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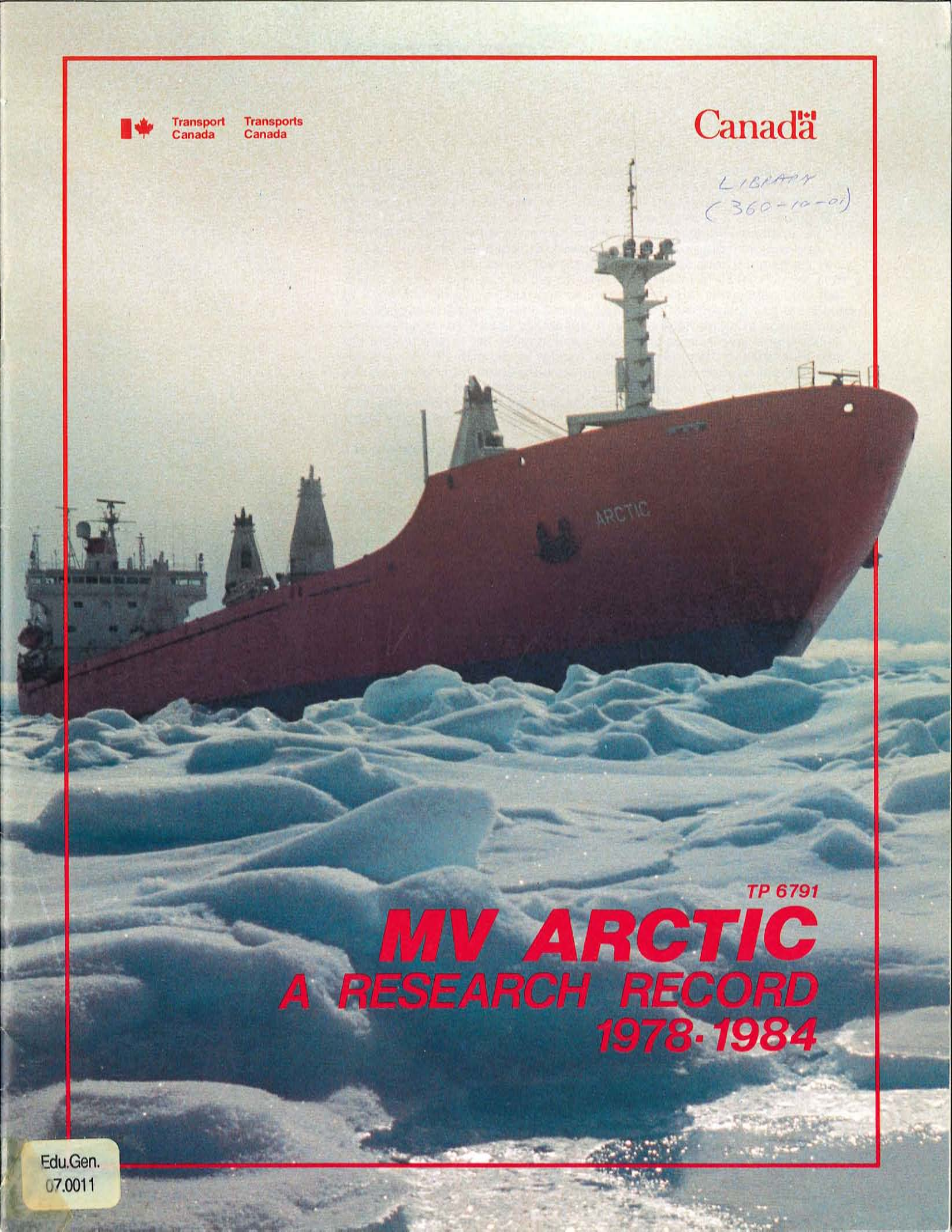

TP 6791

MV ARCTIC
A RESEARCH RECORD 1978-1984

Acknowledgements

This brochure has been prepared to coincide with a special seminar on the MV ARCTIC held in Montreal on September 16-17, 1985. It reflects the research performed on, with or in respect of the MV Arctic since her delivery in 1978. This research program is the result of a partnership of interested participants whose efforts have developed a Canadian competence in arctic regulatory knowledge, ship research technology and operations. The success of the research endeavour over the past six years is also due in large part to the officers and crew of MV ARCTIC, the staff of Canarctic Shipping Company Limited, Northwater Navigation Ltd., the Transportation Development Centre, Canadian Coast Guard and the Marine Administration of Transport Canada. It is also appropriate to acknowledge the critical role of the officers and crew of Canadian Coast Guard escort vessels, and the officials of related federal government departments. The private sector contribution has been extensive both through the consulting community and the service sector. In both cases the exchange has been mutually beneficial and has placed Canada at the forefront of commercial arctic shipping technology.

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Introduction

This brochure was prepared to coincide with a special seminar held in Montreal September 16 and 17, 1985, to present to the Canadian marine community the results of research performed over the first six years of the life of Canada's only Arctic Class 2 icebreaking bulk cargo vessel — the MV 'Arctic'. The brochure is designed to provide a capsule summary of (and index of references to) all major research performed by Transport Canada, and other agents of the federal government, on, in respect of, or otherwise relevant to the MV 'Arctic' or Canarctic Shipping Company Limited.

The material in the brochure has been organized to provide the Canadian marine industry with an overview of key aspects of the MV 'Arctic' research program. In presenting this information, it is also Transport Canada's objective to alert the industry to the extent of the Canadian knowledge base and to the worldwide leadership we enjoy in commercial arctic marine transportation. It is also our conscious objective to encourage the submission of new proposals from the private sector for specific research involving the MV 'Arctic', in order to further develop the potential for Canadians to participate in all aspects of future arctic resource development.

There are two compelling factors which underlie Canada's resolve to make possible safe and reliable access to our arctic regions. The first is economic. Valuable resources lie beneath our arctic lands and ice-covered waters. They are by definition difficult to obtain, and even more difficult to transport in practical and reliable ways. The second relates to the exercise of sovereignty — the control of our lands and waters.

The recent decision to upgrade the MV 'Arctic' is one example of our strong desire to maintain Canadian competence and leadership in commercial arctic navigation, while encouraging Canadian ship operators to develop "self-serve" capability in selected areas of arctic marine operations. The Bent Horn (Cameron Island) demonstration project illustrates Canada's capability to provide skilled crews and commercial vessel capacity.

In addition, current operations in arctic waters allow the expansion of Canadian competence in arctic navigation and ship design technologies. This competence is a stepping stone to future opportunities, and the MV 'Arctic' is one instrument in the development of those opportunities.

Ship Bio

Historically, arctic shipping has taken place in the "open-water" season. More recently, and in compliance with the Canadian Arctic Waters Pollution Prevention Act (AWPPA), ships have begun to navigate in an extended season. As the economics of arctic development become more favorable, a fully extended season, including navigation in the most rigorously controlled zones, is anticipated.

In 1975, the Government of Canada agreed to participate with a group of shipowners and shipbuilders in the construction of an Arctic Ice Class 2 icebreaking cargo ship. The Canarctic Shipping Company Limited was established as the operating agency. Canarctic Shipping is a consortium of the federal government, acting through the Marine Transportation Administration of Transport Canada, and North Water Navigation which, in turn, is a consortium of private sector shipping companies including Federal Commerce and Navigation, Upper Lakes Shipping and Canada Steamship Lines.

