ICETECH 2010 - ABSTRACTS

Abstracts for papers and presentations on the Conference Proceedings CD (Pre-Conference Edition, August 2010) are listed here. Abstracts are arranged by session.

I. PLENARY SESSIONS

106 ***Arctic EER Today***

Author: Frank Bercha

This paper describes developments in technologies, engineering and analysis, and regulatory provisions relating to arctic Escape Evacuation and Rescue (EER). The developing national and international regulatory performance based regime has necessitated the development of tools for the evaluation and setting of performance based goals such as availability and reliability requirements, mirrored in current draft Transport Canada and ISO standards. To facilitate the reliability assessment and consequent setting of reliability targets in the Canadian standards, a multifaceted research and development program was initiated in parallel with its regulatory developments. Full scale manned and model tests, engineering and computer simulation, and world wide consultations and studies on human performance in life threatening conditions, comprise this R&D programme. Use of conventional EER systems and technologies has limited applicability in ice populated waters, requiring the development of systems and procedures suited to the environmental, operational, and logistical requirements of arctic offshore regions. The paper summarizes available and emerging regulatory, modeling and research, and technological developments in arctic EER and gives recommendations on a number of promising directions.

112 ***Ice Risk Management for Stationary Vessel Operations in Moving Pack Ice in Ice Offshore Experience and State of Art***

Author: Arno Keinonen and Evan Martin

Stationary operations with vessels in moving pack ice in the ice offshore have taken place in several projects since the early Beaufort Sea days from the late seventies. The one thing that has changed more than anything else since those early days of ice offshore operations, is the requirements of today's World. The early highly experimental operations with not clear measure of what was safe is no longer acceptable. A fully safe and environmentally low impact operation is a must. Development of gradually more advanced approaches to controlling the risks to such operations has taken place.

Simultaneously costs of such operations have been driven up, and with this the pressure to achieve high uptime in such operations. This has created a demand for efficient and simultaneously safe solutions. Even to get a permit to operate is today require rigorous, systematic ways to control the pack ice risk.

This paper is a state of the art review of the safety of such operations:

- Systematic pack ice risk management, allowing operators to make rational operational planning and decision making, with a confidence of taking only acceptable risks.
- Development of physical ice management techniques and efficiencies, from original utilization of traditional icebreakers, to addition of recent development of azimuth icebreaker technology to drastically expand the low risk operational envelope

The paper uses real life operations as its basis. It illustrates the increased understanding of pack ice risks to such stationary operations. It describes the development of ice risk management and physical ice management during these projects. The operations used as references are:

- Beaufort Sea Drillships, 1975 till ~ 1990
- Kulluk, 1983-1993 Beaufort Sea
- Dynamic Positioning operations in the Sakhalin offshore 1999
- Sakhalin 2, phase 1, oil production and export with tankers in the presence of ice, 1999-2007
- Arctic Coring Expedition in the central polar pack 2004

The paper concludes summarising current status of managing pack ice risks in stationary operations of vessels in the Arctic or other ice covered waters. It also discusses the possible developments towards increasingly higher degree of operability, whilst simultaneously ensuring increasing confidence in the high safety of such operations.

153 ***Past Experience from Arctic Commercial Expeditions***

Authors: Ove Gudmestad, Johannes Alme

In the past, Norwegian vessels have entered the Arctic in hunt for fish, whales and seals. The seal hunters needed to go to the ice-edge or into the ice to catch the seals and their activity created much needed income in the past. These seal hunters came mainly from the Aalesund area of Norway (many came from the village of Brandal) and from the Tromsø area in the north.

Although seal hunting is controversial to day, there might be important learning to bring to new industries like the offshore oil and gas industry and to the navigators in ice infested northern waters. An activity within the research project "PetroArctic" at NTNU has focused on collecting data from the seal hunters. A number of interviews with elders (age 80+) have been conducted with focus on the physical environmental conditions and vessel behavior in ice. Newspaper records from the early decades of the 20th century have been reviewed.

Before the time of steel hull ships with diesel engines wooden ships with steam engines were used. There were frequent losses caused by ice pressure and vessel implosions. Losses were also due to interaction with the "ice foot" of multi year ridges or due to hits from floating ridges on waves.

The paper will present characteristic features of vessels used and ice conditions for the different areas where seal hunting took place. These were the Newfoundland area, Labrador coast, Danish Strait, Area in vicinity of Jan Mayen, North East Greenland coast,, Spitzbergen, Eastern Barents Sea towards Novaya Zemlya and the mouth of the White Sea. The causes for the loss or damage to vessels will be reviewed in details. In this respect it should be noted that although the ice cap might be shrinking, there will be ice parts of the year and the ice might even move faster than in the past and to new areas that traditionally have been ice free. This also relate to the ice of the polar pack that might move more than in the past. There is as such a strong encouragement to implement the learning of the Arctic pioneers.

157 ***The Arctic Council's Marine Shipping Assessment***

Author: Lawson W. Brigham

Not available at this time.

183 ***Arctic Challenges - A Treatise of Past and Recent Developments***

Authors: Abdel Ghoneim, A.B. (Gus) Cammaert, and Morten Mejlænder-Larsen

In view of the recent announcements by the USA government permitting further drilling in certain areas offshore Alaska and the steady increase in oil prices, it may be again possible to predict that Arctic oil and gas development and transportation projects are imminent. The challenges associated with design and operation of Arctic exploration and production installations are many and have been exhaustively discussed in the past. This paper will summarize these challenges and show how a significant number of them have been addressed in the past and how new technologies may be implemented to alleviate the remaining challenges.

In the late seventies and early eighties extensive Arctic R&D work was carried out. A small sample of this work includes the Arctic Pilot Project, the CANMAR icebreaker research program with full scale testing, the Tarsuit artificial island, the Hans island ice load monitoring programs, and the Canadian Coast Guard development of the Canadian Arctic Shipping Pollution Prevention Regulations (CASPPR). The R&D work carried out in Finland and Russia is also discussed. This paper demonstrates how the available results from these projects may be applied in the development of current and new rules and standards. The issues that are still outstanding are highlighted and proposals for possible resolution thereof are made.

A presentation of ongoing work for the development of new DNV design guidelines on ice-structure interaction will be presented. The work will be completed in 2011 or early 2012. The project will be based on the new ISO 19906 standard, and will cover both fixed and floating installations.

The paper also describes results from a recently completed real-time ice load monitoring program onboard an icebreaking vessel and shows correlation with proposed formulations.

186 ***What's Going on in the Russian Arctic***

Author: Evgeny Velikhov, Vyacheslav Petrovich Kuznetsov, Vladimir Ivanovich Makarov, Vladimir Vladimirovich Mikhailichenko, Stanislav Alexandrovich Lavkovskiy, and Ivan Fedorovich Glumov

This paper provides an overview of the status of affairs and activities currently going on in the Russian Arctic. It covers issues such as: delimitation of the Arctic Shelf; operation of the nuclear icebreaker fleet; development of oil and gas deposits in coastal areas and in the Barents and Kara Seas; development of Russian territories situated beyond the Ural; operation of the Northern Sea Route and activities of Non-Commercial Partnership "Northern Sea Route".

188 ***Overview from Canadian Coast Guard***

Author: Dave Jackson

Not available at this time.

II. TECHNICAL SESSIONS

1. Ships in Ice

1(a) Navigation

Day 1, Discovery Ballroom, 1020-1120

170 ***Differences in the Characteristic Shapes of First Year and Multi-Year Pressure Ridges***

Authors: Peter Wadhams, J. Rodrigues, and N. Toberg

Pressure ridge distributions in two parts of the Arctic Ocean are compared, in both cases using mainly data collected by the submarine "Tireless" in March 2007 during two specific grid surveys, in the Beaufort Sea at about 73°N, 146°W (some 200 km N of Prudhoe Bay), and north of Ellesmere Island at about 83° 20'N, 64°W. In the Beaufort Sea the ice was mainly first-year (FY), and subsequently melted or broke up as this area became ice-free during the subsequent summer of 2007. In the region N of Ellesmere Island the ice was mainly multi-year (MY). Ridge depth and spacing distributions were derived for each region using the boat's upward looking sonar, combined with distributions of shapes of the ridges encountered, from the Kongsberg EM3002 multibeam sonar fitted to the boat. The different shapes of FY and MY ridges are consistent with two later high-resolution multibeam studies of specific ridges by AUV, done in the Beaufort Sea in spring 2007 (FY ridge) and off Ellesmere Island in spring 2008 (MY ridge system). FY ridges are found to fit the normally triangular shape template in cross-section (with a range of slope angles) with a relatively constant along-crest depth, and often the constituent structure of small ice blocks can be distinguished. . MY ridges, however, were often found to have been split into a number of independent solid, smooth blocks of large size, giving a very irregular ridge profile and even producing a number of pinnacles seemingly without linearity. The roles of consolidation, penetrative currents, melting and the opening of cracks and leads through the ridge as it ages are all discussed as mechanisms for this evolution, and the implications for estimating the strength of a MY ridge are considered.

121 ***Ice Navigation Curriculum Using the AVTEC Ship Simulator, Seward, Alaska***

Authors: Orson Smith, John Schibel, Scott Hamilton, and Robert Thomas

Alaska's Arctic offshore has unprecedented attention from the private and public sectors for its prospects of mineral extraction, tourism, and new marine cargo delivery routes made possible by diminished ice cover and improved technology. Maritime authorities are planning for increased ship traffic, support facilities and attendant risk of accidents at sea with the associated threat of pollution. The ship simulator operated by highly qualified and experienced mariners of the Alaska Marine Training Center at AVTEC in Seward, Alaska, with four independent bridges has extraordinary capabilities for training ship officers for ice navigation duty, including simulation of multiple ice conditions in the same voyage with variable winds, currents, and sea states. A curriculum is being developed by AVTEC in collaboration with the University of Alaska Anchorage, Alaska State Pilots, and corporate maritime industry stake holders for application of these and other ice simulator features to satisfy requirements of the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) published by the International Maritime Organization (IMO). A series of simulated scenarios both for purposes of instruction and for knowledge and skill assessment will be supplemented by multi-media classroom training and assessment materials. A rigorous review is provided of ice physics, classification of river, sea, and glacier ice, ice regimes in

different regions of the Arctic, and ice movement in response to wind and currents, and related interpretation of radar and satellite imagery. IMO standards for ship operations in remote areas and for operation of ship's boats and tenders in icy waters and winter conditions are also reviewed. The curriculum of simulator practice includes single and multiple vessel ice breaking, breaking out of a vessel fast in the ice, and dealing with superstructure ice accumulation, ice friction, ice sky and water blink. The performance in ice of a range of vessels sizes and types are simulated consistent with ships anticipated to encounter ice in Alaskan waters. The curriculum is being developed to train mariners without ice experience and to provide refresher training for ice navigation veterans to satisfy the training standards set under STCW. The AVTEC Maritime Training Center simulator is also available for research addressing ice scenarios outside the training environment.

179 *Ice Hazard Radar*

Author: Barbara O'Connell

Ships transiting polar regions would benefit from a marine ice navigation radar that could help them differentiate between dangerous multi-year ice and thick first-year ice. The influx of multi-year ice from the Arctic Ocean into the Canadian Arctic Archipelago results in navigational hazards for any vessel heading to northern locations or transiting the Northwest Passage. It can be difficult to detect multi-year ice from the bridge of a ship, particularly when it becomes embedded in thick first-year ice, as the topography of the ice may be obscured by snow cover or poor visibility.

The Canadian Coast Guard (CCG) is working in partnership with Transport Canada and the Program of Energy Research and Development (PERD) to develop an "Ice Hazard Radar", a dual-polarized, high-speed marine radar that will produce high resolution images of the ice, with a clear contrast between the dangerous multi-year ice and other sea ice.

The Ice Hazard Radar system consists of two high-speed radar scanners. The master scanner transmits and receives in horizontal polarization (HH); the second scanner is vertically-polarized and set to receive-only (HV), synchronized to the transmitting radar in rotation, frequency, and pulse timing. Polarimetric research has indicated that the radar signal undergoes volume scattering within ice features, returning a much stronger signal from the fresher multi-year ice and iceberg ice as opposed to the more saline first-year and grey-white ice. Enhanced processing of the integrated horizontal and vertical-polarized radar data will provide the polarimetric behaviour of the ice, with enough information to provide an effective classification of the ice types. The radar will be able to generate coloured HH/HV radar images instead of the usual grey-scale HH image, with multi-year ice a distinct colour from first-year ice.

