SESSION III

CHAIRMAN'S COMMENTS - J. Doherty

The Chairman opened the session by reviewing the history of the use of air cushion technology for icebreaking and the part that Transport Canada and in particular, the Canadian Coast Guard and the Transportation Development Agency, had played in its development.

As a result of the 1971 Sunoco Trials at Great Slave Lake using the Arctic Systems air cushion transporter, it was demonstrated that this vehicle could break up to almost 30 inches of ice. The significance of this discovery was recognized and further trials were carried out. In 1972 using the same vehicle at Tuktoyaktuk the capability was again demonstrated; in 1973 a small Terracross raft exceeded expectations during icebreaking trials in Montreal. In 1974 trials were carried out in Toronto, again using the Terracross raft and also the Hover-JaK air cushion raft. While these were carried out under some difficulties, the concept was again proven.

Also in 1974 to confirm a theory that had been developed, that the thickness of ice broken was directly related to the cushion pressure, the Coast Guard decided to carry out trials with Voyageur. The Voyageur trials confirmed this but also brought to light another unexpected method of breaking the ice at high-speed.

A government interdepartmental working group had been formed in 1972 of which I was Chairman, to look into this technology. This group had representatives from the National Research Council, Transportation Development Agency, Department of Environment, Department of Industry, Trade and Commerce, and Canadian Coast Guard Waterways and Operational Branches. This committee served a most useful purpose in that it brought together some valuable talent in the field of icebreaking, and gave support to proposed trials programs.

One of the technical papers which you are about to hear will review the slow-speed method of icebreaking as demonstrated by the combination of the Coast Guard Vessel Alexander Henry and the ACT-100. The other technical paper will cover the high-speed method as demonstrated by Bell Voyageur. It is interesting to note that Voyageur's operations in conjunction with the St. Lawrence Seaway and our Laurentian Region have been developed to the point that the Voyageur is now accepted as an operational icebreaker.

The third paper which is being presented on behalf of the Dominion Marine Association will review the economic and social benefits that would accrue if the St. Lawrence Seaway season could be extended and may indicate a part that the use of air cushion technology can play in this.

CONTINUING ADVANCES WITH AIR CUSHION ICEBREAKING*

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SUMMARY

The advent of air cushion technology for icebreaking promises to revolutionize the traditional methods of relentlessly pounding away at our ice barriers with high powered energy hungry ships.

This paper traces the history of air cushion icebreaking and its development in Canada, with particular regard to methods of assisting shipping to continuously navigate through intact ice cover, by attaching an air cushion platform to the bow of a ship.

The first successful full-scale trials of the air cushion bow platform concept were conducted at Thunder Bay, Ontario, during January-April, 1976.

The trials program is documented and the results discussed; from the initial findings it is concluded that for smooth freshwater first year ice, an air cushion platform attached to the bow of a ship can significantly increase the icebreaking envelope of that ship, at the same time providing a dramatic reduction in fuel consumption.

Following on from the successful trials, Transport Canada plans to develop this revolutionary method of icebreaking, which in this energy conscious era appears to have tremendous potential.

INTRODUCTION

Historically, water transport has served as a major stimulus to the nation's economy and even today water transportation is unchallenged in its capacity to move large tonnages with minimum fuel consumption. Unfortunately, Canada's climate dictates that for several months each year our waterways are ice covered, causing a serious impediment to navigation.

Our ice infested waters, particularly in the Great Lakes and Arctic, are the subject of growing government and industrial concern as economic pressures increase for an extended navigation season.

In recent years there has been an almost continual series of tests and studies of various icebreaking and ice clearance techniques conducted by

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* The subject matter of this paper will, in due course, be published as a much larger report by the Transportation Development Agency, Transport Canada.

many "ice-interested" nations around the world as efforts to extend the navigation season have become more intense.

Despite the concentrated efforts, there have been few revolutionary advances in the technology, and today's major icebreaking technique still consists of expending tremendous amounts of energy pounding away at the ice with the traditional heavy, high-powered conventional icebreakers.

Although the development of more sophisticated, economical, conventional icebreakers continues, it is heartening in these times when energy conservation is of paramount importance to know that there is now one revolutionary concept that has considerable potential for improving our icebreaking effectiveness - that is, by harnessing the principles of air cushion technology.

It is barely five years since the phenomenon of air cushion icebreaking was observed at Yellowknife, N.W.T., in 1971, during winter trials of a large air cushion transporter, ACT-100, conducted by Sunoco E&P Ltd. (Reference 1).

Since 1971, the Canadian government has pioneered the research and development of this unique and fascinating way of breaking ice.

As a result of promising findings from early trials, a multi-year program was developed within the Ministry of Transport to enhance conventional icebreaking capability by using air cushion technology.

This paper details one aspect of the development program, that of investigating the practical feasibility of attaching an air cushion platform to the bow of a ship, with particular emphasis on determining the effect of installing a full-scale air cushion bow platform on the continuous icebreaking capability of an icebreaker.

The highlight of the first phase of the program was the successful full-scale trials of the concept. These trials were conducted at Thunder Bay, Ontario, by the Canadian Coast Guard, under the auspices of the Transportation Development Agency of Transport Canada, between January and April, 1976, using the Canadian Coast Guard light icebreaker, CCGS Alexander Henry and Arctic Systems Ltd. air cushion platform ACT-100.

BIRTH OF THE CONCEPT

As previously mentioned, the recognition that air cushion vehicles had an ability to break ice over which they are propelled was first significantly demonstrated during the ice bearing trials with the ACT-100 air cushion transporter, that were conducted by Sunoco E&P Ltd., at Yellowknife, N.W.T. during the winter of 1971-72.

Since the Yellowknife trials, the Canadian government has initiated several full-scale trials and model tests with the object of understanding and evaluating the potential of this type of icebreaking (Reference 2). Both air cushion platforms and self-propelled ACVs have been used. From the experiments conducted, it was found that there were two distinct speed regimes where the air cushion icebreaking phenomenon occurred. For simplicity, these are known as "high-speed" and "low-speed".

In the high speed case, discovered during tests with the self-propelled CCG Bell Voyageur (Reference 3), at velocities near and above "hump-speed" a wave system is generated, causing the ice to flex and break. This method has been used very successfully by the CCG Voyageur during the past two winters, for ice clearance and flood control work in the Montreal area (Reference 4). However, it is the low-speed method that is more applicable to the bow platform concept.

UNDERSTANDING THE PHENOMENON

From close observation of the early trials, an informal understanding of how an air cushion vehicle breaks ice in the low-speed regime has been formulated.

As the air cushion vehicle approaches the edge of an ice sheet, or operates over a hole in the ice, the air pressure generated and contained within the vehicle's flexible skirt system depresses the water level beneath the vehicle relative to the surrounding surface by an amount equal to the air cushion pressure head. As the vehicle moves on to the ice sheet, the skirt rides up over the ice still maintaining its air seal. The ice sheet penetrates the pressurized air zone where the depressed water level allows an air cavity to form between the ice and water, which extends forward and around the advancing vehicle. The ice sheet with the buoyant force of the water removed, has now become a cantilevered ledge, which will fail under its own weight when the cantilevered section reaches a critical length, failure occurs when the stress in the ice at the forward end of the cavity (cantilever root), due to the ice weight, exceeds the failure stress of the ice, the overhanging ice section then breaks away and falls into the water below. See Figure 1.

Experiments to date have shown that using the low-speed method, significant thicknesses of ice can only be broken if the cushion pressure is relatively high; this implies considerable drag at high-speed, and therefore, it is not practical to make vehicles, using this technique, self-propelled for high speed.

It was felt that the low-speed method might have an application to assisting ships to navigate through ice cover, if the ACV could be associated with the ship.

MODEL TESTS

Early in 1974 the ACV Division of MOT formulated a model test program, using the CCG icebreaker "Norman McLeod Rogers" with the "ACT-100" fitted across and around the bow. These tests took place in the Arctec Incorporated model basin at Savage, Maryland, in July 1974. (Reference 5).

The model tests indicated that the ship's resistance in ice could be reduced by up to 30% by the use of the air cushion bow. As a direct result of these tests, a design study for an air cushion icebreaking platform to be fitted to the CCG Icebreaker "Montcalm" was commissioned in early 1975; Bell Aerospace Canada won the study contract, and completed the study in April, 1975. Figure 2 shows an artist's impression of the study platform.

DEVELOPING THE CONCEPT

Following the encouraging results of the initial model tests and the Bell Study, a multi-year program was proposed to enhance conventional icebreaking capability by the use of air cushion bow platforms on both CCG icebreakers and commercial vessels.

A second series of model tests were conducted, this time the ACT-100 was matched with the CCGS Alexander Henry. The tests were carried out in the Arctec Canada facility in Montreal during the latter months of 1975. The tests consisted of running the ship with and without the ACT-100, in both the notched and unnotched configuration, in simulated (wax) ice. See Figure 3.

Although these model tests showed that the ship's resistance was considerably reduced when operating with the platform attached, problems associated with scale effect and "model ice" characteristics made it abundantly clear that the only reliable and timely method of proving the practical feasibility and potential of the concept was to conduct a full-scale trial.

TRIALS PROGRAM

Objectives

The test program developed for the initial full-scale trials was aimed at determining the handling and maneouvering capabilities of a ship operating in solid first year, relatively smooth ice cover, with an air cushion bow platform attached, breaking the ice ahead of the ship's bow in the continuous icebreaking mode; and to measure the icebreaking performance of the ship with and without the bow platform attached. The specific objectives being:

a) to determine the handling characteristics of the bow platform/ship icebreaker combination;

b) to determine the resistance reduction afforded by the bow platform in the continuous icebreaking mode, up to the limits of the platform;

c) to determine the effect of the air cushion bow platform on clearing ice from the track astern;

d) to correlate data for model scale experiments;

e) to obtain a better understanding of the mechanism of air cushion icebreaking.

General Discussion

Since the projected trials were without precedent on this scale and scope, it may assist the reader to appreciate the later sections of the paper if at this point the previous air cushion platform icebreaking demonstrations are related to the trials objectives.

All demonstrations to date had indicated that the ice sheet beneath the air cushion platform failed as a cantilever in bending, provided that the air cushion pressure head was slightly in excess of the ice thickness, thus allowing the air to displace the water buoyancy under the ice sheet advancing into the cushion.

With a lift air system capable of delivering an air pressure up to about 76 cms (30 ins) of water, it was expected that the ACT-100 would be able to break ice up to approximately 70 cms (27-1/2 ins) thick.

Experience from the model tests had shown that the ship resistance, and hence the thrust requirement, was significantly reduced, typically in the range of 30-40%. (Reference 5). These tests had also indicated that the track astern would be considerably cleared of ice.

The early towing trials with the ACT-100 at Yellowknife (Reference 1) and Tuktoyaktuk (Reference 2) had also indicated that the width of the broken track would be wider than the air cushion platform.

These, therefore, were the broad basic points to be verified, together with technical information that would be gathered to assist in the design of any future air cushion bow platform.