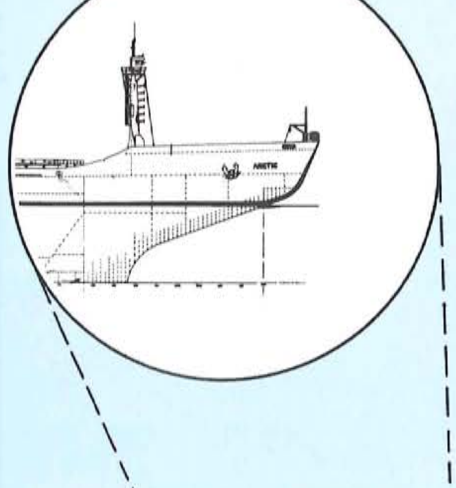
The MV 'Arctic' was designed specifically for arctic operations, and in particular the export of lead and zinc concentrates from the Nanisivik minesite on Baffin Island to European markets. She was built to Seaway specifications at Port Weller Dry Docks in 1978. She is a 28,000 deadweight tonne (dwt) dry bulk cargo vessel, and can transport ores, mineral concentrates grains and other bulk cargos as required. She has a loaded displacement of 38,100 tonnes, and is powered by a single MAN marine diesel engine which develops 14,770 bhp. The vessel is owned by the Royal Trust Co., and is leased to Canarctic Shipping Company Limited on a bareboat charter.

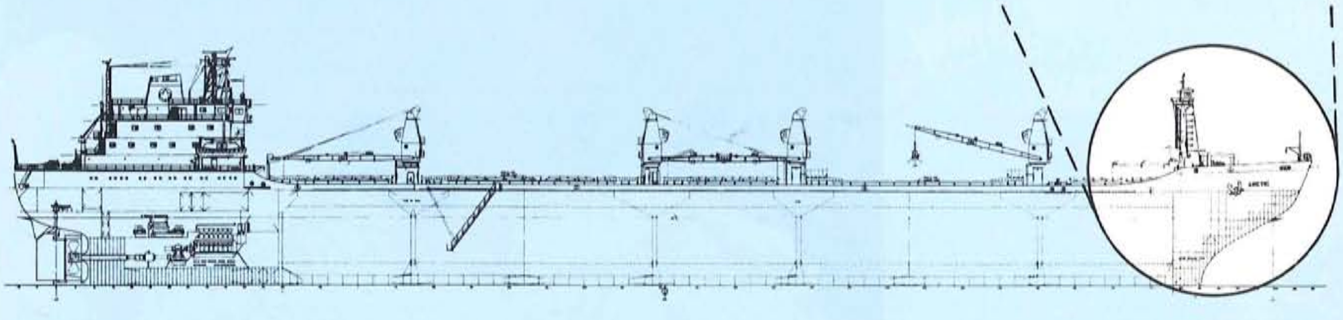
Ship Modifications

A two-stage conversion program was approved by the government in 1984, to permit the MV 'Arctic' to compete for the transport of oil from the Bent Horn demonstration project.

The first phase of the conversion program was completed in July of 1985 at The Port Arthur Shipyard at Thunder Bay. The cargo hold configuration was changed to provide seven holds of equal size (from an original configuration of five). This new arrangement permits the ship to transport bulk crude oil in the five centre holds, with the two end units serving as segregated ballast tanks or dry cargo holds. These modifications conform to the most recent requirements of the International Maritime Organization (IMO) for a new tanker, and will allow the MV 'Arctic' to operate anywhere in the world as an Oil or Bulk Ore (OBO) ship.

The second phase of the conversion work, to be completed in 1986, will increase the Ice Class of the vessel to Class 4 equivalency. Planned modifications include a redesign of the bow structure to optimize its icebreaking performance and strength. Also, the parallel midbody will be strengthened. These changes will make the MV 'Arctic' one of the most advanced ice-capable cargo-carrying ships in the world.





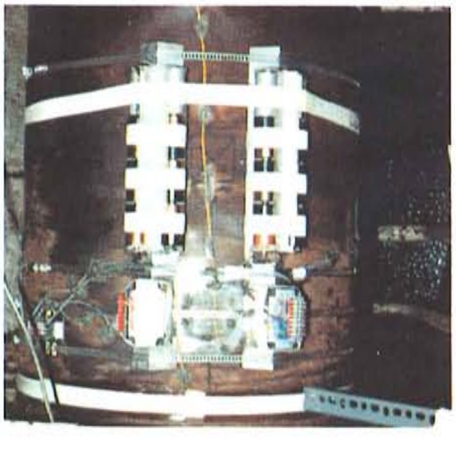
Dedicated icebreaking ships have been routinely operating in ice-covered waters for many years. Extensive civilian and military experience with these ships has resulted in the development of a substantial base of knowledge of the structural and other requirements of ships which operate in ice. In fact, cold-ocean naval design is an expanding field of study, with every major shipyard and/or design firm in the world operating or utilizing dedicated ice tank research facilities.

The initial work of the MV 'Arctic' was directed toward a detailed research program involving the assessment of her own design. The research program included: evaluation of design criteria (e.g. structural strength); evaluation of the seasonal restraints on operation; development of improved navigation and communications equipment; correlation of model testing with actual vessel performance; evaluation of technical features designed to enhance the ship's icebreaking capability; and the development of an instructional base.

Data Collection and Analysis

A data gathering system was installed as part of the permanent architecture of the ship at the time she was constructed. The system originally fitted to the MV 'Arctic' was one of the most sophisticated electronic systems ever installed in a non-military vessel. Key to its operation were sensors on the hull, in the propulsion and other machinery systems (engine, drive train, rudder and propellor, fuel delivery system, etc.) and in other areas around the vessel. Data were picked up by the sensors, and transmitted in analogue form along electronic conduits (called data buses) to a central computer system in the ship's laboratory. Data were converted to digital form, and stored on conventional magnetic tapes.

The original data gathering system is being updated as part of the 1985 and 1986 modifications. Enhanced hardware, software and real-time visual displays on the bridge are considered the most up-to-date available.



TP 2218, MV Arctic Instrumentation and Data Collection System for Ship Operations in Ice — System Operating and User's Manual: Summary Report, German and Milne Inc. (for the Transportation Development Centre), July 1979.

TP 2617, Operational Maintenance Report for MV Arctic Data Acquisition System 1979 Season (Phases I-V), German and Milne Inc. (for the Transportation Development Centre), March 1980.

TP 2627, MV Arctic Scientific Evaluation Project — Data Collection Activity (1979-1980 Season). German and Milne Inc. (for the Transportation Development Centre), July 1980:
Vol. 1 "Normal Voyages";
Vol. 2 "Saguenay River Trials".

TP 2690, Operational Maintenance Report for MV Arctic Data Acquisition System 1979 Season (Phase VI — Refurbishing), German and Milne Inc. (for the Transportation Development Centre), July 1980.

TP 3097, MV Arctic Instrumentation and Data Collection System for Ship Operations in Ice — System Operating and User's Manual, FENCO Consultants Ltd. (for the Transportation Development Centre), May 1981.

TP 3202, MV Arctic Data Collection and Instrumentation (1980 Season), FENCO Consultants Ltd. and German and Milne Inc. (for the Transportation Development Centre), August 1981:
Vol. 1 "Normal Operations Mode";
Vol. 2 "Baffin Island Trials".

TP 3522E, MV Arctic Data Collection and Instrumentation (1980 Season), Summary Report.

TP 3632, MV Arctic 1981 (Early Season) Data Collection and Instrumentation, FENCO Consultants Ltd. and Melville Shipping Ltd. (for the Transportation Development Centre), December 1981:
Vol. 1 "Normal Voyages";
Vol. 2 "Admiralty Inlet Trials".

TP 3644, MV Arctic 1981 (Early Season) Data Collection and Instrumentation, Summary Report.

TP 3894E, MV Arctic Master Data Package, (1979, 1980, 1981 Seasons), Summary Report. RESTRICTED.

TP 3821, MV Arctic Master Data Package, (1979, 1980, 1981 Seasons), German and Milne Inc. (for the Transportation Development Centre), October 1982. RESTRICTED.

TP 3633, MV Arctic (1981 Season) Maintenance of the Data Gathering Instrumentation System, German and Milne Inc. (for the Transportation Development Centre), January 1982.

TP 3634, MV Arctic 1981 (Late Season) Data Collection and Instrumentation, Arctec Canada Ltd. (for the Transportation Development Centre), March 1982:
Vol. 1 "Main Report";
Vol. 2 "Appendices".

