Joint Industry Program:
Development of Improved Ice Management Capabilities for
Operations in Arctic and Harsh Environments

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Introduction

Petroleum Research Newfoundland & Labrador (Petroleum Research) is the principal delivery agent for collaborative research and development projects on behalf of its offshore oil and gas industry members. Members are operators of offshore Exploration, Significant Discovery or Production licenses issued by the Canada-Newfoundland and Labrador Offshore Petroleum Board. Petroleum Research’s current members are Chevron Canada Resources, ExxonMobil Canada, Husky Energy, Statoil Canada and Suncor Energy.

Petroleum Research’s mission is to identify opportunities, develop proposals, fund and manage the execution of research and technology development projects that deliver value to the Newfoundland and Labrador offshore oil and gas industry.

Petroleum Research has prioritized R&D in the “Arctic and Harsh Environments” focus area, with an objective to develop technology to reduce risk and/or cost of operation in arctic and harsh environments. A major multi-year Ice Management Program (IMP) aimed at the development of improved ice management capabilities for operations in arctic and harsh environments is an ongoing core program for the organization. This document serves to capture the vision, strategy and overall scope of this program, developed with input from industry through a series of workshops, and a Gap Analysis conducted by C-CORE, a Canadian consultancy with expertise in harsh environment engineering, in 2010-11.

Background – Ice Management Gap Analysis

Ice management is a critical consideration when operating in sea ice and iceberg-prone environments from both an operational and a design perspective. A fully integrated ice management strategy involves a number of key inter-related components including ice detection and monitoring, drift forecasting, threat analysis, tactical operations (iceberg deflection and icebreaking) and operational procedures and protocols to reduce the likelihood of suspension of operations or disconnection. A general ice management strategy is illustrated in Figure 1.

Detection is the first and highest priority component in the system. The ability to see and identify ice conditions is the primary basis for threat assessment and subsequent risk mitigation or protection. Detection data along with operational and weather data are stored in the data management system and provide input into the forecasting/threat system. The threat system will forecast ice movement and evaluate the associated threat to a facility and its operations. Based on threat and prioritization, tactical management is engaged via icebreaking or iceberg towing to remove or mitigate the risk of interaction with the structure. Should the ice management performance not be adequate, and the threat of a collision increase, the vessel will disconnect and move off location.
Figure 2 illustrates the network logic and flow of information through the key components within an ice management system, which includes data gathering, data handling/storage, data processing, decision making and execution of a tactical risk mitigation plan.

**Figure 1 — Ice Management Strategy**

**Figure 2 — Flow Diagram of an Ice Management System**
The following seven focus areas were selected and considered by Petroleum Research and its members within the IMP:

1. Ice and iceberg detection/discrimination;
2. Enhance iceberg and sea ice drift forecasting;
3. Towing of large icebergs;
4. Operations in sea ice;
5. Station-keeping in sea ice; and
6. Technology integration and training.

The ultimate goal of this program is the development of enhanced ice management technologies and tools for use at various stages of the overall process. Key drivers for success will be field trials as a primary basis for validation, proven technology to be integrated into operations, trained high quality personnel (HQP) that can deliver superior performance, and technologies and expertise that can be exported to other regions with challenging operational conditions and ice management requirements.

**Focus Areas for Research Projects**

A high-level roadmap was developed based on research needs identified during a detailed ice management gap analysis conducted by C-CORE for Petroleum Research in 2011. This program has continued—and will continue—to evolve as new needs are identified and business drivers of industry funders change. The following focus areas were prioritized for investment.

1. **Ice and Iceberg Detection/Discrimination**

   **Objectives**
   - Improve detection of sea ice/icebergs in remote locations;
   - Benchmark performance of existing detection technologies;
   - Determine sensitivity of operation to enhanced detection capabilities;
   - Improve discrimination between icebergs and other targets;
   - Improve detection icebergs and multi-year ice in high seas and in sea ice; and
   - Sea ice characterization (e.g., first year vs. multi-year ice, thickness).