FACILITIES

The Icebreaker

The pushing ship allocated to the trials program was the Canadian Coast Guard light icebreaker and buoy tender, "Alexander Henry". See Figure 4.

This ship is a diesel engine-powered, twin screw vessel with a maximum rated power of 2648 kw (3550 shp), giving a cruising speed (open water) of 12 knots. She has an overall length of 64m (210 ft) and a breadth of 13.25m (43 ft 6 ins), with a displacement of 3195 tonnes (3145 long tons), and a draft of 5.8m (19 ft).

Normally, this ship cannot navigate continuously in ice thicker than about 30 cms (12 ins); even within this capability the ship is continually thrown off course by ice impact and the resulting track is far from straight and heavily congested with ice.

The Air Cushion Bow Platform

The choice of bow platform to be used for the trials was dictated purely on availability of a craft of adequate size and cushion pressure. The only platform available in Canada was the Arctic Systems Ltd. air cushion transporter, ACT-100. See Figure 5.

During the fall of 1975 the ACT-100 was transported from Inuvik, N.W.T. to Thunder Bay, Ontario. There the craft was reassembled and underwent major structural modification to provide a 4m (13 ft) deep vee notch at its aft end to accept the bow shape of the CCGS Alexander Henry.

The modified ACT-100, re-named A.S.L. Iceater I, at the commencement of the trials was originally built in 1971 as an experimental air cushion transporter designed to explore the possibility of oil drilling and heavy equipment transportation in the fragile tundra regions of northern Canada.

The platform is rectangular in plan form, 24.4 x 18.3 m (80 x 60 ft), with a notch depth of 4m (13 ft). The platform hull is of steel construction built to marine standards, with a plate thickness of 4.8mm (3/16 ins).

It was never intended that the platform should operate as an icebreaker when initially designed (future air cushion bow platforms would be suitably ice strengthened).

The air cushion is contained by an ACE designed loop segment skirt, which gives the platform a hoverheight of 1.4m (4 ft.) above the water/ice surface.

The two fans used to generate the air cushion deliver a maximum airflow of 40115 dm/s (85000 cfm) each, giving a maximum cushion pressure of 7.5 kpa (1.1 psi) and are driven by two Caterpillar D348 diesel engines capable of delivering 746 kw (1000 hp) each. The platform has a lightship displacement of 190 tonnes (186 long tons), and a maximum operating weight of 262 tonnes (258 long tons).

Test Area

The test area selected for the trials was Thunder Bay, Ontario. A Canadian Coast Guard sub-base is established there, with a dock and facilities to support the Alexander Henry. An area adjacent to the dock was graded to provide a beaching site for the "Iceater".

The tests were conducted outside the harbour at Thunder Bay. The base and test area are shown in Figure 6.

Modifications Required for the Trials

Prior to the trials the Alexander Henry and the ACT-100 were not a matched pair and both required some modification.

Previous model test experience and practical handling considerations dictated the notch configuration for the platform.

The centre aft section of the ACT-100 was modified to a vee notch configuration to fit the bow of the Alexander Henry. A new skirt and sealing arrangement to minimize the air loss between the platform and ship; to establish the cushion pressure as close to the ship's bow as possible, and to allow the ACT-100 to still hover independently, was provided. Figure 7 shows the notch seal arrangement.

In order to ensure the correct pushing attitude between the ship and the bow platform and also to accomplish a good air seal around the ship's bow, two minor modifications were carried out on the ship. A vertical pushing post was welded onto the bow stem and the anchor pockets were closed off by adding hinged doors. See Figure 8. It is worth noting that these modifications had minimal cost impact and in no way interfered with the normal operation of the ship.

When the air cushion bow platform is pushed by the ship, there is no rigid attachment between the two vessels. The ship nestles into the platform's notch, and is held with restraint cables to prevent surge, but the platform being free to pitch and heave, whilst roll and yaw are limited by the notch geometry.

The method of attaching the platform to the ship had aroused much discussion during the program development as to whether the platform should be rigidly attached or free to pitch and heave. All previous experience had been with freedom in these motions, and also as a rigid connection would have added considerably to the modification and cost, it was decided to go with the free-floating, soft-coupling approach. Figures 9 and 10 show the linked combination of the CCG Alexander Henry and ACT-100 (Iceater I).

Data Acquisition

In order to carry out a thorough test evaluation, a comprehensive data gathering program was planned. This basically consisted of measuring sufficient propulsion system parameters, speed of advance, ice and snow data, together with general meteorological observations, so that the icebreaking potential of the bow platform could be established. The bulk of this work was contracted to Arctec Canada Ltd., and covered essentially three main areas - ice properties, ship parameters, and air cushion platform parameters. In addition, these data were supplemented by visual recording taken on both the ship and the platform; still and movie photography to record the icebreaking action and effect, meteorological data; general technical observations and closed-circuit TV video coverage of the icebreaking action under the air cushion platform.

A complete list of the parameters measured, grouped by source, is shown in Tables 1, 2 and 3.

TABLE 1
DATA PARAMETERS MEASURED
SHIP - ALEXANDER HENRY

Parameter	Method
Propeller Shaft RPM (Port & Stbd)	Magnetic pick-off probes - signal to oscillograph trace recorder.
Propeller Shaft Torque (Port & Stbd)	Strain gauges and transmitter - signal to oscillograph trace recorder.
Propeller Shaft Thrust	Thrust block load cells-signal to oscillograph tracer recorder.
Engine Fuel Consumption	Ship's normal instrumentation - visual reading.
Speed of Advance	Modified chip log system - block time signal to oscillograph trace recorder.
Draft & Trim	Visual readings.
Outside Air Temperature	Thermometer - visual reading.
Wind Speed & Direction	Anemometer and Vane - visual reading.
Water Temperature	Thermometer - visual reading.
Water Depth	Sounding machine - visual reading.

TABLE 2
DATA PARAMETERS MEASURED
AIR CUSHION PLATFORM (ICEATER)

Parameter	Method
Cushion Pressure	"U" tube manometers and differential pressure gauge - visual readings.
Engine/Fan RPM	Tachometer - visual reading.
Pitch & Roll Attitude	Fluidic pendulums - signal to oscillograph trace recorder and bubble type inclinometer - visual reading.
Engine Fuel Consumption	Dipstick - visual reading.

TABLE 3
DATA PARAMETERS MEASURED
ICE CHARACTERISTICS

Parameter	Method
Snow Cover	Measuring stick - visual.
Ice Thickness	Measuring stick - visual.
Ice Flexural	Cantilever beam test - visual reading.
Ice Temperature	Thermometer - visual reading.

Conduct of the Trials

The trials program commenced on 15 January, 1976 with the launching of the modified ACT-100; after initial shakedown runs to check out mating and deployment procedures and safe ship handling, the measured test runs started on 26 January. During an extended three day test away from base, 26-28 January, two sets of data were gathered, but several technical and financial problems were experienced and testing did not re-commence until 25 February.

Due to the ice growth and the limited continuous icebreaking capability of the Alexander Henry, the 25 February test and one test during January were the only ones carried out with the ship alone. As the ice thickness increased, the ACT-100 was "ballasted" to increase the cushion pressure from the "light" condition of 51 cms (20 ins) water-head to a maximum of 74 cms (29 ins). This was done in three discrete steps, by adding concrete blocks to give deck loads of 36300, 54500 and 72600 kg (40, 60 and 80 tons), thus keeping the cushion pressure in excess of the anticipated ice thickness.

Testing continued with the mated combination in progressively thicker ice, with varying snow cover, until 24 March, during which time a total of 13 test runs were accomplished. In addition, four days of open water testing were achieved before the trials program closed on 9 April.

A total of 170 hours of operating experience was accumulated with the air cushion bow platform. This total was made up of 107 hours of data gathering tests with the remainder spent on operating familiarization and ice management evaluation.

The meteorological conditions during the trials were consistent with normal winter weather for the area. Temperatures ranged from a low of -30°C to a high of +6°C; wind speeds up to 40 knots were encountered and several heavy snow falls occurred.

Although not strictly part of the trial, as operating experience was gained, the Captain of the Alexander Henry used the mated combination of the ship and bow platform, on an opportunity basis, for ice clearance and management work in Thunder Bay Harbour.

The experience gained was very valuable, and on one occasion, a track was broken in from the main to south entrance of the Harbour a distance of 1 3/4 nautical miles in two hours, in ice averaging 64 cms (25 ins) thick. The Captain estimated that the ship operating alone would have spent about eight hours on the same task.

DISCUSSION OF TEST RESULTS AND TECHNICAL OBSERVATIONS

Icebreaking

With the air cushion platform attached, the ship showed herself to have superior icebreaking ability over the ship operating alone under the conditions prevailing at Thunder Bay.

The ship's resistance to navigation through an intact ice cover was significantly reduced by a factor of about 3 to 4 during operations in ice thicknesses ranging between 23 cms (9 ins) and 76 cms (30 ins), thus allowing continuous passage through ice about 2½ times thicker than the ship's normal capability, and at a reduced fuel consumption.

On 26 and 27 January, the Alexander Henry with the ACT-100, navigated through 37-42 cms (14-16 ins) thick ice at measured speeds of up to 8.9 knots. Using a similar power level in a later open water test the linked combination achieved a speed of just over 9 knots.

During a test run on 27 January, the ship detached the air cushion platform and attempted to navigate through 38 cms (15 ins) thick ice by herself. Charging the ice cover at full power, she was stopped after a penetration of approximately 100 m (330 ft); the power used being almost twice that of the run, with the ACT-100 attached, through the same ice at 8.9 knots.

As the ice thickened, so the speed of navigation through it decreased, typically to 4-5 knots in 56-61 cms (22-24 ins) thick ice; 3 knots in 73 cms (29 ins) ice and 2.5 knots in 76 cms (30 ins) ice.

Direct viewing and the closed circuit TV showed that the ice within the cushion was failing as expected; this resulted in the ship's bow suffering only minor impacts from ice floes, making course-keeping relatively easy and resulting in a straighter track astern. See figure 11. Failure of the ice extended beyond the air cushion platform, about 2-3 m (6.5 - 10 ft) each side, giving a wider track than normal. See figure 12. In 38 cms (15 ins) ice, the track width averaged 19 m (62.5 ft) compared to the ACT-100 waterline breadth of 15 m (50 ft). Track clearance immediately behind the ship was much improved compared to that obtained when the ship was operating alone. See figure 13.

Although only limited direct comparisons of the fuel consumption of the ship alone and the mated ship and ACT-100 could be made, it is significant to note that when comparing a test of the ship alone making effective progress by ramming of 1/2 knot using 723 litres/hr (159 gal/hr); with the ACT-100 attached operating in the same ice conditions, approximately 38 cms (15 ins) at a speed of 8 knots the combined fuel consumption of the ship and platform was 573 litres/hr (126 gal/hr). Therefore, a given distance could be covered about 15 times more rapidly with the ACT-100 attached, using 80% of the fuel. The net result being that the mated combination used approximately 5% of the fuel which would be used by the ship alone to cover the same distance.