This radar would assist vessels to navigate more efficiently through ice regimes by avoiding multi-year ice floes, reducing transit time, fuel consumption and emissions. It can be used to avoid collisions with dangerous ice thereby reducing the risk of damage and helping to prevent pollution in the vulnerable Arctic marine environment.

This project is a continuation of the project "high-speed marine radar for improved ice detection", presented at ICETECH08.

1(b) Propulsion

Day 1, Discovery Ballroom, 1120-1200

182 *Nuclear Energy - Foundation for the Arctic Icebreakers Fleet*

Authors: Nikolay Khlopkin, Vyacheslav Kuznetsov, Vladimir Makarov

Half a century ago the ice routes of the Northern Sea Route witnessed the first icebreaker started its voyage using nuclear energy. The necessity of significantly prolonging the navigation period and improving the safety of sailing in the Arctic called for creation of such an icebreaker. With this aim in mind, it was necessary to raise the icebreakers power capacity while possibilities of increasing the power of the existing at that time diesel icebreakers were limited.

The advantages of nuclear power plants (NPP) are determined, first of all, exactly by the possibility of obtaining any required power under aboard the ship conditions with the practically limitless autonomy of navigation. The absence of the necessity of bunkering at sea which may prove to be quite risky under ice conditions is the most significant argument in favor of nuclear icebreakers. The period of the uninterrupted functioning of the NPP of the presently existing nuclear icebreakers amounts to 8000 hours which allows them to stay at sea during a year. The uninterrupted functioning period of the NPP designed for the new icebreaker reaches 26000 hours, and in view of this the period of this icebreaker work on the Arctic routes without calling at the base may exceed three years.

Among the positive qualities of the nuclear energy installations on should note their ecological cleanness expressed in the absence of the CO_2 , NO_x , SO_x emissions. As to the safety of the nuclear icebreakers, one should note that more than a half a century of their operation on the Arctic routes had proven the reliability and safety of their nuclear plants. The basic issues of nuclear, radiation and ecological safety of a nuclear ship are being solved yet at their designing and construction stage to be conducted while observing the requirements of the normative and technological documentation of the Russian Maritime Register of Shipping (RS) and the Rostekhnadzor (Russian technological supervision) which is the regulating body in Russia analogous to the US NRC.

The new legal documents on the safety of the ship NPP issued by the Rostekhnadzor in 2000-2001 correspond in full to the contemporary world views on nuclear safety. The RS rules are structured on the basis of the IMO Code of safety for nuclear merchant ships.

Biological protection of the icebreakers reactors is designed with a sufficient reserve in order that under any conditions the admissible radiation doses for the ship's crew are not exceeded. The solid and liquid radioactive wastes produced during the operation of the ship are stored aboard and they are subject to the transfer to the base for treatment. During ventilation of the reactor section a certain amount of radioactive gases, not more than 15 Ci per navigation is discharged into atmosphere. These are mainly ^{41}Ar a short time living radionuclide with the half-decay of 1,82 h. It is difficult to measure its concentration at the point of its discharge into the atmosphere at the edge of the main-mast.

In the nearest future, construction of the above mentioned new universal icebreaker with NPP will start in Russia. The icebreaker universality involves its ability to change the draught within 10,5 m at the deep water areas and up to 8,5 m at the shallow-water ones. The power capacity of the new icebreaker NPP is raised to 60 MW.

Construction of a series of such ships replacing the gradually decommissioned existing icebreakers will provide for enlarging the navigation period and navigation capacity of the Northern Sea Route.

The advanced reactor plant was designed for the new icebreaker which has significantly improved characteristics, in comparison with the existing resource and mass dimensions. The refueling of this reactor will be performed once in 7-10 years. The new reactor plant may in some ways serve as an energy source for more powerful nuclear icebreakers and for the small capacity civil nuclear power plants creation of which is planned in the future.

133 ***Propulsion in Ice - Big Ships***

Authors: Geir Dahler, John Stubbs, and Lasse Norhamo

A full scale test measurement program was performed in the winter of 2008 on the Fednav owned UMIAK I, a 31500 DWT bulk carrier classed by Det Norske Veritas (DNV). The propulsion of the vessel is distinguishable; consisting of the combination of a large bore electronically controlled two-stroke diesel engine directly driving the large controllable pitch-propeller mounted in a nozzle. UMIAK I was awarded the prestigious Ship of the Year Award by the International Bulk Journal in November 2009. The vessel operates year round, unescorted, servicing the Vale Inco Voisey's Bay mine in Labrador, and has also operated into the Canadian Arctic unescorted in winter. The objective of the research project was to better understand the quantification of the loads caused by interaction between propeller blades and ice, and the corresponding dynamic responses through the shaft line and into the main engine, with the vessel moving ahead in thick first year ice; and, when ramming ridges of a depth of up to about 20 metres keel depth.

The shaft line on UMIAK I, propelled by an MAN B&W 7S70ME-C diesel engine rated at 21770 kW at 91 rpm that directly drives a 6.5 m diameter controllable pitch propeller, was designed to comply with both the DNV POLAR notation and the IACS UR PC4.

The results provide an insight into the responses induced into a high powered direct drive shaft line, as most previous documented knowledge has been related to significantly smaller power/shaft installations. The nature of ice-impacts, i.e. the shape of excitation forces; their magnitude, duration and quantity, has been explored. This paper presents highlights from the full scale measurements and theoretical analyses made, but limited to the rotating torsional domain of the shafting system. Analysis results discussed are statistical post-processing of measured ice responses, ice impact modelling in compliance with the latest IACS PC codes, and time domain simulations of transient dynamic responses in the propulsion machinery caused by the ice impacts.

The paper concludes with presentation of an assessment comparison of the UMIAK I propulsion design with scantling for compliance with the IACS Polar Class code for a ship of this size and ice class. The results provide an insight into the adequacy of state-of-the-art shaft line design criteria. It is expected that the results of this research project will serve to give valuable insights into formulating design criteria for future high ice class, higher powered large Arctic cargo vessels.

184 ***Converting an Icebreaker from an Oil Lubricated Stern Tube Bearing System to a Seawater Lubricated Stern Tube Bearing Considering Environmental and Operating Costs***

Authors: Ken Ogle and Craig Carter

Ice breakers and ships operating in Arctic trading routes have led to concern of environmental threats to the Arctic ecosystems including ship source pollution. Zero tolerance for any kind of ship source pollution is now becoming the norm and international regulations are becoming more and more stringent. This is especially true in the Arctic which presents a potentially more serious situation. Detection, monitoring, and cleanup are difficult due to climatic conditions, remoteness, and the shifting interplay between land and sea-ice.

Operational discharges of oil from the stern tube is a common occurrence for ice breakers as propellers are prone to impact from ice causing shafts to flex and seals unable to maintain a complete barrier to keep seawater out or lubricating oil in the stern tube. Whereas solar radiation generally speeds the break-down of contaminants, the reduced level of sunlight in the Arctic lengthens the degradation process and increases the likelihood that toxic substances in the stern tube lubricating oil will find their way into the food chain. Hence, deemed “biodegradable” lubricants may not be as biodegradable in the Arctic operating environments. However, there exists a proven, viable option for vessels operating in the Arctic to eliminate stern tube oil pollution.

This paper outlines the process for converting the sterntube bearings from oil-lubricated, white-metal bearings to Thordon COMPAC seawater lubricated bearings, based on recent works on a twin screw ice breaker at a shipyard in Canada. The paper will present the components of the COMPAC propeller shaft bearing system designed for salt water and ice operation. This includes COMPAC (non-metallic) bearings in carriers, bronze shaft liners, water quality packages, flexible shaft coating, and forward seals.

The installation and performance of seawater lubricated bearings will be reviewed considering installation timing, zero pollution, lower operating costs, no risk of catastrophic failure and low coefficients of friction.

1(c) Ice Loads on Ships

Day 1, Endeavor Room, 1350-1450

110 ***Effect of Moving Ice Loads on the Plastic Capacity of a Ship's Structure***

Authors: Bruce Quinton, Claude Daley, and Robert Gagnon

The new unified polar class rules (IACS, 2007) have moved away from traditional elastic design and instead consider plastic limit states for their ship structural design rules. These rules require that ship structures be optimized for plastic capacity rather than elastic capacity, resulting in more likelihood that ships will exhibit good plastic response and overload behaviour. However, plastic behaviour is much more complex and some aspects are still not fully understood. Questions remain concerning the capacity of ships to withstand progressive damage from moving ice loads. This paper investigates the structural response of an “IACS polar class” large grillage structure to moving ice loads. The “IACS polar class” design scenario is a “glancing ice impact” that is applied as a steady-state static load. It was desired to know if the grillage structure responded differently to moving loads, than it did to static loads. An explicit nonlinear numerical finite element model was created using MPP-Dyna. This numerical model was validated against full-scale experiments involving an “IACS polar class” large grillage structure. Eight moving load scenarios divided into three categories were tested using the numerical model. In addition, strategically placed static loads were modelled in order to provide a basis for comparison between the moving and static load structural responses. It was found that the large grillage’s structural capacity to withstand moving loads was generally less than its capacity to withstand static loads. Further, the structural mechanisms behind this decrease in structural capacity were identified.

138 ***Modeling of Pressured Ice Interaction with Ships***

Authors: Ivana Kubat, Mohamed Sayed, and Anne Collins

The impact of *pressured ice* conditions on ship performance and safety is well recognized. Many reports indicate that such conditions cause the besetting of ships and even damage. The expression *pressured ice* is generally used to describe convergence of the ice cover and the build-up of stresses. But there is no specific definition or quantification of the pressured ice or how different vessel classes would perform under such conditions. Although, large scale ice forecast models can predict the formation of convergence and pressure zones, those forecasts cannot determine the conditions at scales relevant to ship performance. The present paper aims at bridging the gap between large scale ice cover conditions and the small scale

behaviour that influences ship performance and safety.

The paper presents results of numerical simulations of vessel interaction with pressured ice fields. Geometry of the CCGS Louis S. St-Laurent is used as an example. Fields of converging ice of the order of 1 km^2 are considered. The vessel is placed within such ice fields. A number of pressured ice scenarios are tested by applying different pressure and displacement boundary conditions to the ice cover. The simulations address cases of stationary vessel (drifting with the ice cover). Also vessel transit cases are considered.

The numerical model is based on a Lagrangian-Eulerian hybrid formulation. The mass and momentum equations are solved together with constitutive equations describing plastic yield conditions. An extended von Mises yield criterion is used to account for ice cover failure. A depth-averaged version of the model is used, whereby the stresses and velocities are averaged over ice thickness. Ice thickness build-up and lead opening are accounted for in the model. The ice cover is driven by prescribed displacements or pressures at the boundaries. Wind and water current drag are also included.

The results give the forces and pressure distributions on the ship. The role of large-scale ice pressure, convergence, ice thickness and ice strength are examined. In addition, the influence of ship hull-ice friction coefficient and ship velocity are examined. The conclusions provide guidance for predicting the potential for besetting of ships in pressured ice, and estimates of expected ice forces.

141 *Assessment of Ship Ice Loads in Pack Ice*

Authors: Claude Daley and Jiancheng (Jessie) Liu

World trade and exploration for natural gas/oil in the Arctic/Subarctic has greatly stimulated the development of shipping in arctic regions. More and larger commercial vessels have or will operate in the harsh environments. This stretches the validity of the existing ship design rules and raises concerns. To deal with this challenge, owners, designers, operators and regulators have been trying to develop more and better design scenarios. This paper addresses two such scenarios.

Impacts between ships and the discrete ice floes are unavoidable. This paper develops an approach for ice load assessments for a ship interacting with discrete ice floes on the midbody area. Two typical scenarios in those interactions are considered in this paper. One is a midbody impact with a second flow, following a glancing impact between the bow and a first ice floe. The second case is that of a midbody collision during a turning operation. The assessed ice loads for these scenarios are compared to the current requirements of the hull structural strength at mid-body.

The paper present a range of results and makes use of the Design of Experiments (DOE) methodology to give simple analytical formulas to quickly estimate the ice loads due various factors (mass, velocity, geometry).