TP 3645, MV Arctic 1981 (Late Season) Data Collection and Instrumentation: Summary Report.

TP 4824, Report on Evaluation of MV Arctic Computer Operation at the Transportation Development Centre, Peirce Operational Dynamics Inc. (for the Transportation Development Centre), August 1983.

TP 5257, MV Arctic Data Acquisition System Review Report, Peirce Operational Dynamics Inc. (for the Transportation Development Centre), January 1984.

TP 2641, MV Arctic Scientific Evaluation Project — Data Collection Activity (1979-1980 Season), Summary Report.

Ice Transiting Performance

"Ice transiting" describes the passage of a vessel in ice. Transiting can be either "continuous" or by "ramming". Measurement of a ship's performance in specific conditions is used to confirm the validity of design specifications, or identify the need for amendment. Thus, a long series of dedicated tests was conducted, to determine if the MV 'Arctic' performed as anticipated by her designers, and to determine whether regulations governing the construction of arctic vessels were well-founded.

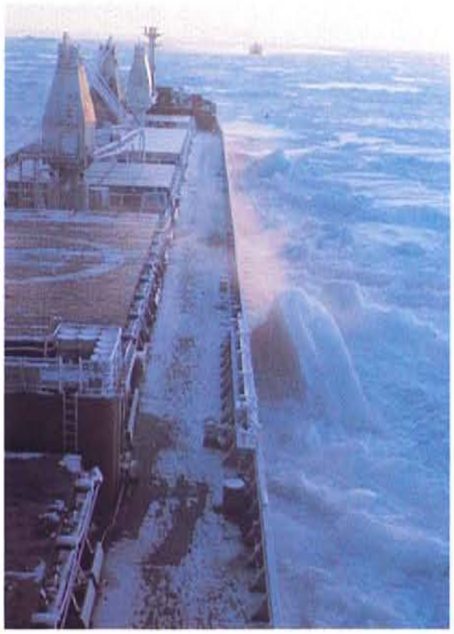
Transiting — Continuous

Early tank testing played a major role in the development of the ship's hull form. Model hulls were studied for their open-water and ice transiting behavior. However, because hydrodynamic and ice tank tests can not simulate all of the conditions likely to be encountered, a detailed transit recording program was undertaken. These tests both confirmed the essentials of her design, and identified areas for possible refinement. The changes to the bow design planned for 1986, for example, result in part from the transiting program. The modifications will increase structural strength, and improve bow lines to optimize icebreaking performance in thick level ice.

Transiting also offers an opportunity to study the performance of engine and drive train in varying ice thicknesses and conditions. It is useful to know what thrust is required to maintain way in given ice and temperature conditions. This information helps in the refinement of future design for installed vessel power plant and drive train configuration relative to specific routes and transit cycles. Costs of these elements significantly affect the owner's economic return over the life of the ship.

Transiting trials were also used to evaluate systems for reduction of hull resistance to ice. One of the applications most thoroughly explored was the bubbler system, of a type first developed by Wartsila, Finland. In this system, air which is pumped through a series of nozzles along the hull behaves as a lubricating film between the hull and contacting ice, in theory easing passage of the vessel. At Lake Melville, advantage was taken of uniform ice conditions to execute sets of parallel transits, with and without the bubbler in operation. These (and other) trials indicated that the system did not provide sufficient advantage over a range of conditions to merit the required use of space and other resources.

Trials of hull coatings have been more successful, and their use is likely to continue, even on icebreakers which see constant duty in severe conditions. Inerta 160 friction-reducing hull coating was applied to the MV 'Arctic'. Results have been entirely satisfactory, though with this product, as with others of the type, proper cleaning and preparation of the hull steel and proper application, are critical.



TP 3646, Report on MV Arctic Experimental Voyage to Lake Melville, Labrador (February/March 1981), Melville Shipping Ltd.; Transportation Development Centre; Arctic Pilot Project; Canarctic Shipping Ltd.; CN Marine Inc.; North Water Navigation Ltd. and the Government of Newfoundland, October 1981:
Vol. 1 "Main Report";
Vol. 2 "Appendices".
RESTRICTED.

TP 3637, MV Arctic 1981 Lake Melville Probe — Data Collection Services, FENCO Consultants Ltd. and German and Milne Inc. (for the Transportation Development Centre), October 1981.

TP 3809, MV Arctic Special Report (Test Parameters) on Lake Melville Probe, Melville Shipping Ltd. (for the Transportation Development Centre), August 1982.

TP 6705, Track Observations in Ice Cover of Admiralty Inlet Following Passage of MV Arctic (June/July 1982), Michael Robson (for Canarctic Shipping Company Ltd.), March 1983.

TP 6748, Analysis of MV Arctic Ramming Performance in Admiralty Inlet (June, 1982), Melville Shipping Ltd. (for Canarctic Shipping Company Ltd.), March 1983.

TP 5170, MV Arctic Ice Transiting Performance — Continuous Mode: Final Report, Albery, Pullerits, Dickson and Associates (for the Transportation Development Centre), May 1984. RESTRICTED.

TP 5319, MV Arctic Ice Transiting Performance — Continuous Mode: Summary Report. RESTRICTED.

TP 5320, MV Arctic Ice Transiting Performance in the Ramming Mode — Final Report, Arctec Canada Ltd. (for the Transportation Development Centre), October 1984. RESTRICTED.

TP 5321, MV Arctic Ice Transiting Performance in the Ramming Mode: Summary Report. RESTRICTED.

Transiting — Ramming

Ice transiting in the ramming mode has shown that vessel operator experience, as well as ice conditions, can profoundly affect the efficiency of the ramming cycle. Analysis of ramming cycles also revealed a number of factors important to efficient vessel operation. In analyzing cycle time, it was found that the performance of the MV 'Arctic' in ridged ice could be improved by optimizing impact speed, increasing the power level during backing in broken channel, minimizing thrust reversal intervals, and elimination of time loss at the end of a ram. The MV 'Arctic' cycle is being computerized, and similar optimum cycle profiles can be generated for other specific ship types. It should be noted, however, that all aspects of the ramming cycle outlined above cannot be applied to all ship types.

As in the continuous mode, the bubbler system appeared to offer no substantive economic advantage, though it was judged to have some positive impact on performance in the ramming mode.

Structural Loading

The structure of every ship is subject to high forces through bending, slamming, torsion and vibration. The larger the vessel, the greater the magnitude and complexity of forces at play. Therefore, the structural integrity of a large vessel in the harsh conditions imposed by arctic service must be beyond question.

Local Loads

One of the areas of concern for ships operating in ice is local loading — the loads exerted by ice impacting on a specific region of the hull. Extensive testing has been carried out with the MV 'Arctic' to measure these loads, and the extent to which the hull plate and internal structures are at risk.

Analysis of test results when ramming, and during continuous icebreaking, has revealed forces in excess of yield strength in the hull plating due to maximum yield-strength loads on the bow frame and stringers. The analysis also showed values in excess of yield strength in the bilge area. These investigations contributed to the design revisions for the bow of the MV 'Arctic' which are to be executed in 1986. Other studies showed the need for strengthening of the hull midbody along the entire length of the parallel sides. This work will also be carried out in 1986.

Related work has involved the investigation and monitoring of inherent flaws in the hull welds and structure. The Canada Centre for Mineral and Energy Technology (CANMET) of the federal department of Energy, Mines and Resources (EMR) hosted a seminar on fracture toughness, with special emphasis on the experience of the MV 'Arctic', in October of 1983. A pertinent report, titled "Fracture Toughness Evaluation of Steels for Arctic Marine Use", by R. Thompson and C.S. Champion, is available from EMR in Ottawa.

Also of more than casual interest in this connection is the "pillow-test" investigation carried out by the Centre for Frontier Engineering Research (C-FER), at the University of Alberta in Edmonton, into the possibility that the continued straining (in tension) of hull plating may improve its overall load-carrying ability. C-FER investigators note that "... once relatively small deformations have taken place, the steel plate begins to act as a membrane, straining in tension inelastically. Increased loading is necessary for the membrane to stretch or deform, and with increased deformation, the plate can carry more load. This action continues until the maximum strain that the plate can withstand has been reached, and rupture finally occurs." This research may have significant implications for the materials and approaches used in the construction of vessels for arctic service.