The reduction in fuel consumption to carry out a given task appears to be of at least equal significance to the improvement in icebreaking performance and whilst one trial with few data points is not offered as a complete assessment, the order of magnitude improvement is such that there can be little doubt that the air cushion platform has great potential in ice of the type prevailing during the tests.

In the thicker ice, progress was occasionally halted, probably due to the ice being very elastic and hence bending rather than breaking, as the air cushion was prevented from permeating under the ice sheet; and also because of heavy wet snow cover which caused considerable drag increase due to snow ploughing of the ACT-100 bow skirt. Loose powder or hard packed snow had little effect on the platform's icebreaking ability; the loose snow was blown away, and the latter tended to act as additional ice thickness.

Remembering that ACT-100 was not designed for this type of work, it is considered that the icebreaking results were most impressive. The reduction in ship's resistance provided by the air cushion platform is of the same general order of magnitude as that found in the model tests reported in Reference 5.

By at least doubling the ice thickness capability of Alexander Henry, with no intact ice contacting the ship, not only would the ship's utilization be greatly improved, should the need arise, but also with no need to ram the ice, the hull maintenance and general propulsion machinery wear and tear should be reduced, along with a reduced fuel consumption.

The wider, straighter and clearer track should be of great assistance to a following ship when being escorted through ice cover.

Result Analysis

The traditional method of analytically determining the icebreaking resistance of a ship uses well established methods, with the data in a non-dimensional form and relates the resistance to ice strength, ice thickness and velocity. The addition of an air cushion bow platform brings into play a new set of parameters which interacts with, or supplants the traditional ones.

With the ice being broken by the air cushion platform cushion pressure head, and not by the ship, the ice immediately prior to failure is no longer supported by the water but by itself, and the failure is a function of the moments and shear forces of the unsupported ice. It therefore appears to be irrational to reduce variables with respect to parameters which are no longer significant in the failure process. For instance, the resistance term will be influenced by a function of cushion pressure, bow platform beam and bow platform Froude number based upon a waterline length.

In order to make valid comparisons between the ship operating alone and the ship/bow platform a new set of non-dimensional parameters which are independent of the configuration must be selected.

The data from the trials was subjected to regression analysis to obtain mathematical expressions for the thrust required to propel the ship, with and without the platform attached. The purpose of this was to simplify the comparison of the two "test vehicles" with one another and with other previously tested ships.

The results of the tests are summarized in Figures 14, 15, and 16. Figure 14 is a plot of measured propeller shaft thrust versus speed from the ship/platform combination. Superimposed on the plot are lines corresponding to dimensional and dimensionless mathematical expressions for thrust in terms of ship speed, ice thickness and strength.

It can be seen from Figure 14 that speed, ice thickness and possibly ice strength variations explain the variations in required thrust. The results of similar tests for the Alexander Henry alone are shown in Figure 15. From inspection of Figures 14 and 15 it is clear that the required propeller shaft thrust for the ship alone will be much greater than that for the Alexander Henry/ACT-100 combination in equivalent ice conditions at similar speeds.

In a further comparison of the ship, with and without the platform, the dimensional data was converted to dimensionless numbers and subjected to regression analysis. The results of this analysis are shown in Figure 16 which shows yet again the superior performance of the Alexander Henry when the ACT-100 was attached.

Ship Handling

When operating in ice, with the ACT-100 attached, the ship's handling and manoeuverability in unrestricted areas was, if anything, improved. Apart from protecting the ship against impacts with the intact ice sheet, the platform appeared to have a stabilizing effect on the ship's handling, and the turning performance was very good except when the platform was operated in the "high-weight" configuration in winds above 25 knots, when it was virtually impossible to turn into the wind.

During the icebreaking operations the relative motion between the ship and the bow platform was slight and mostly confined to pitch oscillation. This tended to confirm the merit of the notched soft-coupling approach used to link the vessels.

The limited experience over open water indicated that at speeds in excess of 5 knots, with the ACT-100, the ship had to operate at significantly higher thrust levels than when operating alone. As expected this effect was exaggerated with increased cushion pressure.

Spray

Heavy air cushion platforms inherently generate vast quantities of spray when operating over water. For the most part it is possible to suppress this spray, but unfortunately, the spray suppression apron fitted to the ACT-100 was not effective, resulting in reduced visibility and moderately heavy icing on both the platform and the fore part of the ship. In the lower temperatures, dense Arctic fog formed reducing visibility even more.

Fitting of an effective spray apron is perfectly feasible and the consequent reduction of spray would reduce icing and its attendant hazards.

Skirt Wear

The expectation that any air cushion vehicle operating in ice will be subjected to high incidences of skirt damage is always uppermost in one's mind when considering the use of ACVs for icebreaking work. Indeed the ice conditions adjacent to the Coast Guard Wharf at Thunder Bay presented a frightening picture of jagged lumps sticking up 60 cms (2 ft) out of the water, see figure 17, but the ACT-100 skirt dealt with this tortuous path with ease.

Prior to the Thunder Bay trials it was hoped that the ACT-100 skirt system would be completely renewed, but due to budgetary restraints this was not possible, so the skirt segments were a mixture of 'new' segments using the latest Avon skirt fabric of 3.34 kg/m^2 (99 oz/sq yd) weight and fabricated using a hot bonded process; and segments that had spent up to four years in the Arctic environment, and were of lighter weight 2.03 kg/m^2 (60 oz/sq yd) and constructed using a bonding and stitching technique.

Of the skirt damage sustained during the trials, the majority of incidents occurred in the 'old' segments and it is encouraging to note that of 39 damage incidents only two occurred in the 'new' type segments. The damage ranged from pinholes to large rips but most of the segments were repaired and returned to service.

It may be assumed that if all of the segments had been of the 'new' variety the number of damage incidents would have been much less and hence it is felt that whilst skirt development must continue, it has been demonstrated that harsh ice conditions can be successfully traversed by a large air cushion platform.

CONCLUSIONS

Experiments conducted to date show that the addition of an air cushion platform to the bow of a ship can greatly increase the icebreaking envelope of that ship when operating in first year, relatively smooth, fresh water ice.

Specifically, the ship is able to navigate continuously through considerably thicker ice; in the case of the Alexander Henry the increase was in the order of 150%.

In ice thicknesses which the ship can marginally handle alone, the addition of the air cushion platform greatly increases the ship's transit speed. In the case of the Alexander Henry navigating in 37-42 cms (14-16 ins) ice, the increase was 16 times.

To perform a similar task, the addition of the air cushion platform reduces the fuel consumed dramatically; with the Alexander Henry navigating in 37-42 cms (14-16 ins) thick ice, the overall fuel consumption with the bow platform attached was in the order of 5% of that required for the ship alone to transit the same distance.

The broken track produced by the linked combination was significantly wider, straighter and clearer; showing an improvement of approximately 40% over the track clearance of the ship alone operating in similar ice conditions, thus potentially making navigation of an escorted ship easier and effectively reducing ship operation time on ice management duties.

The addition of an air cushion platform does not adversely affect ship handling in ice, although in restricted areas and high winds operational techniques have to be developed.

The problems encountered with spray and the consequent visibility restriction, and skirt wear are all capable of solution and well within present technology limits. Overall, the Thunder Bay trials proved beyond doubt that in the conditions prevailing it was practically feasible to push an air cushion platform ahead of a ship and significantly increase the icebreaking capability of that ship.

While the analysis of the trials results continues, the initial findings indicate that a major advance in icebreaking technology has been achieved. Indeed, the success of the trials leaves little doubt that air cushion technology will play a significant part in future icebreaking operations.

It now remains to develop the technology and both the Canadian Coast Guard and the Transportation Development Agency of Transport Canada are actively engaged in planning the future development of air cushion bow platforms; with trials planned for attaching a platform to the bow of a commercial tug and an ice strengthened freighter this coming winter, and for the development of a prototype air cushion platform that can be fitted to the bows of various Canadian Coast Guard icebreakers, in order to investigate the performance of a platform on different ships operating in various ice conditions.

It is hoped that with these plans and their continuing development, the applications of air cushion icebreaking will be stimulated so that the full benefits of this technology can be realized to achieve a further extension of the navigation season.

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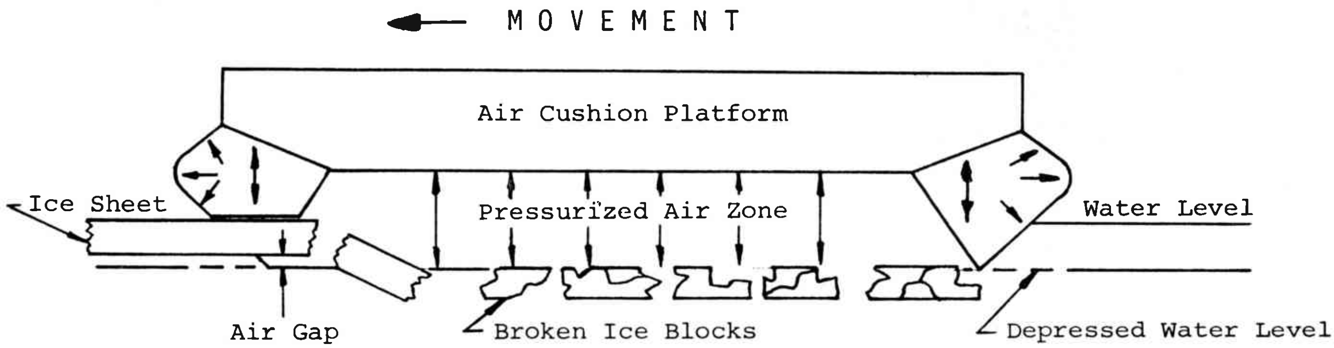

FIGURE 1
Low-speed air cushion icebreaking phenomenon

FIGURE 2
Bell Aerospace artist's impression of ACV bow
fitted to Icebreaker CCGS Montcalm