1(d) Performance

Day 2, Endeavor Room, 1350-1430

111 *The Effect of Icebreaking Bow on the Open Water Performance of a Large Arctic Ore Carrier*

Authors: Han Yu, Sungeun (Peter) Kim, Rae-Hyoung Yook, Dong-Yeon Lee, Hyun-Chae Jung, and Jong-Soo Seo

The exploration of natural resources in the Arctic areas is the main drive behind recent research interest in the harsh environment. The high quality iron ore in the Baffin Island area attracted great interest among the mining and shipping community. The shipboard transportation of the cargo poses numerous challenges considering the potential delivery port in Europe. The ship designer needs to keep a balance between good ice-breaking performance and good seakeeping performance. The hull form of a good ice-breaking bow typically requires a large flare near the waterline, while this can cause severe wave impacts causing increase structural loads. The hull structure is more likely to experience vibratory responses due to the increased wave impacts as the bow flare increases. This hydroelastic interaction of the hull girder in waves can cause increased bending moments and fatigue loads.

This paper introduces recent experimental and numerical studies of seakeeping, wave impact and the hull girder responses of a large arctic ore carrier. A series of model tests was undertaken at Samsung Ship Model Basin to investigate the global motion, hull girder loads and vibratory responses with three different bow shapes including the ice-breaking bow. A segmented model with an elastic backbone system was used to properly scale the hull girder stiffness and to simulate the vibratory responses. The effect of bow hull form on the global motion and hull girder loads are investigated. Numerical analyses are also carried out to simulate the hull girder vibratory responses in regular and irregular waves using the ABS nonlinear seakeeping program, NLOAD3D. Coupled with nonlinear wave and slamming impact loads, it is demonstrated that the elastic beam model successfully simulates the observed hull girder vibratory responses in time domain.

120 *Global Ice Loads on Arctic Drillships*

Authors: Bo Wang, Claude Daley, Mohamed Sayed, and Jiancheng (Jessie) Liu

A key challenge faced by designers of floating structures in Arctic service is predicting ice loads. In the case of drillships there are two distinct modes of operation: transit and on site. The load regimes that apply to each mode are also quite distinct. Ice loads encountered by drillships in transit are essentially those of a trading ship. At site the primary concern is global loads which will be resisted either by a mooring system or a dynamic positioning system. The subject of this paper is global ice loads on Arctic drillships. Generally loading models used in engineering are based on formulations derived applying scientific principles and then calibrating the formulation using data gathered from the field and elsewhere. Useful data can be extracted from damage histories, or can be based on model-scale experiments and, less frequently, on full-scale experiments. Furthermore numerical methods are now maturing to the point where predictions from this source are useful additions to the database of ice load estimates.

This paper reports on an exercise to predict ice loads on drillships using all such methods. An example drillship has been employed, and pack ice has been considered in theoretical and numerical analyses. Two analytical models for predicting the ice force have been developed for the head-on ice-ship interaction scenario with low ice concentration. One model is that the ice load is estimated as the average rate of momentum transfer between ice floes and ship hull. Another model is that the ice load is estimated form the motion and drag of ice floes as they move around the ship. In numerical modeling, a parametric study has been conducted to simulate different ice-structure interaction scenarios using the Particle-In-Cell (PIC) method. Different parameters including ice thickness, ice concentration, floe size, ice movement velocity, and ice movement direction have been investigated in the interaction modeling. Based on numerical results, a formula for calculating the ice load has been developed to reflect the role of the pertinent parameters on expected ice forces and movements of the drillship. This study serves to help bound estimates of load and also provides insights into the different methods of global ice load prediction for this particular application.

1(e) Icebreakers

Day 3, Discovery Ballroom, 1000-1100

147 *MOERI's Ice Model Test for Korean Icebreaking Research Vessel*

Authors: Seong-Yeob Jeong, Chun-Ju Lee, Seong-Rak Cho, and Eun-Jee Chun

The Maritime and Ocean Engineering Research Institute (MOERI) ice model basin was completed at MOERI in August 2009 and Korean Research Icebreaker Araon, successfully navigated through frozen waters in Antarctica.

Estimation of Ice model test is important in connection with hull form of an icebreaker, propulsion of a ship and determination the engine power of the ship. In this Paper, MOERI (Maritime and Ocean Engineering Research Institute)'s ice model basin facilities is simply introduced, Ice model test procedures and results at MOERI's Ice Tank studied. MOERI's ice tank has created 12's ice sheets and procedure of ice model test is in progress. Ice model test is used MOERI's ice breaker model which was conducted in Helsinki university ice model basin in 2004-2005 and five hull forms of the arctic shuttle tank. The ice model test predictions for MOERI's icebreaker model ships are discussed.

123 *AURORA BOREALIS - A New European Combined Research Icebreaker and Drilling Vessel*

Authors: Willy Doelling, Albrecht Delius, Lester Lembke-Jene

The polar oceans are currently subject of intensive scientific and environmental discussions. In order to learn about and to understand the processes in the polar areas, research work must be done including the scientific drilling operations in ice covered waters up to 5000m in depth penetrating another 1000m into the seabed.

Because of the immense expense and difficulty of such drilling operations, the German Science Council recommended the design and construction of a combined Research-, Icebreaking- and Drilling vessel which shall be able to navigate autonomously up into the highest ice-covered polar regions at all seasons without any assistance of other icebreakers.

Wärtsilä Ship Design Germany developed the initial design concept of the AURORA BOREALIS, conducted all general arrangement planning, verified the vessels ice breaking performance by means of model tests, conducted all necessary calculations and investigations and prepared the full tender specification.

AURORA BOREALIS is designed to IACS class notation PC1 and above. She features an overall length of 199.95m and a maximum breadth of 49.00m. The installed power is 94MW and the main propulsion power is 81MW. Accommodation is provided for 120 persons.

She is able to pass through 2,5m thick multi year level ice at a speed of 3 knots and she can manage with ridges of 15m thickness. All ice operations shall be executed as well forward as astern with the propulsion and manoeuvring devices being virtually free of ice.

Special attention is paid to the accommodation of the two moon pools and the deep sea multi-beam sounders located in the bottom of the forefoot which must always be free of ice and without the risk of any damages by ice floes.

The diesel-electric main propulsion consists of a fixed pitch triple screw arrangement with one centre rudder. Six retractable transverse thrusters each of 4.5MW allow together with the main propulsion plant for station keeping and manoeuvring in drifting level ice.

Extensive model tests have been carried out to verify on the ice breaking capabilities in transit as well as in DP-mode, the manoeuvring ability, the sea-keeping and the resistance/speed/power predictions.

AURORA BOREALIS is scheduled to enter into service in 2014.

155 *North Slope Trends in Sea Level, Storm Frequency, Duration and Intensity*

Authors: Nels Sultan, Kenton Braun, Dempsey Thieman, and Ajay Sampath

The arctic North Slope offers unique coastal and offshore challenges, including eroding shorelines, logistics and schedule constraints, sensitive arctic environmental issues, and limited ice and met-ocean data. The need to design for both ice and waves involves sometimes conflicting design criteria. Acceleration of environmental change is a recent issue, potentially related to reduced ice cover and global climate change. This paper presents analysis of North Slope storm intensity, sea level and shoreline erosion trends. Included is analysis of tide gage data, wind records, and aerial photography. Data needs and suggestions for future research are identified.

Limited metocean and ice data complicates the design of arctic shore protection and offshore structures. The lack of long term wave buoy data prevents direct calculations of the wave height return period, and verification of numerical models. However, the NOAA tide gage at Prudhoe Bay provides a record of water surface elevation from 1993 to present. The tide record is useful for identifying storm surge and set-down events, and long term trends in relative sea level change. In addition, wind data is available from the Deadhorse airport since 1974. The wind data and tide gage records are together applied to identify easterly and westerly storm events and trends in their duration, intensity and frequency. The return period of water level and wind speed are estimated.

Analysis of shoreline location from historic aerial photos and charts allows calculation of the rate of shoreline erosion/accretion, and how that rate has changed over time. Analysis of aerial photography for a recent North Slope project shows limited changes in the rate of shoreline erosion since the 1950's. This may provide insights into past changes in the environment. However, shoreline erosion is influenced by a range of factors, including storm frequency and duration, ice cover, and ground temperature, which complicate the interpretation of the data.

Design for ice runs and ice loads often control the design of coastal and in-water structures. Ice thickness has been well studied. However, data related to the movement of ice is very limited. Data for ice pile-up and ride-up associated with ice run are a key need for developing improved design criteria.

As arctic energy exploration and development continues it will involve new challenges in the coastal, nearshore and offshore environments which will require innovative solutions and improved data collection. A Joint Industry Project is proposed to collect long term ice-run and wave data.

1(f) Transit Analysis

Day 3, Discovery Ballroom, 1120-1220

151 *An Analysis of Sea Ice Condition to Determine Ship Transits through the Northwest Passage*

Authors: Todd Mudge, David Fissel, M. Martínez de Saavedra Álvarez, and John Marko

An analysis was carried out to determine the duration of the summer shipping season for deepwater vessels transiting through the Northwest Passage Route. The Northwest Passage is the shipping route between the Atlantic Ocean (Baffin Bay) to the Pacific Ocean (Bering Sea). The most likely route segment to obstruct shipping is the western portion of Parry Channel. The region is typically characterized by the presence of high concentration

mixtures of deformed, thick first year and multiyear ice in Viscount Melville Sound and its adjacent passages, including the very narrow Prince of Wales Strait. Based upon historical ice data, the blockage and delay problems in these areas are sufficiently serious as to preclude extended duration shipping seasons except for occasional exceptional years. On the other hand, recognized possibilities for dramatic climate change-induced amelioration of Arctic ice conditions combined with several occurrences of the needed exceptional conditions during the last decade, has encouraged a more optimistic view of Northwest Passage traversal prospects. The times of ship transits through the passage is determined from the computer-based analysis of digital Canadian Ice Service weekly ice charts which are available from the late 1960's to the present. The criteria for successful ship transits is based on specified maximum partial ice concentrations by ice type with high concentrations of old ice combined with thick first year ice representing the limiting conditions to ship transits. Automated computer-based algorithms were developed to estimate the number of, if any, ship routes that would successfully allow transit of selected segments of the Northwest Passage Route using CIS digital egg code ice data available at 4 km resolution. The results show a very large year to year variability in the duration of the summer shipping season with the trend towards slightly improving ice conditions. The possibility of future increases in old ice concentrations in western and central portions of Parry Channel due to an apparent trend towards more rapid passage of this old ice through the Queen Elizabeth Islands to the north will be discussed.

173 ***Arctic Sea Route Transit Analysis for Large Cargo Vessels***

Authors: Kyungsik Choi, Jong-Ho Nam, and Seong-Yeob Jeong

The purpose of this ice transit analysis is to determine the optimum sea routes and to estimate the operation cost, transit hour, and average speed for large cargo vessels navigating in the Arctic Sea Route prior to an actual deployment of commercial cargo vessel fleet. Four different Arctic ships, such as two bulk carriers, an LNG carrier and a crude oil tanker, are selected for Northern Sea Route and Northwest Passage transit simulation. Ice and environmental information such as sea ice thickness and concentration, wind direction and wave height are gathered and their probabilistic distribution are used to carry out a transit simulation. In ice-covered sea, the size and distribution of sea ice significantly restrict the operation of ships and the icebreaker assistance may be an important decision for keeping the speed and direction as planned. Information of multi-year ridge formation and water depth along the Arctic Sea route are added in this analysis. After the selection of optimum sea route, total transit distances and hours, average speed, cost for icebreaker escort and total operation cost are calculated in sequence for each vessel.

177 ***The Transportation of Large Modules through the Northwest Passage***

Authors: Gareth Igloliorte and Andrew Kendrick

A review of the feasibility of transporting large modules through the Northwest Passage via heavy lift vessels or a tug barge arrangement is discussed in this paper. The review included an assessment of ice conditions during the late spring, through early fall months, heavy lift vessels on the market, a risk assessment and a safe harbours survey. The ice conditions in the Northwest passage were developed based on data from the Canadian Ice Service. Both ice charts and consolidated data were reviewed for further use. The consolidated information is broken down by region within the Arctic Archipelago and was successfully used as part of a transit model. A market survey of heavy lift vessels, focusing on capacity and ice strengthening was also performed, as well as a review of available ice breakers to provide an escort role for the heavy lift. Heavy lift ships under consideration included Lift-On Lift-Off, semi submersible, and large, ice capable cargo vessels were considered.

A transit model based on the Transport Canada Arctic Ice Regime Shipping System (AIRSS) was developed based on the ice conditions and vessel market survey that was used to develop transit duration estimates based on the time of year the Northwest Passage was attempted. The paper concludes with a feasibility assessment of the enterprise.