Detection and monitoring of ice conditions and features are critical first steps in an ice management program. If an ice feature cannot be detected, there is no basis for engaging further management and/or risk mitigation activities. For icebergs, size, shape, and location are important parameters, while for sea ice, concentration, thickness, floe size and ridging must be known as well as the ability to discriminate between first year and multi-year ice. An added challenge for ice detection is that frontier areas may not have the infrastructure or resources to
support traditional monitoring. A significant shortcoming with respect to operational impacts is reliable detection of icebergs in sea ice.

The objectives for sea ice/iceberg detection focus area projects are to assess and develop new technologies that will lead to enhanced detection capabilities, especially in poor environmental conditions. Emphasis is placed on discriminating between ships and icebergs and icebergs from surrounding sea ice using radar detections (ship, aircraft and satellite), characterizing sea ice features, and evaluating new sensors for integration into operations. An integrated detection system is envisioned, which will use a data fusion strategy to combine detections for different sensors that vary in space and time.

Iceberg detection on the Grand Banks is being carried out successfully using a combination of technologies, but there is opportunity for improvement. Although sea ice monitoring is less of a concern on the Grand Banks it must be considered in many arctic and sub-arctic regions. Improvements in sea ice monitoring will be explored primarily through enhancement of radar technologies from various platforms.

The following is a list of challenges in which improvements would be beneficial, for iceberg detection on the Grand Banks or in the Arctic:

- **Environmental conditions** – Poor visibility, high winds/seas and storm conditions are a challenge for existing iceberg detection technologies. Fog, cloud cover and nighttime all limit the ability to detect and characterize icebergs visually. High winds and seas limit the effectiveness of radar sensors and visual observations and aerial reconnaissance may be limited in storm conditions;

- **Detection in sea ice** – Icebergs and sea ice have similar electromagnetic signatures and appearances and it is challenging to distinguish between the two types of targets visually or with radar technology;

- **Determining iceberg size, shape and mass information** – Characteristics of icebergs are not readily observed using radar data and visual observations may be subjective due to a lack of frame of reference on the ocean surface. Iceberg mass is estimated from knowledge or models of iceberg size and shape;

- **Discrimination between icebergs and ships** – Radar detections of marine targets do not indicate target type and visual confirmation may not always be possible. As well, icebergs and certain sea ice features may have similar signatures in radar data. It is also difficult to identify icebergs in sea ice, especially at longer distances and for smaller icebergs;

- **Data fusion** – Detections from multiple sensors separated in space and time may represent separate icebergs or multiple sightings of the same iceberg. Effective data fusion leads to a more accurate assessment of total iceberg populations;
• Strategic and remote area surveillance – Gaining an understanding of iceberg populations north of the operations area may be limited in favour of tactical operations. Longer-range surveillance can assist with resource planning. Surveillance of remote areas will be needed for new Arctic regions; and

• Additional resources required for monitoring – Traditional monitoring requires infrastructure to support aircraft and vessels and the required level of infrastructure may not be fully developed in the Arctic.

Research in several technology programs may improve the effectiveness of iceberg detection including dual polarized marine radar, exploitation of advanced satellite radar capabilities, development of tactical unmanned aerial vehicle (UAV) technology and implementation of a data fusion tool.

A number of projects have been completed or are ongoing in this focus area, including the enhancement of Rutter Inc.’s dual-polarized Sigma 6 marine radar platform for better detection and discrimination of multi-year ice, and a project led by C-CORE to extend the capabilities of satellite radar to distinguish multi-year and other ice variations. A project to develop a radar system for characterizing ice thickness for tactical ice management purposes is also in progress. Further field trials of these and other emerging technologies are being considered.