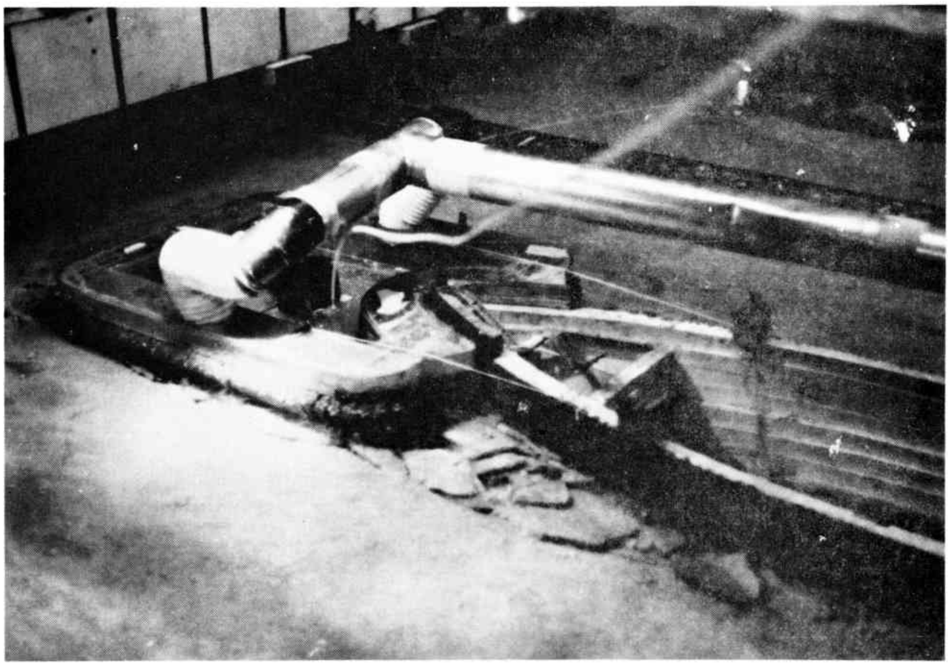

FIGURE 3
1/24 scale model of ACT-100 attached to Alexander Henry's bow for tank tests in simulated ice - Montreal, 1975

FIGURE 4
CCGS Alexander Henry

FIGURE 5
ACT-100 prior to modification

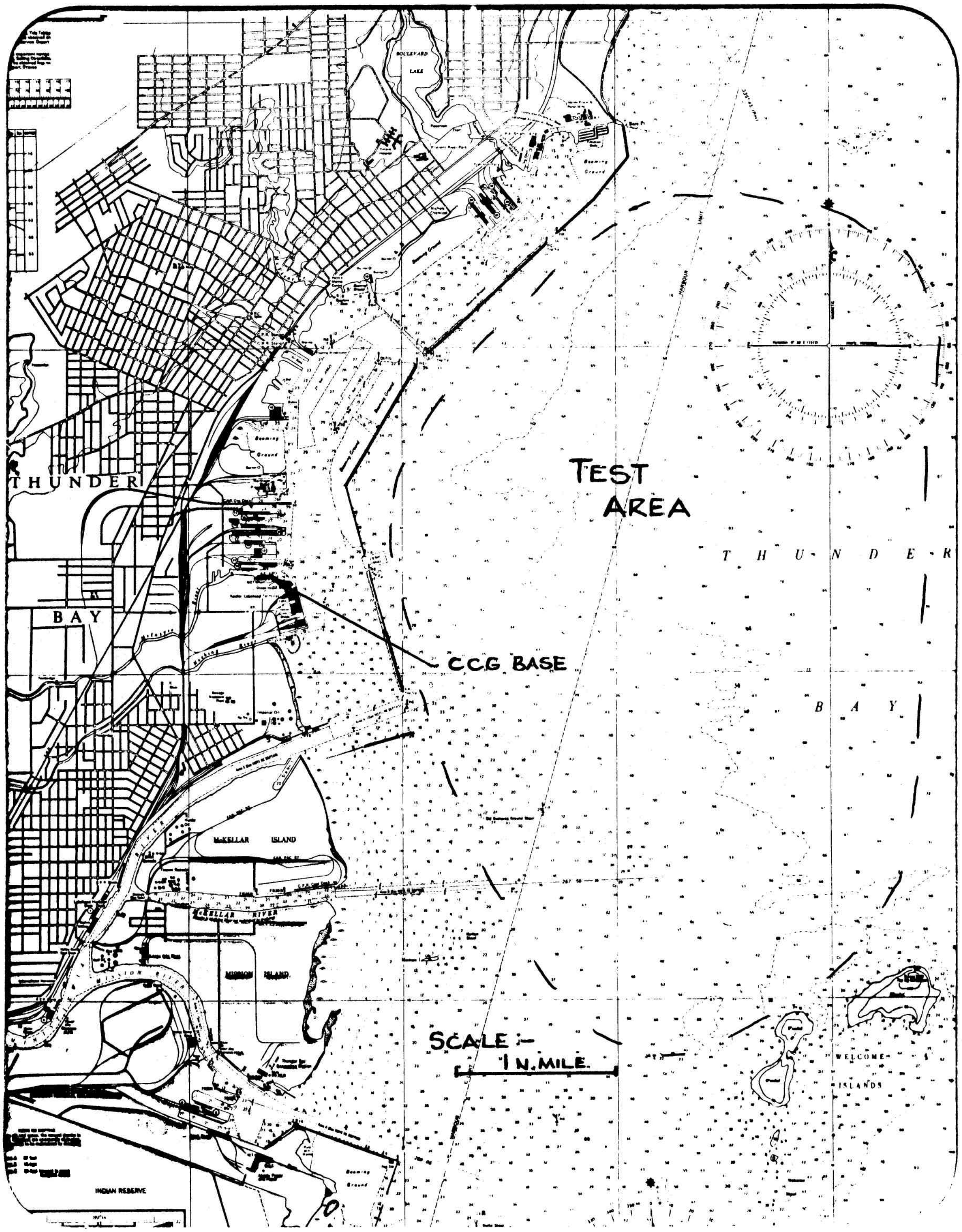

FIGURE 6

Chart of Thunder Bay showing CCG Base and test area

FIGURE 7
Notch seal arrangement

FIGURE 8
Modifications to Alexander Henry pushing post and anchor pocket doors

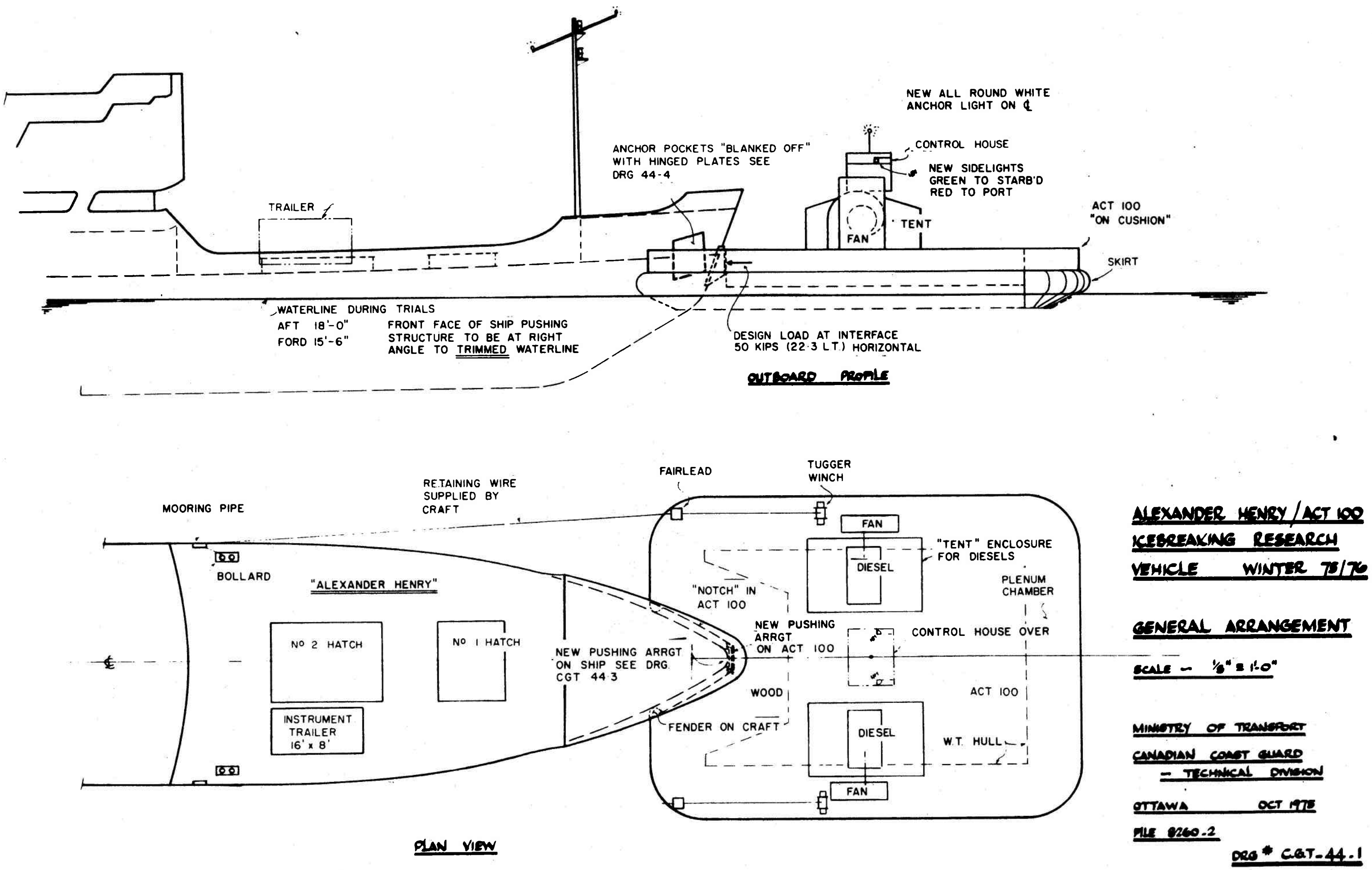

FIGURE 9

General arrangement of ship and bow platform

FIGURE 10
Linked combination - CCGS Alexander Henry with
ACT-100 (Iceater I) attached

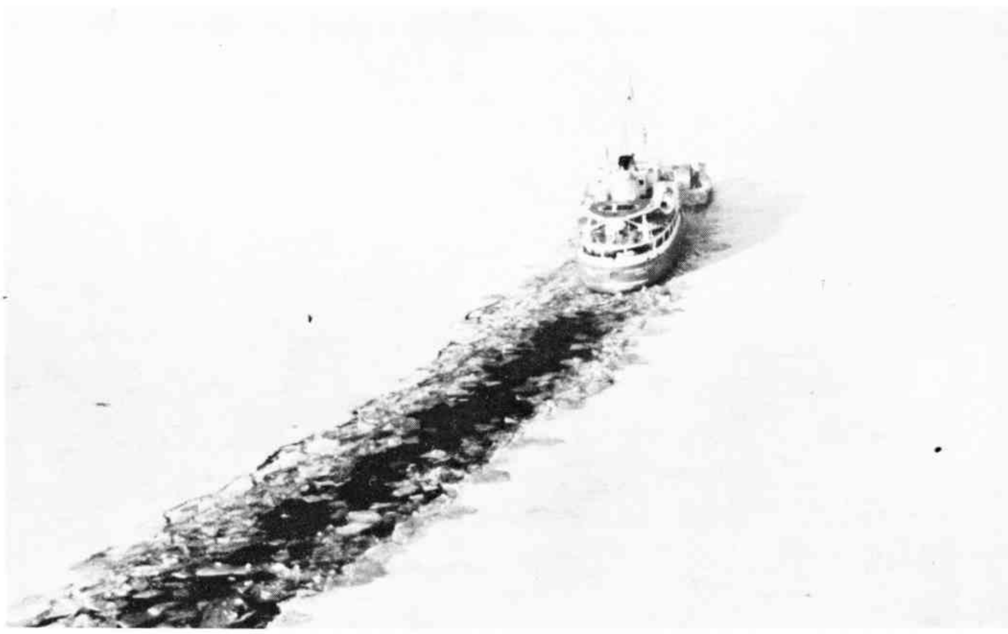

FIGURE 11
Track broken with air cushion platform attached to
Alexander Henry - operating in ice 37-42 cms (14-16 ins) thick

FIGURE 12
Alexander Henry with ACT-100 (Iceater I) operating in ice 61 cms (24 ins) thick. Note the cracking pattern and ice failing outside the skirt line.