1(g) Arctic Tankers

Day 3, Discovery Ballroom, 1350-1510

119 ***Structural Integrity Assessment for a Polar Class Arctic Tanker under Ice Loads***

Authors: John Dolny, Shewen Liu, Dongki Won, Jae-Yeol Lee, Joong-Hyo Choi, and Myo-Jung Kwak

The recent surge of interest in potential oil and gas reserves in the Arctic regions has resulted in vital technology developments in the field of Arctic shipping. New, larger vessels of novel designs are entering the Arctic where the industry has limited experience. The design of large vessels presents new challenges for designers and operators. ABS and DSME have collaborated in a joint developmental project of a 107,000 DWT Arctic crude oil tanker designed to comply with the International Association of Classification Societies (IACS) Polar Class PC4. The Polar Class Rules which went into effect in March 2008 provide minimum scantling requirements. However, they are new to the industry and have no service experience. Hence, it was considered prudent to investigate the hull structural strength subject to loads derived from several ship-ice interaction scenarios not explicitly considered in the Polar Class Rules. In addition, the Polar Class Rules require appropriate methods of grillage analysis to be carried out for frames and load carrying stringers. This paper presents the procedure and results of the structural strength assessments of the bow and midbody subject to possible ship/ice interaction scenarios. The static nonlinear finite element analysis and a novel plastic grillage analysis method were used to check the structural strength under different ice load conditions. Grillage analyses of three midbody configurations (a transversely-framed and two different longitudinally-framed midbody sections) were carried out to investigate the effectiveness of different structural arrangement subject to large ice loads. The results of the nonlinear FEA and the new grillage analysis method are compared and it is shown that the plastic grillage analysis method provides an efficient and practical alternative for predicting the plastic strength of grillages under ice pressure.

131 ***Fatigue Damage Estimation of Hull Structure of Large Arctic LNG Carrier Due to Ice Loads***

Authors: Hisashi Ito, Yongsuk Suh, Kibok Jang, and Seungmun Park

Possibility of fatigue damage due to ice loads is investigated for the hull structure of a large LNG carrier which is developed based on the rule of Russian Maritime Register of Shipping for LNG transportation from Arctic area to western countries. The Ice class is Arc4.

In a former work, the initial hull design of this vessel was performed using a direct calculation method, where ice loads that act on hull structure were calculated by a collision model using Kurdumov-Kheisin hydro-dynamic model (HDM) which has been used in Russia for a long time. The safety of the hull structure and the cargo containment system of this vessel was verified for several possible scenarios.

In this report, fatigue damage due to ice loads is evaluated using a direct calculation method. Ice load estimation for collision with ice sheet is performed based on HDM basically. Ice thickness is roughly idealized as three categories and independent ice operation without an escort by ice breaker is assumed because this vessel can be operated in the maximum ice thickness (0.7m) specified by the RMRS rule. To reduce the direct calculation efforts, some dimensional analyses are employed with information from experts. Ice load frequency is also roughly estimated by another direct calculation method.

As far as the authors know, direct calculation methods have not been applied for fatigue strength assessment due to ice loads so far. Therefore, several hypotheses which have not been fully proven are inevitably employed. Therefore, it is recommended that they will be modified in a more sophisticated

manner through ice operations of large merchant ships in Arctic seas in the near future.

As a result, fatigue damage due to ice loads is found to be negligibly small comparing with that due to wave loads in a given scenario.

Summary of the proposed direct assessment method and the fatigue evaluation results are explained.

135 *Arctic Tankers: Current and Future Structural Design Practice*

Authors: Robert Tustin, Mikko Niini, and Erkki Ranki

Recent projects for Russian Arctic resource developments in the Pechora Sea have required the design and construction of specialized 70,000 tonne deadweight Arctic shuttle tankers. Future exploration and exploitation of oil reserves in the Arctic Basin are likely to be supported by Arctic tankers serving these remote fields.

There is a need for industry to understand how recent Rule and Regulatory developments, implemented since the design of the most recent Arctic Tanker projects, will affect future Arctic tanker designs from a practical standpoint. This includes the implications on future Arctic tanker designs of the IACS's Common Structural Rules for Tankers as well as the IACS Polar Class Rules.

This paper details the co-operative work undertaken by Aker Artic and Lloyd's Register to investigate and update an Arctic shuttle tanker design to latest Rule and Regulatory requirements, and considers the implications for Arctic tanker designs of the future.

The key content of the paper focuses on:

- Feasibility of upgrading a current 70k Arctic shuttle tanker design for compliance with latest international regulations
- Optimal structural arrangements and configurations for 70k Arctic shuttle tankers
- Design implications of the application of IACS Common Structural Rules and IACS Polar Class Rules for 70k Arctic shuttle tankers

Aker Arctic's Arctic shuttle tanker design for the Prirazlomnaya field has been used as a real ship case for this co-operative study. Learning from experience with the design, construction and Class approval of this ship for the Prirazlomnoye project is also considered in the study findings. Finally consideration is given to application of these findings to larger tanker designs that are expected for operation in the Arctic in the future.

2. Structures in Ice

2(a) Moored Structures 1

Day 1, Endeavor Room, 1020-1120

104 *Fast Ice Drilling System - FIDS - An Improved System for Shallow Water Arctic Drilling*

Authors: Randall Shafer, Peter Noble, and Alex Iyerusalimskiy

The Fast Ice Drilling System (FIDS) is a concept to extend the season for Ice Island drilling and to move it into deeper water as an alternative to bottom supported drilling units, such as the Steel Drilling Caisson (SDC). As currently conceived, the FIDS can enable drilling of up to four wells during the course of one winter season.

The FIDS is designed to overcome one of the limitations of current ice island drilling, i.e. the requirement for shore access via an ice road. Building of ice roads can delay season start and shore leads and over-flooding in the spring can make the ice road unusable while the ice island platform is still stable and intact. By using marine logistics and supply FIDS obviates the need for shore access via ice roads.

The FIDS concept uses logistics vessels to position construction and drilling equipment, camps, fuel and other supplies in the vicinity of the target well locations. Spray ice islands are constructed as drilling platforms and are interconnected by ice roads to each other and the vessels.

After completion of drilling and well testing, all drilling equipment and remaining supplies on the islands will be returned to the logistics vessels which remain in the ice until break-up the following summer.

The novel aspect of FIDS is the use of an SA-15 or similar, ice-capable logistics vessel to position itself with construction and drilling materials at an ice island location around late November. This approach allows for the earliest start of ice island construction and correspondingly maximizes the time available for drilling a deep and complex well at this location.

The paper will report on all aspects of the FIDS system which were studied including:

- Marine equipment and operations
- Ice island design and construction
- Well design and construction
- Ice conditions and monitoring using satellite imagery

115 *Arctic Deepwater Development Drilling System Design Considerations*

Authors: Theodore Kokkinis, Carl Brinkmann, John Ding, and Daniel Fenz

A significant amount of oil and gas is estimated to exist in the Arctic, with a significant portion in offshore deepwater areas. However, these resources remain largely unexplored, because of the challenges the arctic environment presents for exploration and production. Currently no viable platform concept exists for development drilling and production (year round) in water depths greater than 100 m. Bottom founded platforms are limited to lesser water depths, and floating platforms must avoid ice or resist heavy loads from drifting pack ice.

Focusing on development drilling, a large number of wells have to be drilled over a relative short time span, given the size of resources and pace of development necessary to enable economic exploitation. This makes it necessary to conduct development drilling operations year-round and imposes a requirement for the arctic development drilling system to operate in the most severe winter ice conditions occurring in the arctic seas.

A system can be designed combining available technology elements (hull geometry, azimuthing propulsion, disconnectable mooring, marine anchoring and ice management) in an optimal manner, balancing system stationkeeping capability with ice management capability, to achieve the objective of year-round operation without significant downtime due to extreme ice conditions.

The development drilling system is only one part of an overall arctic deepwater offshore resource development plan. Core design considerations are outlined, involving construction, transportation, installation, stationkeeping and disconnection issues. Further the impact of HSE, drilling, re-supply and other operational issues on the design is assessed. Key technical challenges and associated research and technology development needs are identified.

159 ***Pack Ice Forces on Floating Offshore Oil and Gas Exploration Systems***

Authors: Lei Liu, Dexin Zhan, Don Spencer, and David Molyneux

As oil and gas exploration moves into ice covered water, then it is important to be able to predict the ice loads acting on the offshore structure. This is necessary for developing suitable mooring systems or dynamic positioning systems so that exploration and production time is maximized. It is likely that many offshore systems will experience heavy pack ice as the limit of normal operation, since support vessels will be used to break up the largest ice floes and manage ice conditions as much as possible. Numerical methods are the preferred approach at the early stages of the design process, since different concepts can be evaluated without the need for expensive model experiments. However, the accuracy of the numerical methods is critical to their successful application.

This paper presents the results of computer simulations of pack ice forces on three candidate offshore systems (which consist of a drill ship, a semi-submersible and a spar) using the computer code DECICE, which is a time-domain solver that uses discrete elements to model ice engineering problems. The elements undergo rigid body translation and rotation according to Newtonian mechanics. Interaction forces, both normal and tangential (resulting from friction) forces, are modeled when bodies contact one another. Each body can be elastically deformable and can fracture under internal stress to produce new elements. The fracture model is based upon Mohr-Coulomb failure criteria with a tension cutoff. Brittle failure modes can be either compressive, shear, tensile or flexural. External loads may be applied, such as those resulting from DP system thrust, mooring lines, wind or current. The 2-D version is useful for modeling large-scale ice transport problems, while the 3-D version is applicable to ice-breaking ships or general ice-structure interaction.

Two dimensional and three-dimensional cases are run for all three candidate offshore systems. DECICE is used to predict two force components (in the plane of the waterline) and moments acting on the structure for a range of ice drift velocities, ice coverage from 60% to 95% (as a percentage of total sea area) and heading angles relative to the ice drift. The results of the simulations are compared with data from scale model experiments (where it is available), and it is shown that the discrete element method is suitable for preliminary estimates of total ice forces and moments due to pack ice, and that the predicted ice flow patterns around the structure are realistic.

2(b) Moored Structures 2

Day 1, Discovery Ballroom, 1350-1450

160 ***Mooring System for Moderate Sized Arctic Vessel Terminal in Heavy Ice Conditions***

Authors: Axel Bonnaud, Ove Tobias Gudmestad, and Erlend Hovland

With a considerable amount of oil and gas resources, the Arctic zones are becoming more and more attractive for oil and gas exploration and production. However, to be able to produce oil and gas in this region, several new challenges have to be faced. One of these is the heavy ice condition. Thus, to face this challenge new technologies are required.

In drifting ice to heavy ice conditions, a floating stationary unit must withstand the design loadings. Disconnection may be needed in the event of loss of position. Due to these loadings, a safe design of the vessel to seabed connection, however, cannot rely on thrusters' utilization alone. A mooring system needs to be particularly reliable and strong.

With regard to these observations, it seems relevant to compute and analyse the loading in the mooring device. The vessel studied in this paper is a moderately sized mono-hull icebreaker suitable as offloading terminal for shallow water or onshore facilities, as control centre for subsea facilities, as process facility with a small process plant or used as intervention vessel for subsea satellites. .

Due to weight limitations, it is challenging to design a mooring system for arctic deep water made of chain or wire. The use of polyester ropes may be an attractive alternative. Due to its particular features, the polyester rope's behaviour is not fully understood and it is needed to be further studied for use with a moored installation in this region with very large mooring forces.

The Arctic Ocean has a water depth varying from tens of meters (Pechora Sea and Kara Sea, parts of the Beaufort Sea) to a couple of thousands meters (Canada Basin). This implies finding different mooring solutions to suit these different water depths.

This paper aims at submitting the results of ice load calculations on mooring systems composed of different kinds of mooring elements (polyester ropes, wire ropes, chains and buoyant elements) and proposing different geometries according to the water depth.

174 ***Construction and Monitoring of an Ice Platform in Siberia***

Author: Volker Neth

A group of international scientists planned to conduct a deep hole drilling research program over a period of several months from a floating ice platform at a crater lake, in North East Russia during the 2008/2009 winter season. The lake, Lake El'gygytgyn with a diameter of about 13 km, was created as the result of a meteorite impact 3.6 M years ago. Drill cores from a 375m thick sediment layer within the lake will be analyzed to trace back climatic changes in the Arctic over the past 3.6 M years.