In addition to the problems of local loads on the bow and sides of ships working in ice, there is the hazard of random ice encounters while navigating (at speed or in heavy seas) in open water. Such encounters with iceberg fragments, called "bergy bits" or "growlers", are especially hazardous since a strike can occur above the strengthened portion of the bow. The MV 'Arctic' has suffered damage on at least one occasion in such an encounter, illustrating how critical is the need for effective ice hazard detection tools and techniques. Operating experience in the fall of 1984 in Lancaster Sound also reinforced awareness of the hazards of ice pressure, when the vessel was seized fast in shifting ice.

TP 6765, Assessment of the Strength of the Bow Hull Structure of MV Arctic Under Ice Loads Caused by Multi-year Ice, VTT (for Canadian Coast Guard Northern), June 1982. RESTRICTED.

TP 4191, Development of a Prediction Model for Dynamic Response and Bow Loading of Ships, Melville Shipping Ltd. (for the Transportation Development Centre), May 1983. RESTRICTED.

TP 6224, MV Arctic Midbody Damage Analysis: Final Report, Canadian Marine Drilling Ltd. (for Canadian Coast Guard Northern), March 1985. RESTRICTED.

Global Loads

Operational and research experience with the MV 'Arctic' has helped to identify precisely the global loads (forces exerted on hull girder, deck structure and bilge area) as a result of ship-ice interaction. In early trials with the MV 'Arctic', a "whipping" or longitudinal vibration of the hull was observed during ice transiting and ramming. Subsequent investigation of this phenomenon yielded important structural information.

Studies of the bending of the main hull girder show a low risk of fatigue in normal (ice) operations. Also, in comparative tests it has been found that wave-induced still-water bending stress is higher than ice-induced bending stress. The severity of initial bending stresses and subsequent "vibrations" decreases as the extent of the floe or ice-sheet being rammed increases.

Experiments have also been conducted to minimize the still-water bending stress equivalent by redistributing water ballast in ballast tanks. By taking indicative values of stress variations for both ice ramming and continuous operation in ice, it has been shown that such redistribution (or redisposition) of ballast water reduces peak dynamic stresses in the hull girder. In the above analysis, the mechanics of ice failure, and the role of ice failure in vessel dynamics, have been central to modelling various hypotheses. This work is referenced under "Ice Property Definition".

TP 1449, A Study to Verify Design Criteria Used in Developing the Instrumentation System for Installation Aboard the MV Arctic by Testing Prototype Equipment Under Actual Icebreaking Conditions, German and Milne Inc. (for the Transportation Development Centre).

TP 2881, MV Arctic Hull Vibration Study: The Recording and Analysis of Hull Vibration Measurements During Dedicated Ice Trials (October-November 1980), Lloyd's Register of Shipping (for the Transportation Development Centre), January 1981.

TP 6753, Continuation of Stress Analysis: Interim Report on Mathematical Model of the Hull Girder Structure of the MV Arctic, Melville Shipping Ltd. (for the Transportation Development Centre), March 1982. RESTRICTED.

TP 5891, Continuation of Stress Analysis of MV Arctic Dynamic Exciter Tests: Interim Report, Melville Shipping Ltd. (for the Transportation Development Centre), March 1982. RESTRICTED.

TP 6750, Measurement of Hull Girder Bending Strain and Vibration in the Hull of the MV Arctic in Admiralty Inlet on the Voyage to Strathcona Sound (July 1981): Final Report, Melville Shipping Ltd. (for the Transportation Development Center), June 1982: Vol. 1. RESTRICTED.

TP 5747, Study on the Redisposition of Ballast Water in Deeply-loaded Ballasted Icebreaking Conditions to Minimise the Hull Bending Moment of MV Arctic (Report and Addendum), Intercan Logistical Services Ltd.; Canada Steamship Lines Inc.; and Melville Shipping Ltd. (for the Transportation Development Centre), June 1982.

TP 6749, Continuation of Stress Analysis Measurement: Recording of Deck and Bottom Stresses on MV Arctic During a Trans-Atlantic Crossing, Melville Shipping Ltd. (for the Transportation Development Centre), July 1982.

TP 6755, Continuation of Stress Analysis: MV Arctic Hull Girder Stress and Vibratory Response During Ship-Ice Interaction, Melville Shipping Ltd. (for the Transportation Development Centre), July 1982. RESTRICTED.

TP 5888, Measurement of the Hull Girder Bending Strain and Vibration in the Hull of the MV Arctic on the Voyage to Strathcona Sound (June 1982), Melville Shipping Ltd. (for the Transportation Development Centre), RESTRICTED.

TP 6754, Measurement of Hull Girder Strains and Vibration During Ramming of Multi-year Ice Floes in Lancaster Sound (November 1981), Melville-Marine Consultancy (for the Transportation Development Centre), March 1983. RESTRICTED.

TP 6756, Nonlinear Analysis of MV Arctic Stringer, VTT (for the Transportation Development Centre), April 1983. RESTRICTED.

TP 4792, MV Arctic Scientific Program: Interim Report, Peirce Operational Dynamics Inc. (for the Transportation Development Centre), July 1983.

TP 6775, Results from Statistical Measuring System on Board MV Arctic (1982), VTT (for the Transportation Development Centre), July 1983. RESTRICTED.

TP 5377, MV Arctic Beam Modelling: Final Report, Canadian Marine Drilling (for the Transportation Development Centre), March 1984.

TP 6699, Results from Statistical Measuring System on Board MV Arctic (1983), VTT (for Canarctic Shipping Ltd.), March 1984. RESTRICTED.

TP 5701, Segmented Model Testing in Ice-Development of Techniques: Final Report, Arctec Canada Ltd (for Transportation Development Centre), 1984.

TP 5702, Segmented Model Testing in Ice-Development of Techniques: Summary Report.

TP 6572, Results from Statistical Measuring System on Board MV Arctic (1984), German and Milne Inc. (for Canarctic Shipping Co. Ltd.), 1984. RESTRICTED.

TP 6270, MV Arctic Dedicated Field Tests — Ship/Ice Interaction (Ramming Results and Analysis), German and Milne Inc. and VTT (for the Transportation Development Centre), January 1985. RESTRICTED.

TP 6345, MV Arctic Scientific Program: 1979-1981 Performance Review, Peirce Operational Dynamics Inc. (for the Transportation Development Centre), April 1985. RESTRICTED.

TP 5682, MV Arctic Structural Performance: Interim Report, Arctec Canada Ltd. (for the Transportation Development Centre), October 1984. RESTRICTED.

TP 5680, MV Arctic Structural Performance: Final Report, Arctec Canada Ltd. (for the Transportation Development Centre), April 1985. RESTRICTED.

TP 6536, Parametric Model Study of MV Arctic Hydroelastic Response during Multi-year Ice Impacts, Arctec Canada Ltd. (for Canadian Coast Guard Northern), June 1985:
Vol. 1. RESTRICTED.

Bow Structure

Intensive study of the role of bow structure and design in vessel performance, and analysis of local bow damage sustained in ice operations, led to proposals for redesign of the bow of the MV 'Arctic'. A design process using predictor equations produced five modified hull form models. Two of these were judged to be most promising, and were subjected to further model testing, along with the existing bow, both in Canada and abroad. Bow form models were designed by Melville Shipping Ltd., and built by the Institute for Marine Dynamics (IMD) of National Research Council Canada. Open-water testing of these models, including propulsion efficiency tests, was conducted at IMD, and ice testing was carried out in the ice tank of Arctec Canada Ltd., and others. The testing showed that one of the new design options, the Melville Bow, offered a marked improvement over the existing bow, and subsequent analysis suggests the revised design is sound.