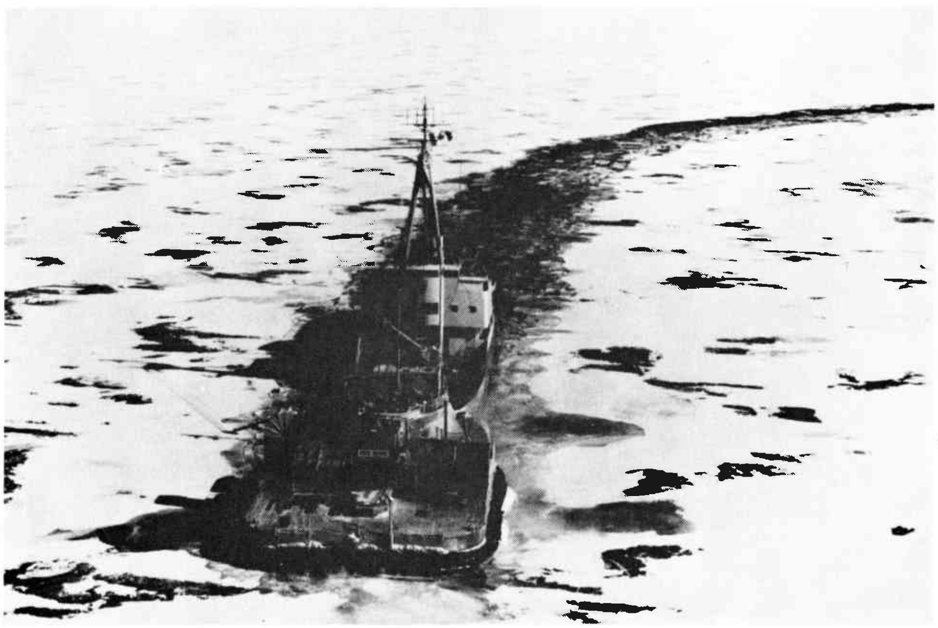

FIGURE 13
CCGS Alexander Henry with ACT-100 (Iceater I). Note the ice is broken along the side of the ship giving a wider effective track than with a ship operating alone.