This paper describes the planning, surveying and monitoring of a 7.5 km long ice road as well as the design, construction and monitoring of an ice platform, measuring 100x100m, in the middle of the lake.

Ice bearing capacity calculations indicated that the ice cover was thick enough to support equipment travel on the ice road by mid January 2009. However, the ice platform needed to be thickened to about twice the thickness of the naturally grown ice to support the drill rig.

Because of its remote location and its unknown working and environmental conditions, on-ice safety constituted an important component of the entire project. An Ice Monitoring and Safety Plan (IMSP) was developed for Russian and international personnel working on the ice.

Rapid ice growth was observed at the beginning of the freeze up in early November 2008. By mid January, however, the entire lake ice was covered with densely compacted snow. Frequent snow storms resulted not only in considerable snow drifts along the ice road and on the drill pad, but caused also delays for the on-ice work.

Snow delayed ice growth and depressed the ice cover. Based on numerous drilled holes, it can be assumed that the entire lake was subjected to negative freeboard.

Load calculations, based on snow density measurements, indicated that substantial snow accumulations (drifts) on the drill pad exceeded the rig weight by a factor of 10, resulting in freeboard losses of more than 30%. Snow fences and wind rows, which were installed upwind from the ice pad proved to be very effective in minimizing snow accumulations on the drill pad.

This project presented the unique opportunity of acquiring field data by a professional over a period of about six months. Also, the long term

relationship between load and loss of freeboard are presented in the paper and the results are compared with commonly used analytical methods.

This project had demonstrated that an ice cover can be used effectively as long as project specific safety rules are being followed. No ice related incident occurred throughout the duration of the drilling program.

149 *Research Vessel SIKULIAQ: Wartsila Ice Capable Run Quiet Propulsion*

Author: John Hatley

The National Science Foundation as owner, with operator University of Alaska Fairbanks, contracted recently to build a new oceanographic research, state of the art ice capable vessel R/V SIKULIAQ. This research vessel combines many leading technology breakthroughs for exploration off Alaska's cold ice infested waters and including frontier areas north of the Arctic Circle. The vessel features an advanced Polar Class propulsion system employing cutting edge ice pulling thrusters designed by Wartsila's world leading hydrodynamics center in the Netherlands. This twin propeller propulsion system presented unique design challenges to Wartsila with two diametrically opposite engineering features; first provide steerable pulling propellers with robust strength for Polar Ice rating and secondly also incorporate a very delicate low radiated underwater noise signature enabling sensitive mammal and fisheries research efforts. The key design criteria threshold requirement was to achieve stringent noise reduction and cavitation free propeller blade operation at tow load speeds for a vessel capable of also operating in ice near 2.5 feet thick. Expressed in lay terms, provide an ice capable margarita blender that runs quietly! The vessel shipyard construction build program is now underway in the lower 48 states and is slated for delivery during 2014 with the ship ready to commence scientific efforts. This Power Point presentation introduces the project, provides highlights of the Wartsila propulsion design features that combine such diverse functionalities, and draws conclusions about this vessel's cutting edge technology with wide reaching employment applications for other Arctic vessels.

This Power Point presentation will be of keen interest to scientists, engineers, Arctic researchers, Naval Architects, Marine Engineers, and operators whose firms are engaging business within the Polar Arctic regions.

2(c) Fixed Structures

Day 1, Discovery Ballroom, 1510-1650

102 *Parametric Trends of Arctic Gravity Based Structures*

Authors: Paul Spencer and Alec Bound

Gravity Based Structures (GBS) have been used as hydrocarbon exploration or production structures in arctic regions to a water depth of about 30m and sub-arctic regions up to about 100m. The weights of the construction materials for the GBS and hence its cost depends on a large number of engineering parameters and constraints. For a particular location/field, the site specific values would be used in the design. There is however, useful guidance that can be obtained by performing a parametric analysis of a GBS over a wide range of engineering requirements that may be required in future structures.

In this paper we cover the results of a parametric investigation into the minimum size of caisson shaped production GBS in ice covered regions. In previous publications by Spencer etal, (POAC 2005 Vol 2 pp 825-835; POAC 2005 Vol 2 pp 835-845; POAC 2007 Vol 2 pp 54-64) the GBS sizing methods were described and aspects of the parametric trends with design ice load were reported. In the current paper, the size of the candidate GBS were determined as a function of other important engineering parameters. The water depth at the set-down site was varied from 50m to 150m, the soil strength at the site used a 30deg frictional model or a 40 to 80kPa cohesive model, the construction material for the GBS was either steel and/or concrete, the product storage requirements were varied from 0 to 4million barrels, the solid ballast requirements were varied and the maximum floating draft for the structures set to either 30m or 60m. The 100 Year return period value for the ice loading and wave loading and the 500 Year seismic level for loading on the structures were chosen to be representative of a range of arctic and sub-arctic environments. The environmental force inputs were kept fixed for this parametric analysis.

The trends in the size, cost, material construction weights of the caisson design GBS are described. In addition, aspects such as the solid ballast requirements and the floating draft of the structures are discussed. The applicability of the various design combinations is also discussed with reference to the Chukchi, Beaufort and West Greenland Seas.

164 *The Challenges and Synergy of the Winterisation for Ships and Offshore Installations*

Authors: Robert Bridges, Herbie Battye, Des Upcraft, and Trevor Butler

The implications for the design and construction of offshore structures for cold climates is far reaching and includes environmental and operational aspects, as well as specific design considerations, and compliance with relevant rules and regulations. This paper provides an overview of some of the design considerations required, with particular emphasis on the operational challenges from a marine shipping perspective that icing and low temperatures impose.

158 *Testing of Northstar Artificial Island in Ice Model Basin*

Authors: Göran Wilkman, Guang Li, and Sami Saarinen

The Northstar man-made island has been on stream for some years (since 2001) already, and experienced more frequent and severe storm conditions than initially expected. As a result, its armor slope-protection systems required annual maintenance.

To study the possibility to improve the durability of the island BP launched a testing programme to compare two different enhanced slope protection systems.

In September 2008 altogether three weeks of testing in ice in various ice conditions and island configurations were performed at the Aker Arctic Technology model basin. The tests were quite complicated and time consuming.

The paper discusses the test set-up, tests performed and learnings.

172 *Bond Enhancement for Sandwich Shell Ice Wall*

Authors: Peter Marshall, Andrew Palmer, JY Richard Liew, Tongyun Wang, and Ma Khine Wa Thein

A previous paper (cited below) describes the Singaporean concept for an Arctic caisson, consisting of a pre-fabricated hollow steel shell, transported to site on a submersible heavy-lift vessel, and filled with concrete after being set on a prepared foundation. The resulting curved sandwich shell, steel-concrete-steel (30-500-30 mm), was shown to be capable of resisting the full range of broad-area and higher localized patch loads specified in the draft ISO 19906.

Tests of a large-scale shell reinforced with J-hook radial ties inside the sandwich showed excellent performance. However, this would be more

expensive to fabricate than a plain double shell. Finite element analysis and large-scale testing of the latter showed it to be vulnerable to early disbonding and loss of serviceability, even though its ultimate strength exceeded the ISO guidelines. **The case of "perfect bond" is examined with ABAQUS-explicit as an exercise in goal-setting.**

Various methods of bond improvement have been proposed, with the goal of approaching the shear and tensile strength of the fiber-reinforced bulk concrete. Recent small scale testing (ASTM shear push-out) will be reported, exploring two methods of surface treatment which improve strength and ductility at the concrete-steel interface. These are being called "hairy epoxy" and "steel Velcro."

Marshall PW et al (2009). The effect of bond enhancement on curved sandwich shells under contact loading, Proc Structural Stability Research Council, Phoenix

2(d) Ice Loads 1

Day 2, Endeavor Room, 1120-1220

116 *Multi-Year Ice Interaction with Downward Breaking Cone Structures*

Authors: Zhong Ding, Daniel Fenz, Theodore Kokkinis, and Carl Brinkmann

The Arctic is one of the last areas with major oil and gas resources that remain largely unexplored, particularly in offshore deepwater areas. For future exploration, development and production, potential arctic offshore structures may be exposed to severe ice conditions. Ice loads on floating platforms with a downward breaking cone at the waterline could be lower than loads on vertical surface-piercing structures.

This paper describes a test program ExxonMobil Upstream Research Company carried out in 2009 to study loads from multi-year ice on downward breaking cone structures, to understand the physics of ice and cone structure interaction, to evaluate ice loads for different model scales and geometries, and to assess the repeatability of ice model test results. For these purposes we used both 6-degree-of-freedom force measurements and detailed above- and under-water video recordings.

Four series of tests were carried out at the Institute for Ocean Technology in St. John's, Canada, on caisson models made up of a downward breaking conical structure at the waterline and a cylindrical neck below. Three different cone geometries were tested, including two different cone angles and three different drafts (water-line diameters), for the purpose of evaluating the effect of the clearance distance (from water line to cone bottom) on the characteristics of ice-structure interaction. Also tests of one model were performed at 3 different model scales to assess the influence of the scale on results. All cone surfaces were coated with the same low friction smooth paint to give a uniform friction coefficient. During the test extensive ice property measurements were carried out to ensure desired ice properties are reached.

The paper discusses observed ice failure mechanisms at model scale, the effect of model scale on test results and the repeatability of results in multiple runs under the same conditions.

117 *Critical Roles of Constitutive Laws and Numerical Models in the Design and Development of Arctic Offshore Installations*

Author: Ahmed Derradji Aouat

Over the last half a century, predicting accurate ice loads on arctic offshore structures has been a real challenge. Perhaps, it is time for both constitutive models and failure criteria for ice to join efforts with numerical methods and computer simulations to provide a powerful tool to ice engineers to compute ice loads on arctic structures and investigate the response of the structures with a higher degree of confidence than ever before. Considering the power of computers today and the complexity of ice behaviour when interacting with offshore structures, the combined constitutive-numerical models seem to be one of the most appropriate and effective engineering tools to calculate ice loads and realistically simulate ice-structures interaction processes.

Constitutive modeling deal with the material behavior of ice (elastic, plastic, visco-time dependent) and its damage (micro-cracking at the grain and grain boundaries and large fracture in the ice mass), while numerical modeling take into account the engineering problem, its geometry and boundary conditions, and solvers for the governing equations to obtain engineering results, such as reactions, forces, stresses, strains, and displacements.

The generalized visco-elastoplatic constitutive model (Derradji Aouat et al, 2000) and the multi-surface failure criterion (Derradji-Aouat, 2003) were combined with LS-DYNA explicit FE code (www.lstc.com). Then the combined constitutive-failure-numerical model was used to compute ice loads generated by ice masses when pushed against offshore platforms and marine vehicles in a typical arctic ice environment. Examples include the loads from an ice sheet on a fixed offshore platform and the loads induced by ice on a submarine sail when breaking through arctic ice sheets.

More importantly, the above examples show how a combined constitutive-numerical model can be used as a tool to search for an optimum platform for oil and gas production in the arctic. This is achieved through numerical testing; where several conceptual platforms can be designed (CAD) and meshed (FE), and then subjected to typical arctic ice-structures interaction scenarios (Constitutive-Numerical Solution). The comparison of the final results will point out the to the most promising "most effective" platform. An example of a moored spar platform in the north east of the Canadian arctic, subjected to pushing actions by level arctic ice sheets (1 to 4 m thick), will be presented and discussed.

122 *A Closer Examination of the May 12, 1986 Ice Floe Impact with the Molikpaq*

Authors: Denise Sudom and Robert Frederking

The impact of a very large ice floe with the Molikpaq on May 12, 1986 resulted in some of the highest measured loads on this offshore structure. Numerous types of data were collected during the Molikpaq's 1985–86 season at the Amauligak I-65 site in the Beaufort Sea, including video recorded by time-lapse cameras that were directed at two faces of the structure. For this paper, a new analysis has been performed on the captured video images for the May 12 impact event. Knowing the approximate location of the video cameras, a 3-D rendering of the Molikpaq caisson and water surface can be overlaid on the video image. From the video analysis, refined estimates are made of the thickness of ice interacting with the structure, and the rubble height and rubble extent. The caisson was instrumented with several types of load measurement devices, including extensometers for caisson ring distortion, strain gauges for deformation in the steel, and MEDOF pressure panels for direct measurement of load on the face of the structure. Ice load estimates are made based upon instrument results as well as an analysis of the floe deceleration. An estimate of the global load is presented using available data from the north, northeast and east faces of the structure. To determine the loaded area of the structure, the event videos and the loading on pressure panels have been studied in detail. From ice velocity estimates, the amount of ice moving past the structure and the amount of generated rubble can be assessed. The rubble features indicate the possibility of ice grounding during the event, which could affect the measured ice load. Individual aspects of the event, such as a major spall in the floe and the possible overloading of one pressure panel, are also studied with relation to the effect on global load.