TP 4192, MV Arctic Bow Redesign Study: Phase 1 (1983), Melville Shipping Ltd. (for the Transportation Development Centre), January 1983.

TP 5044, MV Arctic and Two Alternative Bow Designs — Results of Resistance, Propulsion and Overload Experiments with Model Hulls 326, 326B and 326C, and Model Propeller 68, Arctic Vessel and Marine Research Institute of NRC Canada (for the Transportation Development Centre), May 1983.

TP 5456, Redesign of the MV Arctic Bow: Design and Model Testing, Melville Shipping Ltd. (for the Transportation Development Centre), 1984.

TP 5455, Redesign of the MV Arctic Bow: Design and Model Testing, Summary Report.

Machinery and Systems

Propulsion Systems

The propulsion systems fitted to the MV 'Arctic' have been studied extensively for both functional efficiency and vulnerability to damage. Though her propulsion systems are in no sense revolutionary, they are certainly state-of-the art, and their performance in Canadian conditions in a vessel of her size and type was unproven before she went into service.

Although the soundness of the basic design is accepted, some potential problems have been identified; these will be considered in the design stage of future arctic ships. Of particular interest has been her propellor. It is of a ducted type, the duct serving to shield the propellor from the impacts of ice fragments above a certain size. Typically, a solution brings a new problem. The duct can create a phenomenon in which fragments of ice become trapped in a vortex around the propellor, grossly reducing its efficiency. Although this has not been a problem to date, a viewing port has been installed in the ship to permit direct viewing of the propellor in operation, if necessary.

Investigations of the propulsion system have, of necessity, involved evaluation of the risk of major failure of a main component. The component deemed most likely to suffer such a failure is the main drive shaft. Studies suggest such a failure is highly unlikely. Other studies have been undertaken elsewhere in Transport Canada relating to water-lubricated bearings, tribology, off-spec fuels, waste heat recovery, alternate fuels and combined-fuel (COGAS) systems for LNG carriers.

TP 6767, MV Arctic Machinery Vibration (O/D Box), Arctec Canada Ltd. (for Canadian Coast Guard Northern), February 1983. RESTRICTED.

TP 5167, MV Arctic Propulsive Performance: Final Report, Melville Shipping Ltd. (for the Transportation Development Centre), March 1984. RESTRICTED.

TP 5168, MV Arctic Propulsive Performance: Summary Report. RESTRICTED.

TP 6706, Fitting of a Viewing Port in the MV Arctic, Arctec Canada Ltd. (for Canarctic Shipping Co. Ltd.), March 1984.

Materials

Materials used in the construction of ships have been studied since the beginning of navigation. Some recent studies have been of great interest to the vessel operators because of the unique problems encountered in arctic conditions.

One of these involved heat flow in ships. It revealed among other things that, because a ship hull is internally "cellular" in form, some variations in temperature can occur from one section to another.

A team of consultants also researched the properties of steels at low temperatures. Of interest was the tendency of steel to become brittle, and fracture, at cold temperatures. Their report offered an assessment of test procedures for steel and welding metal as elements of a fracture control program. This is important because the role of temperature as a factor in increasing the risk of damage in Arctic-class ships is not clearly understood. The 1986 modifications will include the selective use of high-tensile cold grade steels. Though more expensive than regular steel, these specialty steels are expected to add less weight.

TP 2717, A Review of Steel Properties at Low Temperatures, FENCO Consultants Ltd., Lloyd's Register of Shipping and National Boring and Sounding (for the Transportation Development Centre), December 1980.

TP 6766, Brittle Fracture Risk Assessment of MV Arctic, VTT (for Canadian Coast Guard Northern), June 1983.

TP 4516, Evaluation of Steel Grades for the MV Arctic, Det norske Veritas (for the Transportation Development Centre), June 1983.

TP 5001, Modelling of Heat Flow in Ships, H.G. Engineering Ltd. (for the Transportation Development Centre), September 1983.

Arctic Environment Development Program

From the point of view of a ship operator, the arctic environment divides neatly into two areas. One is the living environment — the people, animals and plants. The other is the ice environment, a determining feature of life in the far north. In the one case, the vessel operator must consider the impact of ship operations on the balance of this complex and sometimes fragile system. In the other, the ice environment itself imposes harsh restraints on vessel activities.

The Living Environment

Several studies of the relationship between shipping and the environment in the high arctic have been undertaken. In particular, two studies have addressed the impact of operations of the MV 'Arctic' on respectively, northern native peoples, and the behavior of marine mammals. One involved icebreaking operations concurrent with hunting by Inuit in Admiralty Inlet. It was found that the vessel did influence the pattern of breakup, *but* the broken ice track did not pose an unusual or exceptional risk to over-ice travel by hunters. The other was an examination of the reactions of marine mammals (narwhals and belugas) to ship noise and the noise made by icebreaking operations.

TP 6757, Reactions of Beluga Whales and Narwhals to Ship Traffic and Icebreaking along Ice Edges in the Eastern Canadian High Arctic (1982-1984): An Overview, LGL Limited (for the Department of Indian and Northern Affairs Canada), November 1984.

TP 6758, Spring Icebreaking Operations of the MV Arctic and Concurrent Inuit Hunting in Admiralty Inlet, Baffin Island, 1984, FMS Engineers Ltd. (for Canarctic Shipping Co. Ltd.), October 1984.

The Ice Environment

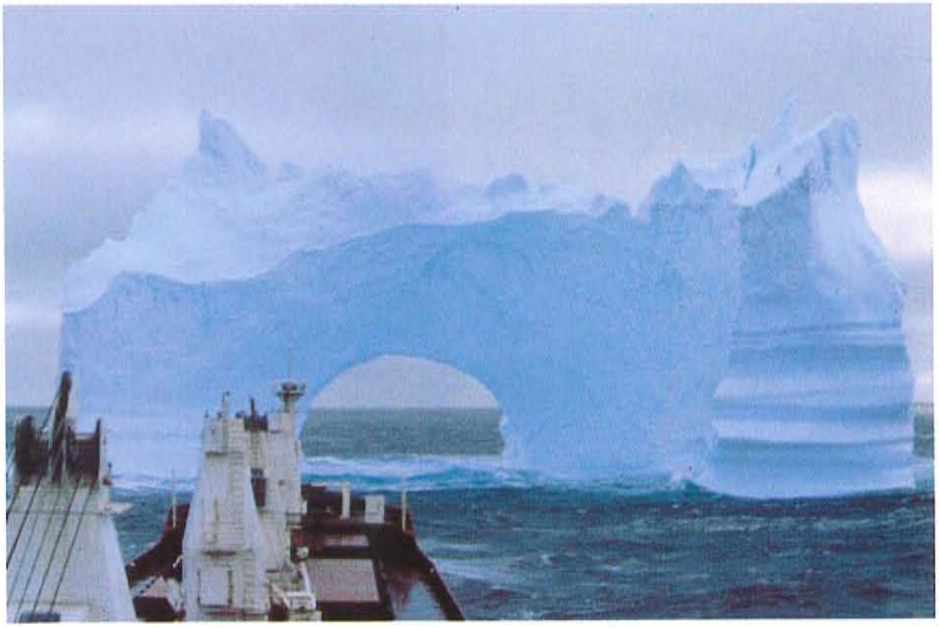
Ice Property Definition

A central field of study is ice itself, and its properties as a material. Sea ice is a material with many faces. Ice may be smooth and level, or heavily ridged, and accordingly relatively easy or very difficult to transit. It may exist as loosely spaced floes, with plenty of open water to permit navigation, or it can be packed by wind and currents into a solid mass which can seize and hold a ship no matter what action is taken to escape. Depending on the season, even solid pack ice may be soft, and yield easily to the breaking action of the icebreaker.

Ice is classified as first-year (new) ice, or multi-year (old) ice. New ice is not more than one winter's growth, and varies in thickness up to about two metres. First-year ice, if consistent and not rafted or ridged, can be challenging but is typically not dangerous.