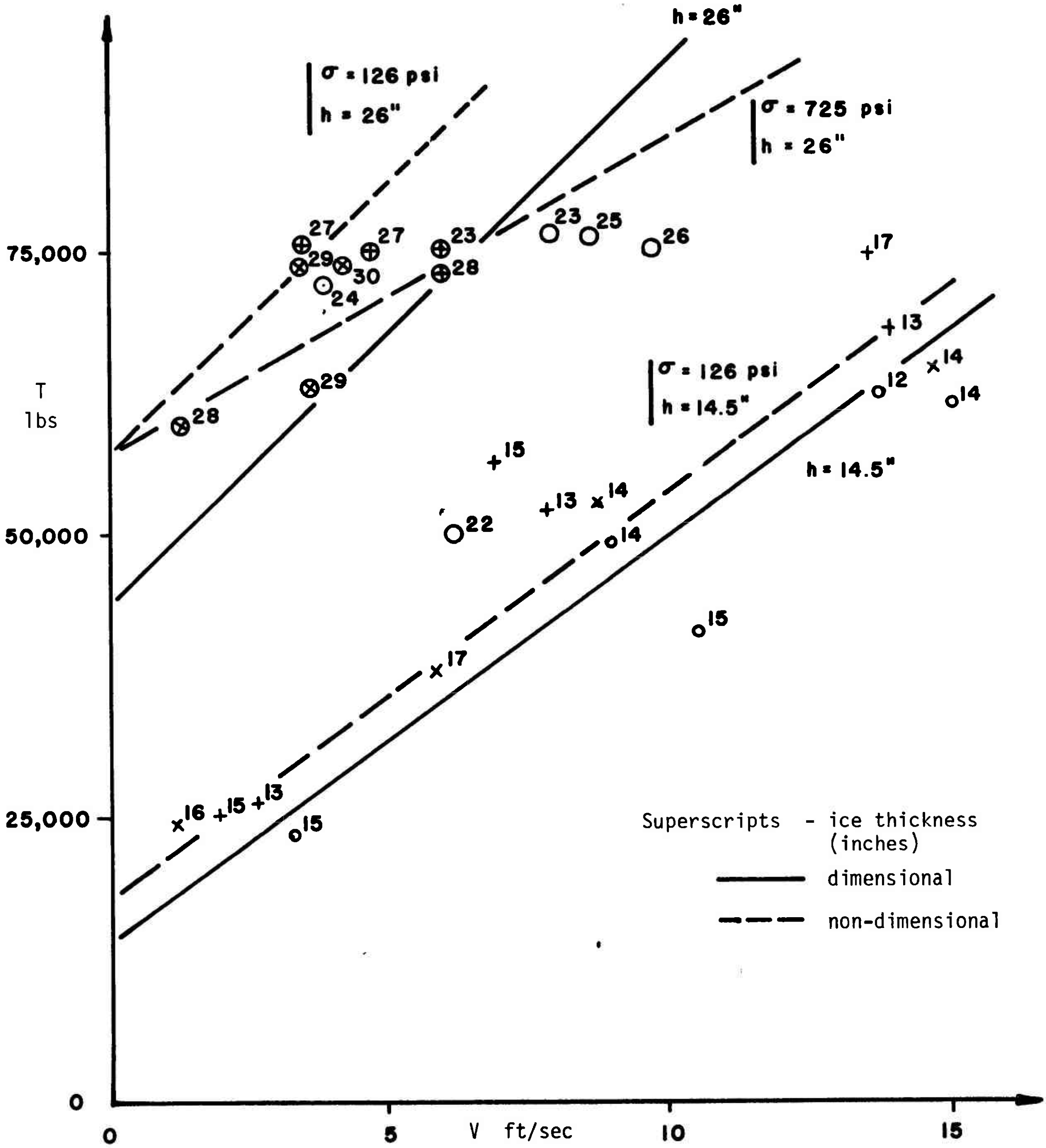

FIGURE 14

AH + ACT-100 Thrust versus Speed

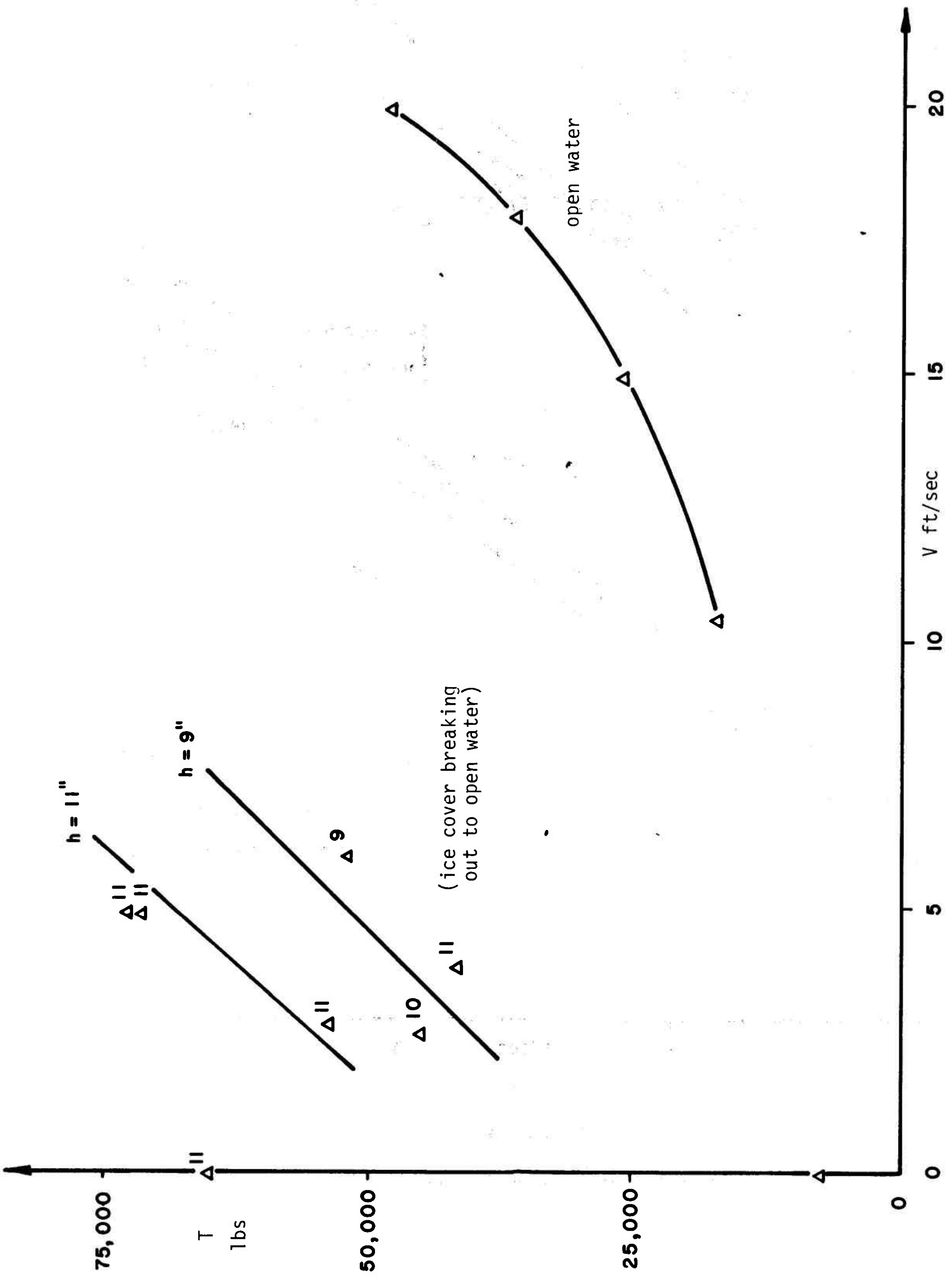

FIGURE 15
Henry alone - Thrust versus Speed

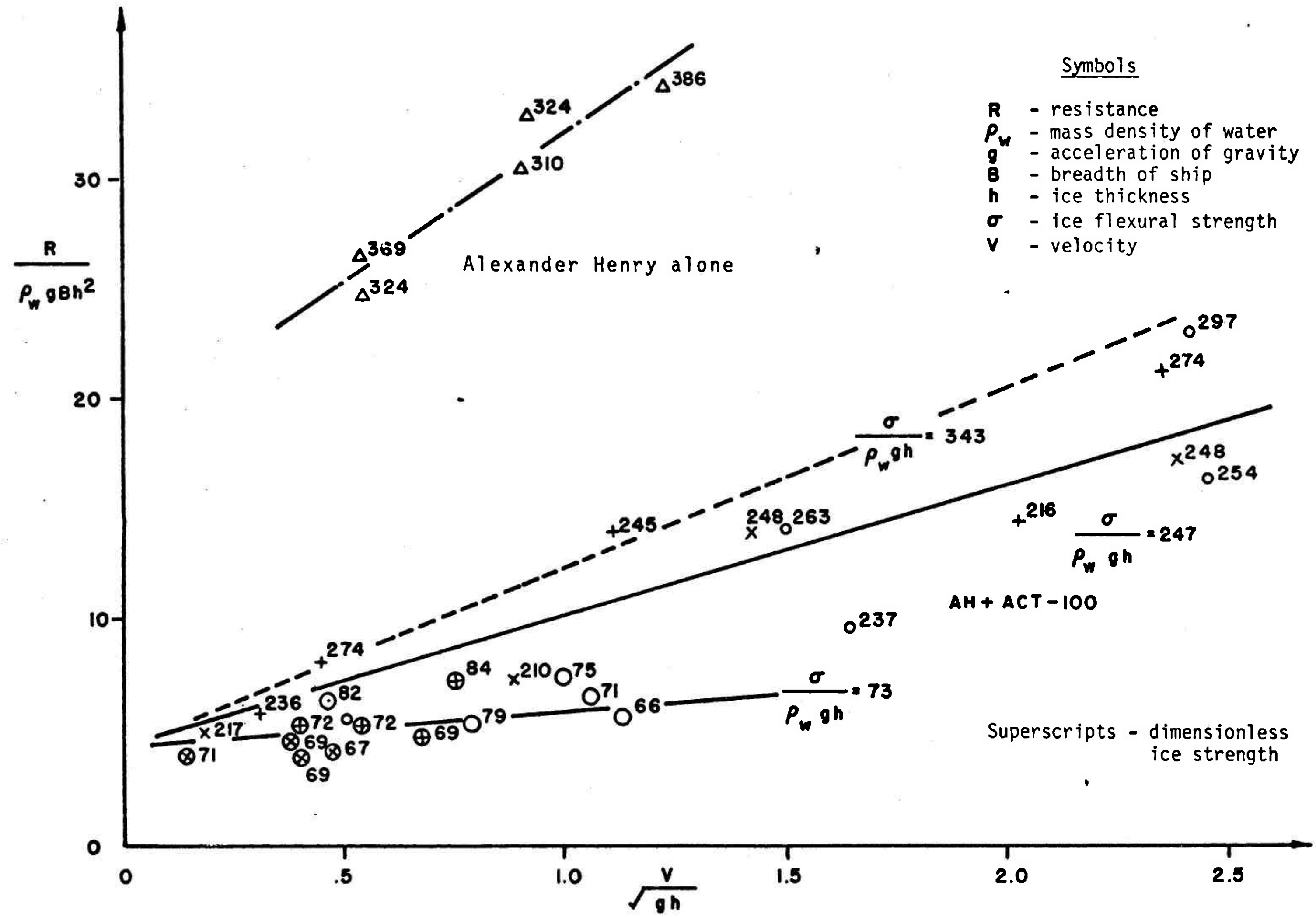

FIGURE 16
Dimensionless Resistance versus Dimensionless Velocity

FIGURE 17
ACT-100 (Iceater I) winching to Alexander Henry at CCG Sub-Base, Thunder Bay. Note jagged ice rubble.

THE HIGH-SPEED METHOD OF AIR CUSHION ICEBREAKING

B.W. Robertson
Canadian Coast Guard
Transport Canada

INTRODUCTION

For the past two years the Bell Aerospace Voyageur has been tested in a variety of Coast Guard roles; one of the most encouraging of these has been icebreaking in first-year freshwater ice. The icebreaking phenomena originally presented to the CASI in 1974 (reference 1) has been expanded upon and documented by the Canadian Coast Guard Air Cushion Vehicle Evaluation & Development Unit. References 2 and 3. Each series of high-speed icebreaking tests that the craft undergoes reveals even greater accomplishments than were first anticipated, but still a full understanding of it all alludes us.

Preliminary calculations made on the low-speed icebreaking method indicated that an ACV could break ice of a thickness proportional to its cushion pressure expressed as a head of water. With Voyageur, this would be 23 cms (9 ins) of ice thickness at 15 to 33 km/hr (9-21 mph). The test in Parry Sound set out to prove this theory.

The Bell Voyageur, designed as a multi-purpose cargo carrier with a 21000 kg (46297 lbs) payload capacity has a maximum all up weight of 40000 kg (88000 lbs) and is powered by two Pratt & Whitney Twin-pac multiple fuel turboshaft engines, model ST67-75, developing a maximum of 2536 kw (3400 HP). Reference 4.

DISCOVERY

While proceeding to the Georgian Bay test area for low-speed trials, the transit speed was in excess of 32 km/h (20 mph). As the craft passed through "hump-speed", roughly 29 km/h (18 mph), a large wave was noticed astern of the craft similar to that produced in water. At its maximum the wave is stable at one-half craft length astern with an amplitude of 1.4 meters (4-1/2 ft.). A broken track of 76 m (250 ft.) in width was left in the ice measuring 45 cm (18 ins.) thick. This discovery of a high-speed method of breaking ice opened an entirely new concept in ACV icebreaking.

DEVELOPMENT

Further trials were carried out in the Montreal area using the same craft. Due to the lack of suitable ice for recording scientific data, the craft entered a fully operational program, breaking ice in shallow rivers and clearing Lake St. Louis for the opening of the 1975 shipping season in the St. Lawrence Seaway. Some valuable information was documented as to how this new resource might be best used.

Operating at or below hump-speed over open water tends to generate spray which can cause the accumulation of ice on the craft at or near freezing temperatures; however, this speed is essential for producing a high stern wave which will be carried into the ice. Maintaining the largest possible stern wave under these conditions requires absolute speed control. This is accomplished by running on the ice parallel to the ice edge and adjusting speed to allow for the changes in water depth. As the depth decreases so must the craft's speed decrease in order to maintain the same wave height. Just outside the deep water channel of Lake St. Louis, the water depth varies between .3 and 3 m (1 and 10 ft) which would require speeds ranging from 19 to 29 km/h (18 mph). Approaching the ice at 90° to the ice edge at full power as a conventional icebreaker does, would only succeed in breaking the first 6 m (20 ft) or so. From there on, the craft would shoot along the ice like a hockey puck. Carving off the ice in this matter 3 sq km (1.2 sq m) of 45 cm (18 in) ice can be cleared each hour. Reference 2.

This year during recent clearing operations in Lake St. Pierre, this figure was increased to 24 sq km (7 sq m) of 62 cm (24 in) ice being cleared in one hour under spring thaw conditions. Reference 5. The date was 3 April 1976.

FLOOD CONTROL

This spring Voyageur had a brief but dramatic encounter with ice causing record flood conditions in some tributaries of the St. Lawrence River. Voyageur broke ice at the mouths of the Nicolet, St. François, Richelieu and Bécanour Rivers, advancing up rivers as far as the first impass clearing upwards of 105 cm (41.3 in) thick ice in the process. The high water level of the Bécanour River prevented the craft from passing under the highway bridge to release jammed ice further up stream. With the assistance of the local police, traffic on the highway was stopped permitting Voyageur to cross the highway under her own power to continue the ice clearing operation up-stream of the bridge.

As a result of Voyageur's efforts in these rivers, the flood waters were forced to crest prematurely permitting the swollen rivers to flow faster and thus reduce the flood levels. In the Richelieu River area residents were evacuating their homes which were threatened by flood water 5 m (17 ft) above normal. After 16 hours of icebreaking effort, Voyageur forced the river to crest which allowed the flood waters to drop 45 cm (18 in) in an hour thus permitting the residents to return to their homes.

During this operation it was dramatically demonstrated that an ACV can break ice in shallow restricted waters which is not possible for conventional icebreakers. It can also cross over highways to continue up-stream of flooded bridges, a very unique characteristic. Together with its unequalled speed for clearing lakes, it can get around ice jams without releasing shore fast ice. It can transit open water at speeds up to 110 km/h (69 mph) to check and remove small jams before they can block the entire channel.

HOW DOES IT HAPPEN?

The factors attributing to the unexpected success of highspeed ACV icebreaking are still under investigation. One unofficial theory as to the physics of ACV icebreaking is that related by the ACV Evaluation & Development Unit. We believe the greatest factor contributing to an ACV's efficiency in breaking ice is that of its wave-making capabilities. Based on the observations that the most energetic icebreaking takes place behind the craft, in its wake, also the effect of land forms, which magnify or diminish wave height also increase or decrease the effectiveness of high-speed ACV icebreaking.

Briefly as we see it, an air cushion vehicle at rest but on cushion displaces water similar to a vessel with a solid hull. This depression in the water is approximately 23 cm (9 in) deep for Voyageur. When the craft is put into motion it generates a series of waves like any flat sterned vessel. The first wave is a compression wave which precedes the craft for a distance of 900 m (1/2 mile) but its amplitude is very shallow, perhaps 5 cm (2 in). This wave is not perceptible in deep water but can easily be seen on the shore of a channel before the craft passes a given point. As this compression wave advances under the ice sheet, it lifts the ice ever so slightly over a large area. In the depression following the compression wave is the concentrated weight of the craft exerting a downward force of 36000 kg (80000 lb). This is only

1.9 kpa (.27 lbs/sq in); however it is in a depression between two wave crests and the weight of the ice itself would normally contribute more to the downward force than the craft would indicating that the function of the craft is primarily a wave generator. Directly behind the advancing craft is the stern wave caused by the sub-surface water rushing into the depression left by the craft. This return of the water to its original level is slightly over exuberant and causes the water to pile up in a wave approximately 1.4 m (4-1/2 ft) high. This wave action is transmitted laterally as well as in the direct line of the craft but its energy and breaking action are reduced.

The failure of ice as thick as 80 cm (31-1/2 ins) is not visible to observers on the craft or on the ice at the time of the craft's passing but very slight vibrations are felt by those on the ice. In less than 30 minutes after the craft passes, the ice can be seen to separate with the current showing a random cracking pattern over the entire area where the craft was operating. The remaining ice outside the Voyageur's track remained intact.

Without the aid of sensitive instruments, we were unable to determine the forces and pressures that contribute to the failing of this thicker ice. It was noticed, however, that the thick ice can be broken easier and at higher speed in deeper water than the same ice in shallower water resulting in the extremely rapid clearing rates mentioned earlier.