2(e) Ice Loads 2

Day 2, Endeavor Room, 1550-1630

136 *Combined Influences of Aspect-Ratio, Dimensionless Velocity, and Material Properties on Dimensionless Ice-Induced Pressure on Structures*

Author: Aaruun Arunachalam

THE ISSUE AT HAND - Estimation of design ice loads on bridge piers and marine structures interacting with moving sheet-ice are important for safe, efficient and economical design, construction and operation of structures for any given ice-structure interaction scenario. There is an extraordinary level of uncertainty between the prediction of ice-induced pressures (p_e) on structures among the scientists around the world, the predictions scattering by a factor of about 10 to 15 (Sanderson 1988; Croasdale and Kennedy 1996; Croasdale and Brown 2000; Schwarz, 2001). What are the potential causes for this extraordinary level of uncertainty in estimating ice-induced pressures on structures?

WHAT IS KNOWN - It is an established fact in ice mechanics that strain-rate (u/h or u/B) influences some of the material properties (σ_f, K_{1C}, E) of ice (Michel and Toussaint, 1977; Kry, 1981; Palmer et al., 1983; Cammaert and Muggeridge, 1988, to name only a few). It is also known that various material properties (σ_f, K_{1C}, E) of different forms of ice (freshwater ice, sea-ice, and various types of model ice) vary significantly under different conditions (Zufelt and Ettema, 1996 for example).

It is also fairly well established, through the works of various researchers (Afaneseyav, 1968; Neil, 1974; Frederking and Gold, 1975) that ice-induced pressure on structures is influenced by the aspect ratio (B/h).

Hence, it is reasonable to expect that all these parameters - aspect ratio (B/h), strain-rates (u/h or u/B) and material properties (σ_f, K_{1C}, E) - would influence any ice-induced pressures due to any type of sheet-ice interaction with any structure. Thus, all these factors should find a place in any predictive equation for ice-induced pressures on structures. However, a review of equations (Arunachalam and Graham, 2009 for example) suggested by various researchers indicates that most of these equations do not include all these parameters (σ_f, K_{1C}, E, u, B, h).

HOW CAN WE APPROACH TO SOLVE THE ISSUE - Not including all these terms - the strain-rate (u/h or u/B) term or velocity (u) term, aspect ratio term (B/h), and terms for material properties of ice (σ_f, K_{1C}, E) - in any equation for estimating ice-induced pressure, will make it inadequate, incomplete and inaccurate. A predictive equation for ice-induced pressure on structures to be adequate, complete and potentially accurate all these terms should properly be accounted for.

In classical analyses, it is well established that dimensionless form of representation of dependent variable and independent parameters would help in understanding the physics of the problem being studied (Langaar, 1951; Pankhurst, 1960; Taylor, 1974; Sharp, 1981; Barenblatt, 1987).

WHAT CAN WE DO - So, if we include all these effects (strain-rate effects, u/h or u/B; aspect ratio effects, B/h; material properties effects) in dimensionless form for estimating ice-induced pressures on structures, we can hope to potentially eliminate or at the least we can reduce the level of uncertainty. If there is some potential for such an opportunity, (1) how do we introduce strain-rate or velocity effect in dimensionless form, in any equation for estimating ice-induced pressure on structure, and how do we quantify the level of influence of strain-rate term or velocity term, in non-dimensional form (Arunachalam, 2005; Arunachalam and Graham, 2008)? In other words, how can we make velocity term as a dimensionless parameter? (2) How do we have a non-dimensional pressure term? (3) How do we have non-dimensional terms for various material properties recognizing that material properties are influenced by strain-rates? (4) How do we analyze the experimental data in the context of dimensionless parameters?

THE SCOPE OF THE PAPER - In continuation of earlier analyses of experimental data, (Arunachalam, 2005; Arunachalam and Graham, 2008), a large number of model test data, medium scale and full scale test data have been analyzed in the context of dimensional analysis and similarity concepts. The dimensionless pressure has been expressed as a function of dimensionless parameters (aspect ratio, dimensionless velocity, and dimensionless material properties). It is shown that all these factors - aspect ratio, dimensionless velocity, and dimensionless material properties - influence dimensionless ice-induced pressure. Using this approach it is shown that we can develop an adequate, complete and potentially accurate equation for estimating ice-induced pressure on structure and reducing the level of uncertainty. The presentation of a more accurate equation for ice-induced pressure on rigid vertical structures is just one more step away.

129 *Seabed and Iceberg Scour Conditions Affecting a Potential Pipeline Landfall Offshore Labrador*

Authors: Tony King and Gary Sonnichsen

Since 2003, the Makkovik Bank region of the Labrador Shelf has been the subject of ongoing efforts to characterize the iceberg scour regime using multibeam seabed surveys in order to determine the risk ice scour would pose to future development of natural gas reserves in this region. Over 4 tcf of natural gas has been identified on the Labrador Shelf during exploration activities between 1973 and 1984, with 3.1 tcf at the Bjarni and North Bjarni sites on the Makkovik Bank. A development study conducted in 1983 identified Cape Harrison as a potential landfall location of a pipeline from the Bjarni/North Bjarni sites. In 2007, a multibeam seabed survey was conducted by the Canadian Hydrographic Service of the Cape Harrison site to assess some of the assumptions made in the 1983 study, namely the presence of a sheltered channel in the inner shelf that allows a pipeline to be routed to landfall free of exposure to iceberg scour. Some assumptions on the trenchability of sediments along a potential pipeline route can be made from 3.5 kHz subbottom profiler data collected concurrently with the multibeam data acquisition. The acoustic data documents a range of seabed types nearshore including indurated bedrock exposures, discontinuous glacial diamict deposits, and fine-grained unconsolidated sediment infill in channels incised into the underlying bedrock. While the 2007 survey did indicate the presence of a largely continuous, offshore to nearshore channel at the site, some iceberg scour features were noted at the entrance to the channel and within the channel itself. Subsequently, the multibeam data were analyzed to extract iceberg scour metrics. These data were reviewed and assessed. Distributions of furrow and pit length, width, depth and other relevant parameters are presented, as well as spatial variations in these parameters. Iceberg scour rates are assessed using observed scour density and an iceberg grounding model. The paper presents an overview of substrate conditions, iceberg scour risk and burial depth requirements for a pipeline making landfall at Cape Harrison.

3. Ice

3(a) Mapping and Dynamics

Day 1, Endeavor Room, 1120-1220

163 ***Mapping Sea Ice Overflood Along the Alaskan North Coast***

Authors: David Dickins, Greg Hearon, and Kim Morris

This study was commissioned by the U.S. Department of Interior, Minerals Management Service (MMS), Alaska Outer Continental Shelf Region to map the extent of peak river overflooding along the Beaufort Sea coast. River overflood on the sea ice occurs annually in this area during a brief period in the spring when river break-up precedes the break-up of the fast ice. River overflood constitutes a potential hazard to offshore oil and gas development, as it relates to facilities access, oil spill spreading, and the associated phenomena of strudel drainage and potential seabed scouring impacts on marine pipelines. The overall goal of this study was to improve the knowledge of the spatial and temporal variability in overflooding aimed at making better assessments of hazards for future developments in the nearshore. Methods included 1) comparison of different satellite platforms with traditional helicopter surveys during a 2007 field program off the Colville Delta; 2) acquisition of visible and SAR imagery covering the maximum seaward extent of river overflood from Smith Bay to Camden Bay over a 13-year period between 1995 and 2007; 3) mapping maximum overflood boundaries using composites of satellite imagery and historical helicopter surveys; 3) interpreting industry-supplied databases in terms of zones of strudel scour potential; and 4) combining all of the overflood and strudel mapping information into a GIS database.

Results clearly showed that helicopter surveys timed to follow shortly after the peak overflood can be used to map the annual overflood limits with the greatest accuracy under most conditions. Overflood boundaries derived from satellite imagery can approach this accuracy under favorable conditions but timing and cloud cover constraints can severely limit the number of useable scenes. The long-term mapping in this study relied on a combination weather independent SAR imagery and historical helicopter surveys. Eleven major river systems were mapped for 129 out of 143 possible river and year combinations – a mapping success of 90%. Strudel scour frequency and severity were segregated into zones according to water depth, with the Primary zone from the bottomfast ice boundary to the approximately 6 m water depth accounting for 32% of the total average overflood area. This type of information can be used to assess the risk to prospective pipeline routes posed by strudel scouring in different coastal areas.

166 ***On the Spatial and Temporal Characterization of Motion Induced Sea Ice Internal Stress***

Authors: Jennifer Hutchings, Cathleen Geiger, Andrew Roberts, Jacqueline Richter-Menge, and Bruce Elder

We investigate sea ice deformation observed with GPS-instrumented ice drifting buoys deployed during late winter through summer in the Beaufort Sea. The Sea Ice Experiment: Dynamic Nature of the Arctic (SEDNA) was designed to investigate the relationship between strain-rate, stress and thickness redistribution of Arctic pack ice. In this presentation we focus on one of the four objectives of SEDNA: "Characterize the relationship between, and coherence of, stress and strain rate at 10km and 100km". Two nested arrays of six GPS buoys each, which were deployed in late March 2007 served as a backbone for the experiment. The two arrays were hexagons with initial widths of 140km and 20km. We assess the scaling relationship between strain rate and the ice area over which the strain rate is measured. Our findings demonstrate localization of strain-rate, with increased variability in the strain rate with finer spatial resolution. We find emergent coherence of deformation, related to the wind forcing, over synoptic and longer length/time scales. There are changes in strain-rate power, and coherence, across scales related to the passage of weather systems. During quiescent, anti-cyclonic, periods there is more power at the small scale. With the passage of cyclones there is enhanced power at the large scale. This can be related to increased convergence of the ice pack during cyclones, and hence longer length scales over which the ice field is connected and internal ice stress can build up, resulting in an increased magnitude of deformation over increased length scale. Coherence of strain rate between the two arrays is investigated with cross wavelet analysis. This shows an evolution in the coherence, which is probably related to disconnection in the ice pack, at the onset of spring, reducing stress transfer through the pack. We find stress measured at a point in the ice pack is related to the dynamic loading (from weather) on the pack, and thermal stresses, with coherent stress between buoys over fortnightly periods prior to break-up. Finally we present a coordinated strain-rate and in-situ measured stress time series, and investigate the relationship between strain-rate (at two spatial scales) and internal ice stress. Our investigation provides insight of the synoptic conditions and break-up events that lead to reduced internal ice stress, which could aid in logistics planning for the ice covered Beaufort.

139 ***Using Position Beacons to Measure Ice Movement for Beaufort and Chukchi Offshore Petroleum Activities***

Author: Scott Tiffin, Roger Pilkington, Merv Edgecombe, and Dave McGonigal

Measuring the movement of different types of sea ice in the Arctic is critical for offshore petroleum operations, marine transport and public regulation to mitigate global warming. Beacons using GPS and satellite transceivers are useful to study: drift and disintegration of ice islands and multiyear hummock fields over several years; microdisplacement of shore fast ice; incursions of different ice types into potential shipping lanes; movement of pack ice over wellsites and into seismic exploration areas; drift of oil spill plumes under ice; and ice loads on structures. There are a variety of instruments available on the market for using different locational and transceiving technologies which function in different regimes of ice and water. Extreme temperatures, remote locations, dynamic ice and marine environments, snow cover, polar bears and arctic foxes all impose significant design constraints and limit the functionality on these instruments, often in ways that the manufacturers are unaware or simply cannot cope with yet. Delivery by air or surface is expensive and sometimes involves hazardous operations. Beacons are often best used in some combination with satellite imaging; lessons from recent projects are suggested in how to optimize this complementary use in terms of minimum cost, operational reliability and completeness of data acquisition. New beacons are coming on the market with radically improved accuracies, functionality and lower cost. New developments in power supplies, software and miniaturization of senors also offer the possibility of developing more complex instruments with additional sensors which can be air dropped or delivered by drones. The trend to more complete, robotic systems is driven not only by technological opportunities and lowering costs, but by increased concerns of operators about safety to personnel.