2. Enhanced Iceberg and Sea Ice Drift Forecasting

Objectives

• Define key needs for iceberg and sea ice forecasts, including the most important ice factors and the associated time and space scales of interest (in relation to clear industry operations scenarios);

• Benchmark existing capabilities, both strengths and limitations, of iceberg and sea ice drift forecasting models that are currently available (and being used);

• Determine the sensitivity/accuracy of existing or enhanced iceberg and sea ice drift models to new developments and potential benefits to current and future oil industry operations;

• Evaluate benefits of including more real-time data into these models;

• Identify and evaluate new technologies and/or enhancements to existing technologies;

• Analyze and develop new novel iceberg and sea ice drift models, including integration of real-time inputs into selected drift models;

• Demonstrate and evaluate model(s), including any new data sources, through field trials; and

• Integrate technology into operational ice management systems, including relevant training.

Drift forecasting involves predicting the future trajectories and sizes of sea ice and/or icebergs using experience, past drift and drift models. Drift forecasts are important to consider for design of new platforms as well as operations, in iceberg and sea ice physical management and for
station-keeping. While forecasting for icebergs and sea ice share many similarities, forecasting sea ice has the added complexity of interactions due to stresses between floes, the possibility of ridging and ice growth as well as new ice formation. For freely floating icebergs, consideration must be given to vertical variation in currents over the depth of the iceberg, deterioration of the iceberg and wave diffraction for larger icebergs.

Operators need long term forecasts of when sea ice will arrive at a location, the severity of conditions and when conditions will become too severe, requiring demobilization. Short term forecasts are needed to determine which ice features present the highest risk and should be managed, and at what point operations should shut down and equipment and personnel moved off site.

Future technologies currently identified for sea ice monitoring include dual polarized marine radar, development of advanced satellite radar, tactical UAV monitoring, networking ULS devices and autonomous underwater vehicle (AUV) monitoring. Some of these projects may use the same base technology as projects discussed for iceberg detection, but additional research and development are required to satisfy the requirements for sea ice monitoring.

An assessment of gaps and opportunities to improve iceberg and sea ice drift forecasting was completed in 2013 and follow-on activities continue, primarily related to improving the understanding and prediction of environmental driving forces.

3. Towing Icebergs in Sea Ice

Objectives
- Develop and test methodology for towing of icebergs in pack ice;
- Develop training material and/or simulation tools for towing of large icebergs.

The presence of sea ice may have a significant impact on iceberg towing operations. To avoid suspension of operations or disconnection, it may be necessary to tow icebergs within sea ice. There is a need to address uncertainty in effectiveness, suitability of towing equipment and towing methodology that may enable the effective handling of icebergs in sea ice. Currently towing in sea ice is believed to only be possible for certain light sea ice conditions.

A JIP to investigate the practical and technical feasibility for towing icebergs in various levels and types of sea ice coverage was initiated in 2013. Initial work is being executed by Canatec and other partners. The scope for this project consists of defining performance scenarios to assess the practical and technical feasibility of towing icebergs and other objects such as work barges in various levels and types of sea ice coverage. The scenarios will consider both first year and multi-year ice coverage from 1/10 to 10/10 with and without icebreaker support. A major
objective is to identify the marine spread – the number and types of vessels required, as well as the costs associated with such an operation and estimate tow loads for selected scenarios. Follow–on work may include field work to collect data for validation of towing feasibility.

4. Station Keeping In Sea Ice

Objectives

- Advance understanding of the magnitude and nature of pack ice loads on vessels, including mooring and/or station-keeping forces;
- Determine response actions necessary for maintaining station;
- Develop technologies to maintain station.

The station keeping system is an integral component of the ice management plan. Limitations of the station keeping system determine the extent of ice management required to stay on location during operations. For projects occurring in ice regions within a pre-existing operational window, research and development relating to improvements to station keeping systems could undoubtedly reduce the ice management requirement. This, in turn, would lead to large reductions in operational costs. The development of enhanced station keeping systems without reduction in the level of external ice management has potential to extend the operating window for petroleum operations in harsh Arctic conditions. Advancements in ice management could help alleviate station keeping requirements in terms of reducing design loads. An integrated design of the ice management and station keeping systems would result in an optimized solution.

There are two station keeping systems that have been used successfully in ice conditions: mooring systems and dynamic positioning systems.