Other factors which determine the amplitude of an ACV's wake and ice-breaking effectiveness are craft trim and effective beam. Better icebreaking results are realized when the rear of the craft is as heavy as possible causing a greater depression and thus a higher stern wave. The actual breadth of an ACV cannot be altered easily to facilitate icebreaking but the effective breadth can be increased by simply turning the craft 90° to the line of advance while the craft is in motion. This causes the ACV's length to act as the effective breadth and thus increase both the compression wave and the stern waves.

RESTRICTING FACTORS

Brief encounters were made with salt water ice on the north shore of the Gulf of St. Lawrence which revealed little difference from fresh water ice in the failing pattern or extent of breaking action. There was a noticeable reduction in the amount of craft icing experienced than would have been expected in fresh water conditions at the same temperature of -3°C. This corresponds to observations made aboard ships for years.

Successful icebreaking operations were also conducted in snow covered ice, frazil ice, grounded ice, jammed ice and harbour ice with varying degrees of success.

During our tests in Montreal Harbour, the ice was approximately 38 cm (15 in) thick, well within the known capabilities of Voyageur. The ice broke to the pier faces in all directions but was not carried away due to the lack of a current. The restricted maneuvering room around ships' and mooring lines hampered the most efficient use of the high speed icebreaking method but the ice was thin enough to fail under the attempt permitting vessel movement.

Montreal Harbour also experiences large pans of drifting ice which form in the shallows to a thickness of 70 cm (27-1/2 ins), then separates from the shore or shallows due to rising water or a ship's wake. These pans of ice are one of the major causes of ice jams in the St. Lawrence River. In the main channel, away from hazards, Voyageur can break these large pans of ice into small harmless chunks in a matter of minutes using the high speed method.

Any ice can be snow covered but Voyageur's progress was not impeded by the 20 cm (8 ins) of snow cover on Lake St. Louis. Up to approximately 30 cm (12 ins) of snow cover the ice will break as well as if the ice were clear. This is believed to be due to the increased thrust required for the craft to push through the snow giving the craft an added stern-down attitude which increases the icebreaking effort. Unfortunately, the full extent of the cracking pattern cannot be appreciated under the layer of snow. Snow thicker than 30 cm (12 in) prevents any ice breaking action from being observed. The craft can travel over snow covered ice without any indication of ice failure providing the craft speed is in excess of 45 km/h (28 mph).

Jammed and irregular ice is very hazardous for an air cushion vehicle to negotiate due to the rafted height and abundance of crevices where air can escape from the cushion causing skirt or hull damage or possibly trapping the craft. Relieving jammed or rafted ice can only be accomplished by keeping the craft in the water and trying to separate the ice by the action of waves generated in the water by turning maneuvers at 18 km/h (11 miles/hr).

Grounded ice is relatively difficult to release with an ACV but the same ice is impossible to release with a ship. Provided the ice does not protrude more than 91 cm (36 ins) from the water the craft can cross over a grounded ice flow in an attempt to break it into smaller pieces of rock while attempting to dislodge the lower extremities of the ice flow. Occasionally, large pans of ice will ground due to an accumulation of frazil ice crystals adhering to the bottom of the solid ice. These ice crystals can be eroded down by patiently rocking the ice flow.

APPLICATIONS

Its past accomplishments in icebreaking as well as other winter and summer operations has prompted many progressive individuals to consider the possibilities of high speed ACV icebreakers to: keeping commercial waterways open during the winter months; preventing flooding in coastal and inland rivers; providing ferry services across ice-choked rivers or straits; and to becoming primary commercial transportation in the Canadian Arctic for the massive wheat and oil trade.

The air cushion vehicle has a definite place in the icebreaking fleet of the Canadian Coast Guard although it is not the answer to all our problems. An ACV relies on a certain amount of support from nature to clear the broken ice. ACVs cannot displace the ice from a channel for escorting ships. The current or wind must clear the ice or the first escorted ship must displace the ice itself. An ACV cannot work in rafted ice as well as a full icebreaker but it does have limited success.

Present day ACVs cannot spend days of concentrated effort on ice jams without returning to a temporary base for a crew change. It is also susceptible to freezing spray, which frequently increases the craft weight forcing it to stop and de-ice to avoid becoming over-weight from ice accumulation.

From the growing evidence we have to date, an ACV could become a major resource for breaking ice in lakes, rivers and channels and the only resource capable of clearing ice from non-navigable rivers or shallows.

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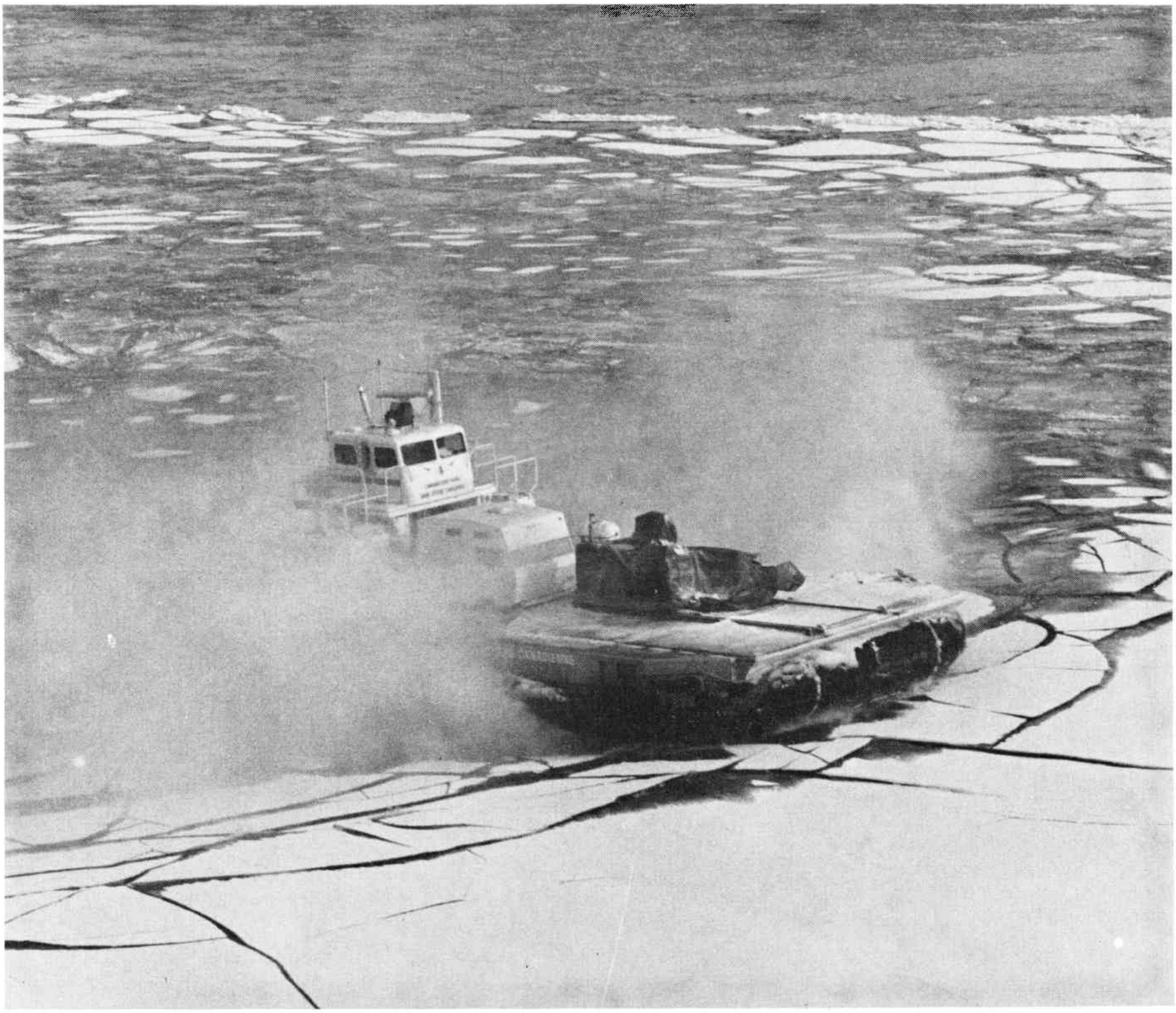

FIGURE 1

Voyageur approaching ice 30 cm (12 ins) thick showing evidence of bow compression wave as ice breaks ahead of the craft from the upward force of the wave. Note the water spilling onto the ice and the cracking pattern radiating from the craft (lower left to centre right).

Air and spray are escaping from under the skirt as the depression in the water extends deeper than craft's skirt (centre).

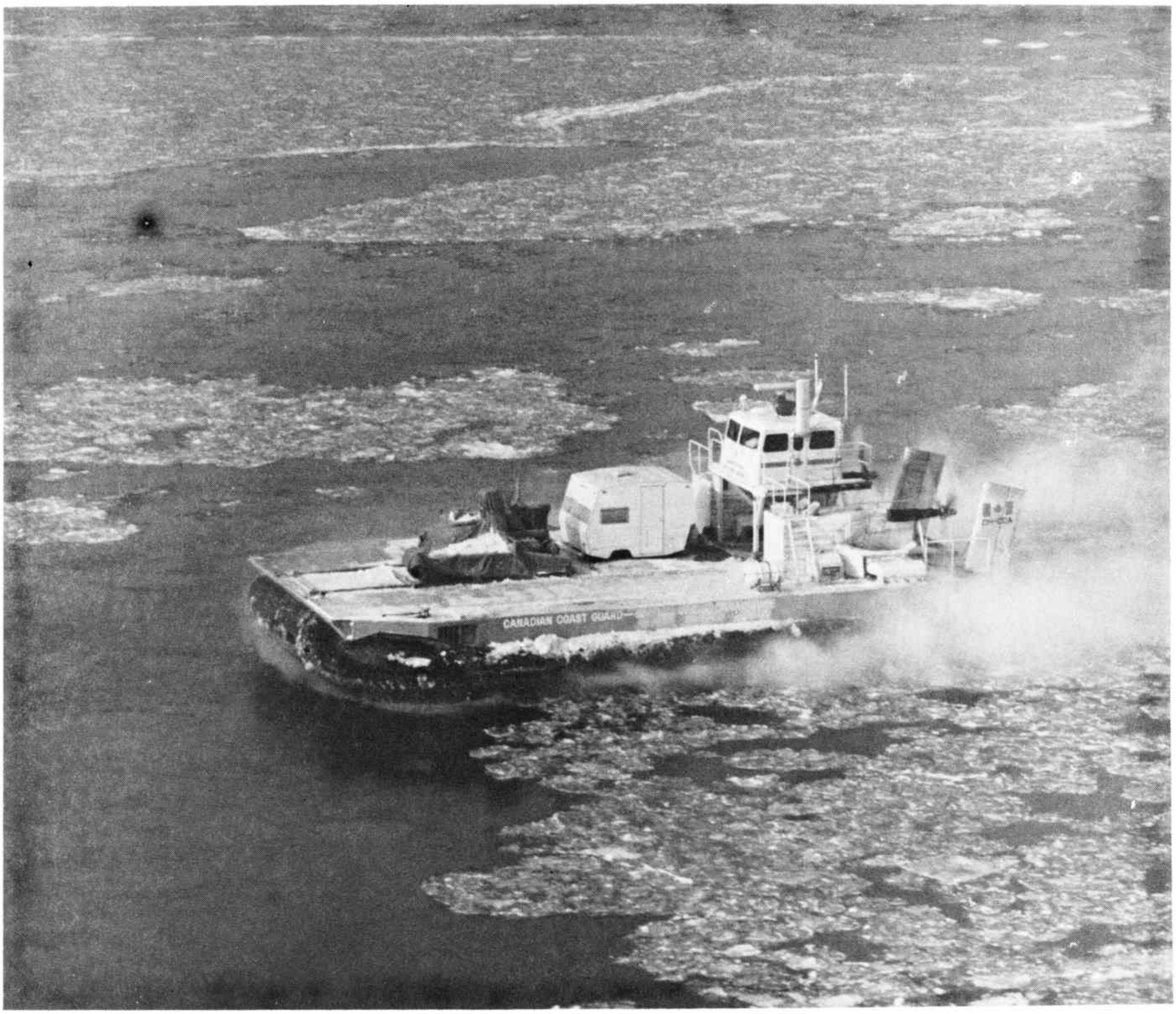

FIGURE 2

Voyageur in high-speed transit. A capability to break ice at this speed has been demonstrated during lake clearing operations.