3(b) Monitoring

Day 2, Endeavor Room, 1020-1120

126 ***Supporting Arctic Operations with Real-time Ice Information from Satellite Images***

Author: Richard Hall

The increase in human activity in the Arctic region has led to a rise in the need for improved management, monitoring and surveillance of the region. The weather conditions may change quickly and dangerously, while the presence of sea ice poses an increased risk to ships and platforms. For these reasons, the need for frequently updated information (ice edge, icebergs, and ice floes, wind and wave conditions) has increased.

In addition, as human activity increases so to does the risk of contamination from an industrial accident, such as an oil spill from a sinking ship, to the local ecosystem increase with detrimental consequences.

The sinking of a ship is the worst case scenario. Any accident will be in a remote and inaccessible location, and this will hinder the planning and execution of any rescue operation. Therefore real-time knowledge of where ships are, and the ice conditions in the surrounding area are vital.

This presentation will firstly demonstrate how real-time information about the sea ice conditions, together with ship positions and environmental data can be made quickly and easily available to the relevant people so that accidents can be prevented and if not then the best available information is easily accessible to allow a fast rescue response.

Secondly, the presentation will demonstrate how ice objects, both floes and icebergs, either within the ice-pack or in open water can be automatically tracked over a period of time. The ITSARI (Iceberg Tracking Using SAR Images) algorithm, originally developed to track icebergs in the Antarctic, has been adapted to track individual sea ice floes in Arctic conditions. Ice floes are identified and tracked using brightness values and shape characteristics. The algorithm has also been adapted to detect the fast ice edge and pack ice edge.

The results will illustrate the successful tracking of ice objects in the Fram Strait using 10 Envisat ASAR wide-swath images over a 13-day period in February 2008, together with examples of the detailed detection of the ice edge.

The tracking of the ice floes within the pack allows an improved understanding of the dynamic forces within the ice-pack, and can provide a valuable real-time input in managing the ice around a platform.

150 ***Automated Detection of Hazardous Sea Ice Features from Upward Looking Sonar Data***

Authors: David Fissel, Anudeep Kanwar, Keath Borg, Todd Mudge, John Marko, Adam Bard

Starting in 1996 for oil and gas applications in Sakhalin Territory, Russia, upward-looking sonar (ULS) instruments have become the primary source of data for extended measurements of sea ice thickness, to accuracies of 0.05 m, as well as for detailed characterization of keel shapes and other ice features. ULS instruments, in the form of ASL's Ice Profiler, have the data capacity and accuracy/resolution sufficient for unattended operation for periods of up to three years. When combined with a companion Acoustic Doppler Current Profiler (ADCP) to measure ice velocities, the instruments provide horizontal resolution as good as 0.5 m. The combined ice thicknesses and ice velocities, measured along thousands of kilometers of ice which typically move over each moored ice profiler location, provide important data for establishing metocean design criteria related to oil and gas operations in areas with seasonal or year-round ice cover. Hundreds of ice ULS deployments have been made with these instruments in the ice infested areas of the northern and southern hemispheres. In recent years, real-time measurements of ULS instrument arrays have been developed and operated in support of shipping and offshore oil and gas exploration. For these applications, there is a need for automated detection of hazardous sea ice features which are embedded within the thousands of kilometers of sea ice passing the measurement site. This paper describes the development of algorithms for the detection and measurement of hazardous ice features including: large individual ice keels with thicknesses of 5 to well over 20 m; long sections of thick rubbled and hummocky sea ice; and occurrences of multi-year ice floes. Large individual ice keels are detected using an ice draft threshold technique to identify very thick ice floes which are then categorized as to total width using a Rayleigh criteria and/or a minimum user-specified threshold value (e.g. 2 m). The detection of thick hummocky ice is based on minimum criteria of ice draft data segments having median values exceeding 2.5 m and segment lengths exceeding 100 m. For qualifying segments, a selection parameter γ, defined as the 90th percentile over the 50th percentile value of ice drafts divided by the standard deviation was computed; hummocky ice is characterized by $\gamma > 2$ and is also very common for $1.5 < \gamma < 2$. Results from the ongoing algorithm development for detection of multi-year ice features will also be discussed.

185 ***Training Courses for Ice Experts as Ice Observers and for Interpretation of Satellite Images to Support Arctic Shipping Operations***

Authors: Graham Thomas, Yevgeny Mironov, Vladimir Smirnov, and Valery Stepanov

Two training courses for training ice experts were developed, arranged and delivered in a joint programme between AARI and BP. In 2007 a course for the training of ice experts–ice observers was developed, and the training of three groups of trainees (39 persons) was carried out in 2007 and 2008 at the Arctic and Antarctic Institute (AARI). Subsequently, practical training for two smaller groups of AARI specialists on board icebreaking vessels was completed in 2008 and 2010. In 2009, a course for training ice experts in the interpretation of satellite images of sea ice was developed and delivered to 16 trainees at AARI.

4. EER

4(a) EER Procedures

Day 2, Discovery Ballroom, 1120-1200

167 ***Traffic and Casualty Trends in Canadian Arctic Shipping***

Author: Brad Judson

Significant research on Arctic sea ice trends and the potential for resource development have been well documented and illustrated as drivers for changes to Arctic shipping traffic patterns. There is a strong awareness of the potential risks to the environment such as an oil spill in ice as well as impacts on traditional human activity. Similarly, there is awareness that there will be a demand for increased navigation services such as aids to navigation, charting and emergency response capacity. However, many questions remain about what impact sea ice trends and resource development have had on shipping and accidents. To date, the Arctic Marine Shipping Assessment (AMSA) project has provided a snapshot of Arctic shipping traffic patterns and activity for the year 2004 and suggests a further research opportunity exists to conduct a trend analysis of shipping activity. The AMSA report suggests that "As marine activity continues to expand in the Arctic, statistical trends indicate that the potential risk of vessel mishaps and marine pollution incidents also increases" (Arctic Council, 2009). However, this is not necessarily the case where risks are managed. Accident trends in the Canadian Arctic suggest that safety management, vessel design and navigation experience have had positive impacts and one must look more closely at specific areas of operation, vessel types and activity to identify opportunities to improve risk management including both prevention and response. So the question remains "What can we learn from recent trends in vessel traffic and accident rates to better understand potential navigation impacts in the future?" Using the AMSA Shipping Database (Arctic Council, 2009) and a spatial trend analysis of Canadian Arctic shipping traffic and vessel accident rates covering the period 1987 to 2008, this paper will report on preliminary findings, show where accident rates are increasing and decreasing, provide traffic trends for each Shipping Safety Control Zone, help to dispel a few myths, and possibly confirm other rumours.

108 *Arctic Offshore Escape, Evacuation, and Rescue Standards and Guidelines*

Authors: Jim Poplin and Frank Bercha

This paper summarizes recent developments in Arctic Escape, Evacuation, and Rescue (EER) standards and guidelines, and describes the ISO 19906 Arctic Offshore Structures Standard that will supersede most existing Arctic EER guidelines and standards worldwide. Arctic EER has received significant attention with the current resurgence of interest in Arctic offshore hydrocarbon reserves, marine tourism and shortening marine transportation routes. Additionally, recent incidents involving the Explorer in the Antarctic, and the proliferation of both industrial and tourist activity in ice covered waters predicate a need for suitable reliable emergency systems and procedures for these operations.

Since 2000, Transport Canada has supported the Arctic EER research project for which the second author's company has been the lead contractor. The research conducted under this program resulted in the development of performance-based standards for offshore petroleum installations and a computer model capable of assessing the reliability and performance of EER processes. Once developed, the initial open water standards were transmitted to the Canada-Newfoundland Offshore Petroleum Board (CNOPB) and the Canada-Nova Scotia Offshore Petroleum Board (CNSOPB) and have now been partially adopted as guidelines for EER. The standards were subsequently expanded to cover Northern and Arctic offshore installation operations, and an integrated set of standards, applicable to both open water and ice covered water were developed and published in 2007.

The ISO, under Working Group 8, developed a Final Draft International Standard addressing Arctic Offshore Structures which is expected to be published in late-2010. The Standard addresses design requirements and assessments for Arctic offshore structures used by the petroleum and natural gas industries worldwide to help ensure that appropriate reliability levels are achieved for manned and unmanned offshore structures, regardless of the type of structure. The Standard also addresses issues such as EER that go beyond design, construction, transportation, installation and decommissioning of the structure as these issues are critical to the safe operation in arctic conditions and are not covered in other ISO Standards. The EER provisions of the Standard are intended to promote the successful escape from the incident, subsequent evacuation from the installation (emergency or precautionary evacuation), and the ultimate rescue of installation personnel. The EER provisions are performance-based. The Standard specifies design requirements and also provides background to and guidance on the use of the document.

4(b) EER Crafts 1

Day 2, Discovery Ballroom, 1350-1450

103 *Operational Limitations of Conventional Lifeboats Operating in Sea Ice*

Authors: Allison Kennedy, António Simões Ré, and Brian Veitch

Increased Arctic activity has led to a growing number of conventional lifeboats being used in ice environments. Conventional lifeboats have not been designed to withstand ice impact loads. It is currently uncertain if these boats have the structural capacity to withstand a collision with ice, or if they have adequate power to drive through concentrated pack ice. The main objective of the research reported here is to determine the structural limitations of conventional lifeboats in order to help devise safe operating procedures for lifeboats in ice.

Three sets of experiments were carried out to gather data required to inform the problem of conventional lifeboats operating in ice. Material testing was conducted on lifeboat fiberglass to determine its strength limitations. Laboratory testing of full scale ice impacts was done to determine controlled impact force values. Full scale field testing was completed to obtain insight regarding realistic loading magnitudes and contact areas.

Material tests indicated the maximum pressure of a 76×76 cm fiberglass lifeboat panel to be approximately 900 kPa. This was the largest panel tested, and is representative of a significant portion of the hull bow area. The maximum pressure arose from an applied force of nearly 33 kN. Laboratory ice impact tests, in which ice spheres were swung into the full scale lifeboat, resulted in impact forces on the order of 40 kN. The field tests measured low impact force values in comparison to the laboratory tests. Maximum impact loads recorded during field trials were on the order of 10 kN. Both the laboratory and field test results were used in the development of a simple energy model representing a conventional lifeboat operating in ice. This model can be used to predict impact forces for different ice strengths and impact locations along the hull.

There are a number of possible practical outcomes from this research. Lifeboat design methods could be improved, new regulatory guidelines could be introduced to assist lifeboat manufacturers, and the insight into operational considerations could also be incorporated in lifeboat training as a practical means of knowledge transfer.

154 *Thermal Requirements for Surviving a Mass Rescue Incident in the Arctic: Project Update*

Authors: Renee Boileau, Michel DuCharme, and Lawrence Mak

The search and rescue community estimates that passengers on cruise ships and aircraft in the arctic could expect to wait days for rescue, depending on weather and availability of large rescue craft. Present standards including SOLAS do not differentiate emergency equipment for arctic and warmer, less-remote regions. Typically a large group of survivors will have to depend on the contents of SOLAS lifeboats and immersion suits or the MAJAID (MAJor AIr Disaster) kit and personal clothing to maintain their body temperature until rescue equipment with sufficient capacity arrives.

Marine and Arctic Survival Scientific and Engineering Research Team "MASSERT" is a group from industry, government and academia working together to recommend equipment and changes in standards that will enhance the health and safety, performance and emergency survival for people working and traveling in the Arctic.

The team is conducting a 3-year study funded through Transport Canada and SAR NIF and in-kind contributions from MASSERT members. The study includes 3 phases. In phase 1, conducted in winter 2009/2010, two thermal manikins were used to measure thermal insulation for clothing ensembles typically available to cruise ship and airline passengers in an emergency, including cabin wear, thermal clothing, SOLAS immersion suits and parkas supplied with MAJAID kits. The tests were conducted in simulated arctic conditions in a cold chamber with large fans and a sub-zero environmental chamber. A sweating hotplate was used to estimate heat loss through wetted garments. In phase 2 (summer 2010), human subjects will be exposed to low temperature for 24 hours to determine whether shivering is a sustainable activity, given typical emergency rations. Metabolic activity will be measured using heart rate monitors, periodic EMG, blood tests, a metabolic cart et al. Cognitive tests will also be performed. The results from phases 1 and 2 are being used to validate thermal models for predicting long term heat loss and survivability in arctic conditions. In phase 3, planned for spring 2011, heat loss will be compared in human subjects exposed to simulated arctic conditions in a lifeboat or MAJAID tent. These subjects will be dressed according to current standards or the recommendations arising from Phase 1 and 2. The final report will provide information to drive changes in existing standards.