Mooring systems are station keeping systems that use mooring lines and anchors to hold an installation at the desired location. The mooring system arrangement is dependent on the anticipated loading and hence is individually selected for each project. In general, redundancy is built into the mooring system design to prevent disconnection in the event of a mooring line failure. Mooring systems are limited by an upper bound on water depth above which they become uneconomical. They are also limited by the geophysical properties of the sea bed since they cannot be used in certain adverse conditions.

An example of a moored system is the Kulluk drilling platform that operated in the Beaufort Sea. The Kulluk mooring system consisted of 12 mooring lines deployed at equal angle intervals around the structure and was designed to withstand the loads from an unmanaged pack ice. The Terra Nova and Sea Rose FPSO’s are also examples of moored platforms that operate on the Grand Banks, off the coast of Newfoundland.
Automated Dynamic Positioning (DP) generally relies on the use of a combination of sensors, computer programs, propellers and thrusters to hold an offshore structure on location. The information gathered by the sensors (e.g., motion sensors, wind sensors, ice sensors, position reference sensors) is sent to the computer program which calculates the required thrust magnitude and direction required to maintain position. The calculations conducted by the DP program are fed to the propulsion system (propellers and thrusters) to direct thrust output. DP operations can also be performed manually but are generally limited to short durations.

Dynamic positioning systems have been used in Arctic conditions during the Sakhalin project as well as the Arctic Coring Expedition (ACEX). The Sakhalin project was subject to less intensive ice conditions than the ACEX project, which occurred in the Beaufort Sea, near the North Pole. Specifically, the Sakhalin region only has first year ice while the Beaufort Sea region has multi-year ice and ridges.

Defining ice loads in terms of how the load builds during interaction with a platform is an area involving much uncertainty. Research into this area would allow for a better understanding of the peak loads to which a station keeping system is subjected during an interaction with different ice features. An enhanced knowledge of ice load development would lead to a comprehensive design of a station keeping system capable of withstanding ice loads that correspond to the region of operation.

Most existing ice load predictions are based on models for fixed structures. An improved understanding of the effects of compliant systems on load development is required for accurate representation of non-fixed structures. A new generation of ice load models could be integrated into a DP system to enhance operational performance. A DP system with ice load prediction capability could prompt for engine ramp up in preparation to exert the required thrust to maintain station.

Petroleum Research currently has two joint industry projects under way to advance industry’s knowledge of the magnitude and time-dependent behaviour of global ice loads on both moored and dynamically-positioned (DP) floating vessels (and vessel responses) in ice.

- Phase 1 of the Ice Loads on Floating Structures JIP (“State-of-the-Art Review, Gap Analysis, and Recommendations”) was recently completed by a consortium led by the American Bureau of Shipping’s (ABS’s) Harsh Environment Technology Center. Phase 2 plans are now being reviewed (October 2014). Potential work includes full scale field data collection of ice loads on, and responses of, moored floating structures in managed and unmanaged pack ice conditions, and related assessment of numerical and physical model tests and load predictions.
A multi-year project to develop “Enhanced Dynamic Positioning (DP) Operations in Ice Environments”, executed by Marine Institute’s Centre for Marine Simulation, the National Research Council of Canada and Kongsberg AS, started in 2014. The estimated total cost of this project is C$8.6 million, including major contributions from the governments of Canada and Newfoundland and Labrador.

The objective is to enhance DP control algorithms to respond to ice loads. The scope includes an extensive series of model tests in ice in support of algorithm development, and deployment of the software into a simulation environment to assist in training, operational assessment, risk analysis and equipment design.

5. Technology Integration and Training

Objectives
- Develop training courses for all personnel involved in ice management covering existing, enhanced or new practices; and
- Develop training material and/or simulation tools to demonstrate incorporation of analytical models into an ice management system.

The integration of any improved models, simulation tools and/or procedures into operational use is an integral component of the ice management plan. This integration process will be a key task within specific JIPs and will vary depending upon the model under consideration: integration may include installing software and equipment, updating documentation, revising business processes and/or targeted user training.

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