Ice which survives two or more years and is more than three metres thick is referred to as multi-year or old ice. Multi-year ice has undergone a gradual process of repeated thawing and freezing which leaches out the salt content, permitting the ice to harden. In time, it is nearly salt-free, and nearly granite hard. Iceberg ice, which is fresh water ice without any salt whatsoever, is truly rock-hard.

Pack ice may consist of mostly first year ice, but with pieces of multi-year ice or iceberg fragments in it. This is the most dangerous situation of all, for, if not detected, a piece of multi-year ice or an iceberg fragment may contact a ship hull during reasonably rapid transit. A non-ice-class vessel might not survive such an encounter. So, as ice defines the environment in the absolute sense, the detection and avoidance of multi-year and floe or berg ice defines our ability to establish safe and reliable commercial shipping operations.



TP 6700, Iceberg Thin Section Program: Phase I, Norland Science and Engineering Ltd. (for the Geotechnical Section, Division of Building Research, National Research Council Canada), March 1983.

TP 6703, Ice Property Investigations during the 1983 Initial Voyage of MV Arctic, Polar Research and Engineering (for Canarctic Shipping Co. Ltd.), September 1983.

TP 6762, Test Ice for Dedicated Tests MV Arctic 1984. Location, Monitoring, Verification and Specific Data — Phase III: Pre-Test Field Survey Report, Norland Science and Engineering (for Canarctic Shipping Co. Ltd.), August 1984.

TP 6713, Ice Load Penetration Model Report 1: Constituents for Ice-Structure Interaction Modelling, VTT and NRC Canada (for the Canadian Marine Transportation Administration), July 1985.

Ice Distribution and Movement

Other studies address the ice environment, and the limitations it imposes on ship operators. Man may never conquer this environment; however, he may be able to function, by learning to understand and avoid the hazards to navigation created by an ice environment.

In each area where commercial shipping activity is required, intensive studies are made of the ice regimes in the major sounds and channels. Proposed shipping routes will be surveyed over several years and at different seasons to identify the seasonal distribution of ice hazards, and thereby determine their "trafficability". This is ongoing work, and will continue for many years as an essential part of the safe opening of our arctic waters to commercial activity. In its execution, trained ice observers travel with the MV 'Arctic' on arctic voyages to record details of the ice environment, and the interaction of the ship with that environment. Observations at intervals as close as 15 minutes have created a valuable databank of information. A special computer program has been developed to store and analyze this data aboard the vessel.

Based on this trafficability information, the Canadian Coast Guard has also developed a computer program which calculates the likelihood of ice damage to a ship operating in a particular arctic waters zone. The program is called the Arctic Shipping Probability Evaluation Network (ASPEN), and it was developed to aid in upgrading zone definition under the Arctic Shipping Pollution Prevention Regulations. ASPEN values are obtained from the chain of events leading to a damage incident. Each link in the chain contains random variables, such as the number of icebergs ahead of a ship and the visibility distance. Quantitative results from each stage are used as input for the following stages. Using accumulated results, the program determines the expected number of encounters, avoidances, impacts and damages likely to be caused by the various hazardous ice types. ASPEN successfully combines much of the understanding of ice regimes gained to date into a comprehensive and useful decision support tool.

TP 6707, Summer Ice Regime in McDougall Sound and Adjacent Channels, Polar Research and Engineering (for Canarctic Shipping Co. Ltd.), October 1982:
Vol. 1 "Main Report and Summary".

TP 6704, Ice Trafficability in Northern Baffin Bay (June 1 to July 15 1982), Polar Research and Engineering (for Canarctic Shipping Co. Ltd.), March 1983.

TP 6759, Ice Regime Study: Report on Observations Program (1982 Season), Michael Robson (for Canarctic Shipping Co. Ltd.), March 1983.

TP 6701, Final Report: MV Arctic Northern Routing Environment, Melville Marine Consultancy (for Canarctic Shipping Co. Ltd.), March 1983.

TP 6705, Track Observations in Ice Cover of Admiralty Inlet Following Passage of MV Arctic (June/July 1982), Michael Robson (for Canarctic Shipping Co. Ltd.), March 1983.

TP 6712, Evaluation of 1982 Ice Conditions Using March (SLAR) and July (Photographic) Surveys of Wellington, Queens Channels and McDougall Sound: Report and Appendices, FMS Engineers and Lavalin (for Canarctic Shipping Co. Ltd.), April 1983.
Appendix A: Photographic Prints of Cornwallis and Little Cornwallis Island Area.
Appendix B: March 1982 SLAR and Overlays of Cornwallis and Little Cornwallis Island Area.

TP 6702, Survey of Ice Conditions Along Shipping Routes to Nanisivik and Polaris Minesites (May 1983), Polar Research and Engineering (for Canarctic Shipping Co. Ltd.), September 1983.

TP 6760, Study and Recommendations Regarding Opening and Closing Dates for Entry of the MV Arctic into CCG ASPPR Zones 6 and 13, Norland Science and Engineering (for Canarctic Shipping Co. Ltd.), January 1984.

TP 6761, Navigation Hazard Seasonal Distribution, Detection and Avoidance for the MV Arctic (1983 Shipping Season), Norland Science and Engineering (for Canarctic Shipping Co. Ltd.), March 1984.

TP 6709, Ice Regimes and Environmental Conditions Encountered by the MV Arctic (1983 Shipping Season), Norland Science and Engineering (for Canarctic Shipping Co. Ltd.), March 1984.

TP 6710, Ice Regimes and Navigation Hazards Encountered by the MV Arctic (1984 Shipping Season), Norland Science and Engineering (for Canarctic Shipping Co. Ltd.), February 1985.

TP 6461, Sverdrup Basin Ice Navigation Study (1984), Canarctic Shipping Co. Ltd. and Norland Science and Engineering (for Canadian Coast Guard Northern), March 1985:
Vol. 1 "Main Report".
Vol. 2 "Imagery Catalogue".

TP 6696, Lancaster Sound Winter Ice Regime Study, Intera Technologies Ltd. (for Canarctic Shipping Co. Ltd.), March 1985.

Ice Failure Mechanics

An important subset of ice research is the mechanics of ice failure, i.e.: the physical processes involved when ice yields to crushing and bending forces. The manner of ice failure affects the deceleration of the vessel, the transmission of loads to the vessel structure, as well as the character of harmonic vibration established in main structural members.

Ice failure has been studied using a continuum-mechanical approach and a micro-mechanical approach. The continuum-mechanical approach yields a fairly general set of findings, while the micro-mechanical approach involves the study of the underlying processes and constitutes a more detailed basis for the mathematical modelling technique. The micromechanical approach examines failure processes at the microscopic level, including dislocation movement within grains and grain boundary sliding. Cracking has also been studied, and found related to delayed elastic strain. These findings are summarized in an initial report of a Joint Research Project Arrangement (JRPA) of Transport Canada and the Ship Laboratory of the Technical Research Centre <Valtion Teknillinen Tutkimuskeskus (VTT)> of Finland. The report points out the need for further information on the influence of multiaxial stress rates, deformation rates and temperature on the strength of multi-year ice.

Arctic Operations Development Program

Navigation

Ship operation in the arctic involves the assurance of vessel security and personnel safety and comfort during long tours of duty in isolation and confined living quarters. Pre-eminent among these is the requirement that ships operate safely despite the hazards of darkness, adverse weather, berg and multi-year ice.

In dealing with the risks inherent in arctic navigation, detection and avoidance of ice hazards is the most critical single factor. Five years ago, this was not possible in any meaningful way. Today, we are advancing rapidly toward viable integrated navigation systems.

Many important gains have come in the areas of radar, and the communication of navigation information. A key advance has been the development of a highly sophisticated airborne Synthetic Aperature Radar (SAR), now commercially available, which enables a skilled operator to distinguish features in solid pack ice. The radar images are captured on magnetic tape by an aircraft which overflys the ship and its planned course, and which is equipped with a digital down-link to the vessel. Five years ago, such radar images were grainy, blurred, and difficult to read. Today, they are of nearly photographic quality. A trained navigator can even pick out the sharper returns which may indicate surface melting, an oddly-shaped piece of ice, or, most important, multi-year ice concealed in the pack.