180 ***Lifeboat Habitability and Effects on Human Subjects***

Authors: Jonathan Power and António Simões Ré

Lifeboats are the most used marine evacuation craft in both the shipping and offshore industries. The International Maritime Organization (IMO) Lifesaving Appliances (LSA) code does not have criteria for the manoeuvring performance of lifeboats nor for their habitability and effects on human subjects.

Standard seakeeping exercises were conducted with a SOLAS approved 20-person lifeboat in Conception Bay, NL by NRC employees wearing certified immersion suit systems. During the seakeeping exercises, skin temperature, deep body temperature, and heart rate were measured on the coxswain and assistant while they were performing their assigned duties.

During the morning of July 24th, 2009, the outside air temperature was 14°C, water temperature was approximately 7.6°C, with little to no cloud cover. While piloting the lifeboat with the hatches closed, the interior temperature of the lifeboat rose from 19.4°C to 28.5°C over the course of approximately two hours. With the immersion suits fully zipped, the coxswain experienced an increase in mean skin temperature of 3.4°C, while the assistant's rose by 2.7°C. The coxswain's mean body temperature rose by 0.74°C, and the assistant's by 1.0°C. After the two-hour time period, both the coxswain and assistant's clothing were heavily soaked with sweat, and both reported moderate levels of thermal discomfort due to the heat.

In the afternoon of July 24th, 2009, the outside air temperature was 15°C, water temperature was 8.78°C, with little to no cloud cover. For these series of trials, the lifeboat hatches were left open, and the immersion suits were unzipped. Over a two-hour period, the interior temperature of the lifeboat rose by only 0.2°C, the coxswain's mean skin temperature rose by 0.5°C, and the assistant's by 0.5°C. After the two hour afternoon session was completed, both the coxswain and the assistant reported little to no thermal discomfort with the interior temperature of the lifeboat.

Based on these preliminary observations, prolonged occupancy of a sealed lifeboat with a high level of clothing insulation may lead to increased thermal stress on the passengers.

4(c) EER Crafts 2

Day 2, Discovery Ballroom, 1510-1550

171 ***ARKTOS Evacuation Craft for Beaufort Sea Shear Zone Operation***

Authors: Terry Hall and Bruce Seligman

The ARKTOS Evacuation Craft has been the primary means of emergency evacuation on Arctic and Caspian Sea bottom founded oil exploration and production facilities for over 20 years. Existing offshore oil developments in the North Slope of Alaska use gravel islands and are located well within the land-fast ice area, which extends between the coastline and the barrier islands and up to a few thousand feet beyond.

Oil production strategies beyond the Beaufort Sea Shear Zone, where the polar pack and land-fast ice meet, are currently being developed. The Shear Zone is formed by the moving polar ice pack shearing against the inshore ice that is held fast to the coastal seabed and the shore. A long lead can open at this interface, forming an area of open water that expands or contracts, depending upon the prevailing winds. Large, irregular ice features can also be formed as a result of the shearing action.

One of the areas of concern for any development beyond the Shear Zone is Escape, Evacuation, and Rescue (EER) capability, due to the extreme environmental conditions that will be encountered. In response to a major oil company initiative, a conceptual design for a 75 person ARKTOS Amphibious Evacuation Craft suitable for operation in this region has been developed.

This paper describes recent advances in ARKTOS Craft technology and new conceptual design features that were developed specifically for the Shear Zone Craft such as increased Craft width and extended track carriages, increased waterjet thrust, self-righting capability, improved vertical ice step climbing capability, hydrostatic drives for improved track performance, fire resistant hull and track material, and davit launching from a production platform onto ice or into open water.

143 ***Effect of Simulator Training on Novice Operators' Abilities to Navigate in Ice***

Authors: Stephanie Power, Jonathan Power, Scott MacKinnon, and António Simões Ré

As shipping and oil and gas industry move further into Northern and Arctic environment, comprehensive plans for EER training need to be developed to include material covering situations in ice-covered waters. Specifically, the training for coxswains for Totally Enclosed Motor Propelled Survival Crafts (TEMPSC) currently holds no information about dealing with sea ice navigation. Delivering training in a safe environment can be very challenging. Simulation training has risen in popularity in the last number of years, mainly in the aerospace and medical industries. Virtual Marine Technologies (VMT), a company in St. John's, NL Canada has developed a full mission simulator with the ability to provide a safe environment for Standards of Training Certification and Watchkeeping (STCW) lifeboat coxswain training in ice–covered waters. The authors examined current STCW training, along with STCW training with an in-class ice briefing and finally training that took place in a full mission simulator with 24 participants. The three training groups – of 8 participants per group- were then put through an simulated ice field of floating -obstacles, set up to mimic 2 $^{1/10ths}$ ice concentration. This was done to attempt to validate the training VMT had developed. In this paper, background information, methodology, discussion, results, conclusion and application will be presented to share the findings of the study.

5. Shipping and Shipping Rules

Day 2, Endeavor Room, 1510-1550

101 ***Canadian Arctic Shipping and Emission Assessment***

Authors: Ernst Radloff and Bohdan Hrebenyk

The changing Arctic environment is a significant consideration in the forecast of future marine vessel emissions stemming from the potential increase in natural resource extraction and inter-and intra-Arctic shipping. The Transportation Development Centre (TDC) of Transport Canada has carried out an emission inventory study for marine vessels operating in Canadian Arctic. The inventory comprises a baseline assessment for the years 2002 to 2007, and forecasts to 2010, 2020 and 2050. The inventory utilizes a bottom-up vessel activity-based approach consistent with current best practices, and was completed using the Marine Emission Inventory Tool (MEIT). The forecasts were based on expected population growth and economic activities in the Arctic, within six regions of the Canadian Arctic. Also taken into consideration are the changes and projections for the Arctic environment, specifically when and to what extent the ice may (will) recede allowing for increased vessel access to the Arctic. Due to uncertainty

about future economic activity in the region, the forecast for 2050 is provided with low, medium and high activity assumptions.

The forecast shows that by 2050 a significant increase in GHG and emissions of criteria air contaminants (CAC) can be expected to occur due to an increase in intra-Arctic shipping linked to resource extraction and eco-tourism. This translates into a five-fold increase for both CO2 and NOx, as well as significant increases in other CAC, especially if large-scale gas production occurs in the western arctic region of Canada. The emission forecast also includes several regulatory scenarios such as the designation of the Arctic as an Emission Control Area (ECA) and the harmonization with EPA and IMO Marpol regulations for marine fuel and engine emission standards, which would have the potential to lower CAC emissions.

148 *Future Possibilities for Trans-Arctic Shipping through the Central Arctic Ocean*

Authors: Robert Tustin and Mikko Niini

The paper will consider future possibilities for the development of Trans-Arctic shipping using very large ships operating on direct routes through the Central Arctic Ocean, in offering opinions of these future possibilities it is not intended to promote specific design concepts, or engineering solutions as such, rather it is the intention of the authors to promote discussion and debate at ICETECH 2010 on the prospects for Trans-Arctic shipping.

Demonstration voyages for Trans-Arctic operations, as well as feasibility studies and design concepts for future Trans-Arctic shipping, will be considered from the perspective of two possible routes;

- The historical perspective, for Trans-Arctic shipping which had, until very recently only considered coastal voyages within the Russian Northern Sea Route, as an extension of the transportation system established on the NSR during the Soviet era.
- Recent feasibility studies for Trans-Arctic shipping routes which envisage deep water voyages of very large ships using the Central Arctic Ocean route.

Feasibility studies, and ship design concepts, developed for Trans-Arctic ship designs will be compared in the paper, to highlight the trend towards an increase in size from the existing Polar cargo vessel fleet to very large concept ship designs considered in recent feasibility studies.

The paper will consider some of the technical and regulatory drivers for consideration of the Central Arctic Ocean route for Trans-Arctic shipping including;

- Changes forecast and seen for the Arctic ice cap.
- Regime of icebreaker assistance and regulations in place in the Northern Sea Route.
- Ramifications of environmental impact regulation and concerns on coastal trading Trans-Arctic vessels.
- Consideration will also be given to the expected impact of planned GHG emission regulations and how these regulations may affect the design of future concepts for "*Green*" Arctic Ships.
- Development of larger Arctic Ships, with higher power, and independent navigation ability

These technical and regulatory drivers will be summarised in concluding remarks offered to the conference for discussion and debate.

6. Various

Day 3, Endeavor Room, 1120-1220

175 *ARKTOS Amphibious Oil Spill Response Craft for Mixed Ice/Water Conditions*

Authors: Bruce Seligman and Terry Hall

ARKTOS Amphibious Craft have the ability to assist in oil spill clean-up by transporting oil spill equipment and their operators in shallow water, in mixed ice and water, in mud and other soft surfaces. ARKTOS Craft can also operate in all weather conditions including extremely hot or cold temperatures.

This paper describes a conceptual ARKTOS Amphibious Oil Spill Response Craft with special consideration of amphibious ice conditions. Areas considered in the paper will be amongst other things:

1. Detection, monitoring and groundtruthing (direct assessment) in amphibious situations.
2. In-situ Burning and potential fire fighting (with a deck mounted spray monitor) if needed. This same deck mounted spray monitor could also assist by herding an oil slick.
3. Chemical applications (dispersants). Including dispersant mixing mode with tracks and waterjets.
4. Towing oil containment booms in any conditions.
5. Mechanical counter-measures (oil skimming).
6. Transporter/Carrier (equipment and operators).

The engineering of these capabilities and their effect on the stability of the Craft will be challenging and some of the most obvious challenges will be discussed in this paper.

152 *Assessment of Lifeboat Laminate Strength*

Authors: Peter Gifford and Allison Kennedy

Lifeboat performance in ice is a relatively unknown area of research which has a growing industrial and commercial application. The objective of this study was to assess the material strength of conventional lifeboat composites and to examine the effect that certain factors have on the strength, using methods of design of experiments. The research was a direct response to the growing need for information pertaining to the performance of lifeboats in ice infested waters. A literature review revealed a lack of information describing the strength of actual lifeboat laminates.

Evaluating the strength of lifeboat laminates was completed through two test programs. The first focused on assessing the tensile strength while the second examined the impact strength. The tensile strength was analyzed by conducting a set of tensile tests to ASTM standards. The impact strength was studied by completing hydraulic ram tests on laminate panels. The factor selection was based on two principles. The first was to quantify the effect of factors that have proven to influence composite strength. The second was to assess how alternative construction methods could improve the hull composite strength.

The tensile tests indicated that heat-treatment and pre-stress both significantly affect the tensile strength of fiberglass. The tests resulted in an ultimate tensile strength of approximately 140 MPa for un-treated, room-temperature fiberglass. The impact strength analysis indicated that laminate thickness, temperature and material type significantly affect the ultimate panel impact force. The maximum impact force for a conventional lifeboat laminate

was found to be 75 kN, while the ultimate impact energy was found to be 1350 J.

Defining the strength characteristics could aid in the numerical modeling of a conventional lifeboat. A mathematical model could be used to numerically predict lifeboat performance as a result of ice impact. The results could also steer the design of a lifeboat that is structurally adequate for ice operation. Another possible outcome is that the information pertaining to factor effects could be used to guide regulators regarding appropriate lifeboat storage and maintenance procedures.

187 ***Arctic and Northern Offshore Oil Spill Probabilities***

Author: Frank Bercha

Current catastrophic consequences of the Gulf of Mexico blowout have refocused interest on the probabilities of such events in both temperate and northern regions. This paper reviews some of the early studies on oil spill probabilities with emphasis on oil blowouts, and details more recent studies carried out specifically for the Alaskan OCS. Due to the embryonic state of offshore oil development in arctic regions, which has been the case since 1976 to the present, it is not possible to base oil spill probability estimates on empirical data. The early studies relied on a detailed fault tree analysis dealing with the operations as systems without history. More recent studies in northern but not arctic operations use world wide data as a starting point. In the recent and current Alaskan OCS studies, statistically significant non-Arctic empirical data from the US Gulf of Mexico and world-wide sources, together with their variance, were used as a starting point. Next, both the historical non-Arctic frequency distributions and spill causal distributions were modified to reflect specific effects of the Arctic setting, and the resultant fault tree model was evaluated using Monte Carlo simulation to adequately characterize uncertainties treated as probability distribution inputs to the fault tree.