactical iceberg drift forecasting is an integral part of ice management decision support for offshore oil and gas exploration and drilling operations. Iceberg drift, however, is inherently difficult to forecast due to the complex geometry of icebergs and the lack of in-situ measured current in the region surrounding the iceberg. As a result, models can have significant error, and often dead reckoning (i.e., linear extrapolation from the last measured points) provides the best estimate for short term predictions. Forecasting accurate iceberg drift trajectories can help to improve ice management in terms of allocation of ice management vessels, prioritization of tow targets when multiple icebergs are present, decisions regarding shutdown of operations, and reduction of downtime and costs.

C-CORE has been able to show that significant improvements in drift forecasting accuracy are possible when measured iceberg profiles are used, as opposed to estimated iceberg draft and mass. In previous forecast models, the iceberg draft and mass were estimated using relationships based on the observed waterline length of the iceberg.

During the 2018 and 2019 offshore programs, iceberg drift tracks were collected in conjunction with the 3D profiled shapes. The 3D profiles provide a means to accurately determine the volume and mass of the iceberg. In the model, the currents and winds are forced against a two-dimensional projection of the iceberg. Average results for the forecast iceberg position versus observed at 24 hours show approximately a 20% decrease in positional error when iceberg profiles are incorporated into the drift model as opposed to using estimated iceberg draft and mass. An example is shown in Figure 7 where the observed drift track (measured from the vessel using radar) is compared with the C-CORE model which uses measured iceberg draft and mass (“measured” in Figure 7) and the older approach which uses estimated iceberg draft and mass (“estimated” in Figure 7).

Summary and Future Work

Two successful large scale iceberg profiling field campaigns have been carried out during the 2018 and 2019 iceberg seasons in addition to shorter duration field programs (on a 9 m survey vessel) in 2015, 2017, and 2018 to aid in the development of SIMS. This work has led to the development of a large database of over 200 high quality 3D iceberg profiles. The database has improved our understanding of iceberg shape relationships and has implications for the design and construction of future surface and subsea structures deployed on the Grand Banks of Newfoundland.

C-CORE is continually improving the SIMS processing speed and cleaning algorithms, as well as the capabilities of the tools to enable

more informed decision making during iceberg management activities. Additional tools will be developed to consider the risk of iceberg contact with both topsides structures and subsea infrastructure. C-CORE is also working to develop a means of deploying the multibeam sonar through the hull as opposed to an external attachment (as shown in Figure 2). This will ensure that SIMS does not affect the regular operations and capabilities of the vessel. ~

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Tony King has 20 years' experience in the ice engineering field and has been Director of C-CORE's Ice Engineering Group for the past eight years. He has a background in risk analysis, probabilistic methodologies, and numerical modelling, and

has performed ice risk analyses for subsea assets in most ice-prone regions of the world. He obtained both an undergraduate and master's degree from Memorial University's engineering program.



Dr. Freeman Ralph is presently VP oil and gas at C-CORE having over 18 years of Arctic/sub-Arctic ice engineering experience with the offshore oil and gas industry. He joined C-CORE's Ice Engineering team in 1999, becoming team Director from February 2004

to December 2010. Following a PhD program in 2010, in 2014 he became Executive Director of C-CORE's Centre for Arctic Resource Development. His applied R&D activities range from iceberg and sea-ice loads on ships and offshore structures, protection of subsea infrastructure including geotechnical considerations, ice management and risk mitigation including detection, forecasting, threat assessment, decision support, and physical action.