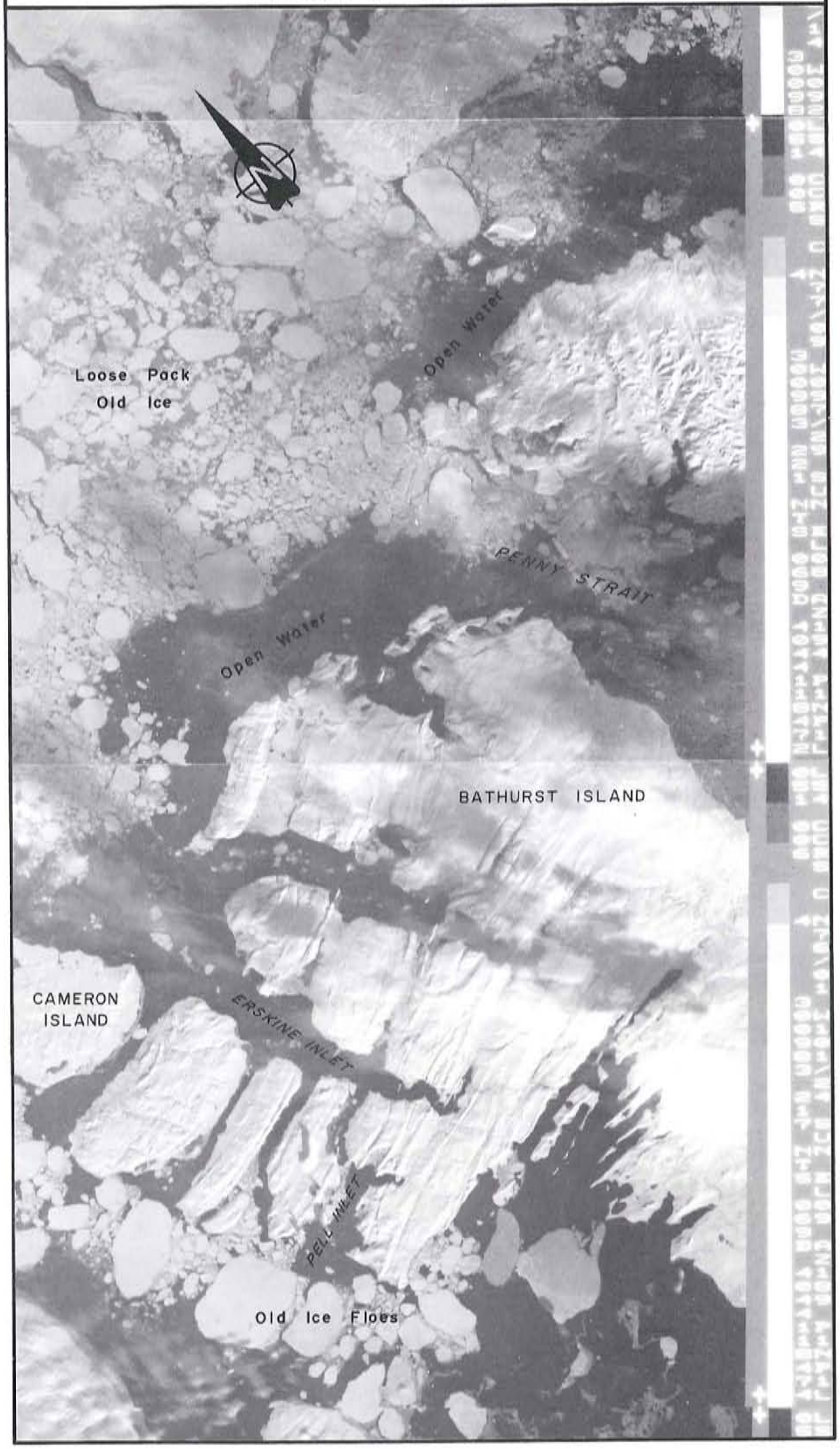
The integration of individual radar and communications technologies into an arctic navigation "package" is now the focus of research. Early voyages of the MV 'Arctic' were hampered by poor data transmission (via HF) of large-scale ice maps from the Department of the Environment Ice Centre to the ship at entry to Lancaster Sound. Continuing communications difficulties north of 70 degrees latitude, and the unsatisfactory resolution of transmitted data, prompted Canarctic Shipping to initiate an aggressive "self-service" ice information program. This included comparison testing of DOE's real-aperature radar, and the SAR technique developed by Interra Technologies Ltd. Evaluation of results led to the selection of the latter (on demand) service. Further advances in the shipboard reception (display and analysis of airborne radar or satellite ice images and other relevant data) spurred the development of the SINSS concept — Shipboard Ice Navigation Support System. Testing of this broad-based concept was begun in 1983, and areas were immediately identified where technology was lacking.

At this point, a basic system integrating the ship's radar, navigation charts, SAR imagery, NOAA satellite imagery, DOE Ice Centre information and meteorological information is in place. Work on enhanced data manipulation capability is underway. An "ice navigation console" is in development. And the bridge of the vessel is being reconfigured to permit the optimum use of the system as an all-weather guidance tool, within ergonomic limitations.

Similar development work is in progress on a more broadly-based regional information system called REMSCAN, and an ice evaluation system called Multi-task Ice Data Analysis System (MIDAS). This work is being undertaken by the Transportation Development Centre of Transport Canada.

FIGURE S-1
SCALE 1:1,000,000

LATE SEASON SVERDRUP BASIN AND BYAM MARTIN CHANNEL ICE REGIME SEPTEMBER 30, 1983
LANDSAT 4 TRACK 51 FRAMES 4-6



TP 6708, Initial Field Trials of a Shipboard Ice Navigation Support System, Phase 1: Final Report, Alan R. Sneyd (for Canarctic Shipping Co. Ltd.), March 1984.

TP 6695, Shipboard Ice Navigation Support System, Phase II: Final Report, Alan R. Sneyd (for Canarctic Shipping Co. Ltd., March 1985.

TP 6711, SINSS: The Prototype Hardware Conceptual Design, Final Report, Intera Technologies Ltd. (for Canarctic Shipping Co. Ltd.), March 1985.

Close-Range Ice Hazard Detection

In addition to the strategic navigation information provided by the high SAR overflights, the vessel also needs closer range tactical information. The captain needs to know which way he may safely turn to avoid a hazard without hitting another. So, short-range ice hazard detection is a matter of pressing concern. Many avenues have been explored. These include sonar, sodar, high-intensity lights and special night-vision binoculars.

Sonar research to date suggests the technology can detect icebergs of all types up to 2000 metres from the ship in open water. Further research will help define the operational design of a sonar sensor, interpretation methods and configuration in an icebreaking hull.

A bow-mounted radar and more powerful searchlights have been installed on the MV 'Arctic' to improve ice detection by eye. Experiments have been conducted with filters to sharpen visual contrast and improve the visibility of ice. Evolving from this research is an advanced multi-sensor system able to support safe operations and adherence to commercial shipping schedules in ice, intermittent visibility and 24-hour darkness.

TP 6698, MV Arctic Lake Melville Probe 1981. Airborne Impulse Radar: Uses and Limitations as an Ice Navigation Aid on Lake Melville, Centre for Cold Ocean Resources Engineering (for Melville Shipping Ltd.), 1982.

TP 5749, Navigation in Ice in Darkness Study: Operational Evaluations of Night Viewing Devices: Report and Appendix, J.M. Robson, October 1982.
Appendix A: "Evaluation of Filters for Identifying Arctic Ice", N.K. Sinha, Division of Building Research, NRC Canada (for Canarctic Shipping Co. Ltd.), October 1982.

TP 5746, Report on an Experimental Bow-mounted Radar System to Detect Ice Hazards: MV Arctic (1982 Season), J.M Robson (for Canarctic Shipping Co. Ltd.), March 1983.

TP 6170, Proof of Concept Tests: Data Acquisition and Analysis for Close Range Hazard Detection, Canadian Astronautics Ltd. (for the Transportation Development Centre and Canarctic Shipping Co. Ltd.), March 1985.

TP 6608, A Study Determining the Target Strength of Glacial Ice as a Function of Acoustic Frequency, C-TECH Ltd. (for Canarctic Shipping Co. Ltd.), March 1985.

Shiphandling

Manoeuvring

The handling and manoeuvring characteristics of the MV 'Arctic' were assessed on a continuing basis through the 1979-1984 period.

It was learned that, in ice, the steady rate of vessel turn decreases linearly with increasing ice thickness, and that as a result of speed loss in ice, the time taken to achieve a given change of heading increases as roughly the cube of ice thickness. Some results suggest that as much as 75% of resistance to turning in ice results from the need to break additional ice with the sides of the ship, with the rest resulting from the need to displace broken ice. The icebreaking component was assumed to be proportional to the flexural strength of the ice.

It was also learned that the controllability of the ship is affected by both type and thickness of ice; multi-year (and therefore probably less homogeneous) ice appeared to cause greater heading variations than does first-year ice, leading to more significant actions by the helmsman to maintain course. Thicker ice is also associated with more helm activity, though this may have much to do with the slower overall response of the ship in such conditions.

Ice impacts with the rudder have been recorded under a variety of running conditions; these generally seem to be associated with ice passing through the propellor nozzle. Excluding such incidents, the presence of ice appears to have little influence on the command-response characteristics of the steering gear.

The knowledge gained in these assessments is valuable in the design of future arctic ships, the design of cargo terminals and the training of vessel crews — possibly on simulators.

TP 4016, Little Cornwallis Island Ice Cutting Trials, Acres Consulting Services Ltd. (for the Transportation Development Centre), December 1982.

TP 3967, Ice Control for Arctic Ports and Harbours: A Literature Review in 2 Volumes, Acres Consulting Services Ltd. (for the Transportation Development Centre and the Canadian Marine Transportation Administration), January 1983.

TP 4204, Study of Ship Ballasting and Fluid Systems for Ice Navigation, Intercan Logistical Services Ltd. (for the Transportation Development Centre), January 1983.

TP 6704, Ice Trafficability in Northern Baffin Bay (June 1 to July 15 1982), Polar Research and Engineering (for Canarctic Shipping Co. Ltd.), March 1983.

TP 6759, Ice Regime Study: Report on Observations Program 1982 Season, Michael Robson (for Canarctic Shipping Co. Ltd.), March 1983.

TP 6701, Final Report: MV Arctic Northern Routing Environment, Melville-Marine Consultancy (for Canarctic Shipping Co. Ltd.), March 1983.

TP 6705, Track Observations in Ice Cover of Admiralty Inlet Following Passage of MV Arctic (June/July 1982), Michael Robson (for Canarctic Shipping Company Ltd.), March 1983.

TP 6761, Navigation Hazard Seasonal Distribution, Detection and Avoidance for the MV Arctic (1983 Shipping Season), Norland Science and Engineering (for Canarctic Shipping Co. Ltd.), March 1984.

TP 6709, Ice Regimes and Environmental Conditions Encountered by the MV Arctic (1983 Shipping Season), Norland Science and Engineering (for Canarctic Shipping Co. Ltd.), March 1984.

TP 5684, MV Arctic Manoeuvring Performance in Ice: Final Report, German and Milne Inc. (for the Transportation Development Centre), September 1984. RESTRICTED.

TP 5683, MV Arctic Manoeuvring Performance in Ice: Summary Report. RESTRICTED.

Cargo Handling

There are unique operational problems associated with cargo-handling in minus 40 degrees F temperatures and icing seas. At such temperatures, the failure resistance of steel can decline appreciably. Accordingly, special attention is required in the design of exposed systems. Severe icing in open water freezes hatch covers, cranes, cables and other equipment. Thus, protection from the elements and in some cases heating is necessary to keep essential equipment (bilge, firefighting gear, lifeboats) operational. In these conditions, special oils are required to ensure lubrication of the moving parts of exposed systems.

At dockside, especially in areas with large tide differentials, a significant "ice bustle" can form on caissons, preventing a vessel from coming to dockside. This presents problems in manoeuvring as well as cargo-handling.

Management of Shipboard Operations

In early 1981, a thorough operational evaluation of the MV 'Arctic' was completed and a report prepared dealing with the first two years of vessel service. The report addresses every aspect of shipboard operations from catering to ballasting. It specifically addressed design peculiarities which affected handling of the vessel in various conditions, and made recommendations on procedures respecting cargo handling, storage, engine maintenance and many aspects of cold weather operations. Some redesign recommendations were made as well. The report was prepared by Captain A. Stockdale of Maricon Ltd., Halifax, N.S.

TP 2956, MV Arctic Operational Evaluation: Final Report, Maricon Ltd. (for the Transportation Development Centre), January 1981.

TP 2984, MV Arctic Operational Evaluation: Summary Report,

TP 5748, A Fuel Saving Study with Reference to the MV Arctic, Melville Shipping Ltd. (for Canarctic Shipping Co. Ltd.), September 1983.

Safety/Accommodation

Recently, studies have been completed on crew accommodation requirements on arctic ships, the problems associated with fighting shipboard fires in very cold temperatures, lifesaving equipment requirements for arctic vessels, and repair and salvage techniques in arctic waters. Problems remain in many areas, especially safety. Distances and remoteness, communications disruptions due to atmospheric disturbances, and weather extremes including storms and whiteouts, all continue to make arctic shipping a challenging proposition.

As progress has been made in ice hazard detection, so will progress be made in other areas of concern. Navigation in ice-covered waters has always been a dream in countries with cold-ocean coastlines, and Canada is no exception. In this country, we are close to realization of that dream, thanks to the MV 'Arctic' and the hardy scientists and mariners who have sailed her.

TP 5361, Lifesaving Equipment for Arctic Ships, Melville Shipping Ltd. (for Canadian Coast Guard Northern), July 1984.

TP 5362, Crew Accommodation on Arctic Class Ships, Melville Shipping Ltd. (for Canadian Coast Guard Northern), May 1984.

TP 5374, Load Line and Stability for Arctic Class Ships, Det norske Veritas (for Transport Canada and Canadian Coast Guard Northern), June 1984.

TP 6225, Special Requirements of Shipboard Firefighting Systems Used in Cold Temperatures, Melville Shipping Ltd. (for Ship Safety, and Canadian Coast Guard Northern), April 1985.

TP 5363, Survey, Repair and Salvage Techniques in the Arctic, Melville Shipping Ltd. (for Canadian Coast Guard Northern), July 1984.

The Future

In the first five years of its operation, the M.V. Arctic has provided Canadian industry and government alike with a wealth of knowledge about the performance of a commercial vessel in ice. This knowledge has provided the foundation for the next phase of research with the M.V. Arctic, research that will focus on the operational requirements for year round commercial marine transportation in the Canadian arctic.

To guide the research activity into the next decade, the Canarctic Shipping Company Limited has designed an Arctic Winter Research Program. This program has been developed to address the need for safe and efficient commercial marine transportation during extended winter season operations. The program has received the support of the Canadian Marine Transportation Administration, the Transportation Development Centre, and the Canadian Coast Guard.

The thrust of the program will be twofold. Firstly, to solve problems associated with all aspects of mid-winter Arctic commercial ship operations including: vessel manning requirements, navigation in ice in darkness, communications in the high Arctic zone, vessel manoeuvring and docking, vessel and personnel safety, and operations management. Secondly, to monitor vessel performance and structural safety utilizing the updated instrumentation system being installed as part of ice class upgrading. This system will also be capable of recording engineering and structural data from full scale tests conducted with the vessel. Due to the broad range of problem areas to be examined it is expected that Canadian industry and government will share in both the costs and the benefits of the program.

Further details on the program, and the implementation of specific tests, are available from:

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