ECONOMIC AND SOCIAL ASPECTS OF ICEBREAKING ON THE ST. LAWRENCE SEAWAY

T.N. Hall
Dominion Marine Association

I am honoured to participate as a speaker at the Tenth ACV Symposium of the Institute. As most of the items involved in your Agenda are naturally oriented to the field of technology, quite obviously over the past two days you have heard from highly qualified technical experts.

I would like to make it clear at the outset that I am not one of that breed, I am one of those who as a youngster at camp did as I was told and went to fetch that bucket of steam. The justification for my presence here was very well expressed, I thought, in one of the letters we received from the Chairman of your ACV Section, Howard Fowler. He noted that while you have papers on the technology of the icebreaking business, you had very little data relating to the reasons for doing the job, or of the economic and social effects which would accrue from, for example, keeping the St. Lawrence Seaway open up to the Lakehead through the winter, as he put it - "The country should not be expected to subsidize very expensive displays of technical versatility without being shown a very real social benefit from them".

We of the Shipping Industry agree and that is why I am here.

First, I think a few words about the nature and function of our shipping industry would be useful. The principal eighteen Canadian companies trading under the Canadian Flag in the Great Lakes - St. Lawrence Waterway are represented by the Dominion Marine Association. The Company of which I am President, Hall Corporation, is one of the members, and as well I am Vice-Chairman of the Association. Member companies operate 150 ships with a total registered tonnage of 1.5 million tons and a carrying capacity of 2.5 million tons. Types of ships include dry bulk carriers, self-unloaders, tankers and a few package freighters. In my own company's case we operate bulk carriers as well as coastal and arctic class tankers and a coastal self-unloader.

The dimensions of the locks of the Seaway limit the size of our ships to 730 feet in length and 75 feet in breadth. A maximum size ship can carry a million bushels of grain or 30,000 tons of iron ore in one load. In 1975 we carried over 15 million tons of grain from the Canadian Lakehead alone, 13 million tons of iron ore from the Quebec-Labrador complex and 33 million tons of coal from U.S. Ports in Lake Erie. These were the principal cargoes shipped by us. The total value of all our cargoes for 1975 was over $10 billion. By way of comparison with rail, a recent study on the Canadian Lake Shipping Industry conducted by economists, Darling and Shaw, revealed that in 1973 our ships carried more ton-miles of cargo in our eight and one half month season that CP rail carried in their twelve month season.

And that, Gentlemen, brings us to the heart of the problem we are discussing here. The operating season for our ships is generally limited to about 8½ months - from April 1 to December 15 - due to conditions of climate.

The short season has two main consequences from the standpoint of our industry. The first is, of course, that most of our ships are constructed for use solely in Canadian inland waters - they cannot be employed elsewhere. The importance of this will be appreciated when I tell you that a self-unloader built today in Canada costs over $30 million and a bulk carrier about $18 million. This investment lies idle, yields no revenue, no jobs for about one-third of the year.

The second important consequence of the short season, as the Darling Shaw Report noted, lies in the fact that the seasonal limitations have greatly influenced the types of traffic that the water carriers have been able to retain in the fact of competition from the land carriers. The preponderance of traffic carried by water "has tended to consist of bulk traffic of low value with low storage costs. The low value factor inhibits the paying of the level of rates required by rail and highway carriers, while the low storage costs reduce the need for the better (i.e. year-round) service that can be offered by those carriers".

I need hardly add that, looking at the matter from the National aspect, rather than simply the interests of the shipping industry, the fact that port facilities, grain elevators and other expensive capital items are idle for about one-third of the year has vast economic consequences as well as social consequences that I will touch on shortly.

In this connection, some comment on forecasts of seaway traffic may be helpful, because of course the whole seaway system is idle during the 3½ month winter season.

In 1975 traffic through the Montreal-Lake Ontario section totalled 48 million tons and through the Welland Canal 59.9 million tons. The record was set in 1973 with 57.6 million tons through the Montreal-Lake Ontario Section and 64.2 million tons through the Welland.

A recent study made by the St. Lawrence Seaway Authority predicts that during the forecast period (1975 to 1990) seaway traffic will increase by about 2.5% annually. This would mean that by 1990 total commodity traffic via the waterway should reach 78.3 million tons on the Montreal-Lake Ontario section and 92.6 million tons on the Welland, an increase of approximately 51% over the 1972-74 average.

Other studies made by the Seaway Authority indicate that the predicted

1990 levels of traffic represent the maximum capacity of the system. Thus it is forecast that, accepting the figures mentioned above, by the autumn of 1990, when the usual late-season increase in grain shipments occurs, serious traffic congestion will occur.

There are several possible solutions to the traffic saturation problem, one is to enlarge the seaway locks and facilities. A fifth Welland Canal could be built with only five or six locks (instead of the existing eight locks) having dimensions (1200' long by 120' wide) that would accommodate larger ships than those of the present canal, where, as I have said, ships are limited to 730 feet in length, with a beam of 75 feet. But the enlargement of the Welland Canal could not be exploited fully unless and until the Montreal-Lake Ontario section is also enlarged to the same dimensions. This, of course, is the logical solution and may well be required in the final analysis if the Seaway is to serve our two nations to the full. You may ask why 1200' locks. The U.S. fleets have built and are building 1000' ships now, capable of carrying close to 60,000 tons.

But the cost of the two projects together represent an investment of $5 billion to $6 billion in today's dollars and there seems little disposition on the part of the Government to undertake an expenditure of that magnitude at this time.

Extension of the navigation season would, at the very least, substantially postpone the attainment of traffic saturation in the existing seaway system.

Canadian authorities like to make the point that considerable progress has already been made in season extension, and the facts support them. In 1959 when the Seaway opened, the season commenced April 25 and closed December 3 in the Montreal-Lake Ontario section, and in the Welland, opened April 1 and closed December 15. In 1975 the opening dates were March 25 for both sections and closing dates were December 21 for Montreal-Lake Ontario and December 31 for the Welland. Thus from 1959 to 1975 we gained 48 days in the eastern section and 22 days in the Welland. I should add that, due to temperature differences, there is less difficulty in keeping the Welland open during winter than the Seaway farther east. In 1974, for example, the Welland was kept open until January 18, chiefly to handle demand for coal from U.S. ports in Lake Erie to the Canadian Steel companies and Ontario Hydro in Lake Ontario.

In the Upper Lakes, season extension has been far more dramatic, due almost entirely to U.S. effort. In 1971 a U.S. program, designed to explore and demonstrate the feasibility of extension, was commenced. In the ensuing five years most of the authorized funds, totalling $9.5 million have been expended. Most of this effort was directed to navigation between Lake Superior and Lake Michigan, and principally covered the shipment of iron ore from the Mesabi Range through Duluth-Superior and Two Harbors on the U.S. side of Lake Superior. As a result of the efforts of the U.S. Government and steel interests, this trade pattern remained open throughout the entire year in 1974 and 1975. In those two years, 7.5 million tons were shipped during the "extended season", i.e. the period between December 15 and March 15.

We cannot conclude from the U.S. success in the upper lakes that season extension in the lower lakes - St. Lawrence waterway is just a matter of time. The problem there is very much greater, and far more complex. One of the major problems farther east is the danger of serious disruption to power production, e.g. in the Beauharnois Canal, through broken ice impeding flow or causing damage to the intakes. Ice booms have been used with some success.

So far, the Canadian program in the eastern area has suffered from lack of funds. There has been no special funding and all projects to date have been financed through ongoing programs of the several agencies directly concerned. Nevertheless, the recent appointment of a high-ranking official to concentrate on season-extension efforts seems to indicate serious Canadian interest in this development.

So much for the facts, and the situation today. If one thing is apparent it is that if further progress is to be made in season extension, very substantial funds will have to be spent. The essential thing therefore is a cost-benefit study. Such a study has already been done by the St. Lawrence Seaway authority. It consists of a 3-phase extension of the season from March 15 to December 31. Phases - (1) Firm up April 1 - December 15, (2) April 1 - December 31, (3) March 15 - December 31. These are some of the conclusions, and the facts elicited in the course of the study -

1. The total capital cost of completing the 3 phases of this program would be about $17 million, to be shared among the Canadian and U.S. Seaway authorities and power authorities. Operating costs, which will be additional, will be "substantial".

2. If extension is carried out, existing cargo levels for the three major commodities through the Welland Canal will be exceeded by 12% to 30% in 1980 and by 14% to 46% in 1985.

3. Inland shipowners indicate they would use their ships through the extended season.

4. Harbour Commissions all felt their equipment would be satisfactory for year-round cargo handling.

5. Labour unions saw no problems, provided working conditions and safety equipment were satisfactory.

6. The benefit - cost ratio would be approximately 1½ to 1. This is more conservative than that

arrived at by the U.S. Corps of Engineers, but the Canadian Seaway Authority considers it sufficient to embark on the program.

Having dealt generally with plans for season extension, I will now attempt to zero in on the role of the ACV in that program. It is axiomatic that in any kind of post freeze-up marine operations involving ports as well as ships, an ice-breaking capability is essential. The ACV, as you have heard or will hear has caught the imagination of the practical seaman as well as the technician and may be the answer or an answer to our problem. Even with the 8½ month season we now have, the icebreaking service has been far from satisfactory, particularly at the commencement of the season when ice conditions are difficult in Lake Superior, Georgian Bay and the east end of Lake Erie. The problem arises mainly from the fact that MOT is unwilling to commit its more effective and expensive icebreakers to inactivity in the lakes for the entire winter season, to be ready for spring operations in the Lakes. They are needed during that period in the areas east of Montreal and in the Gulf.

Development of the ACV with, hopefully at a cost per unit far below that of the conventional icebreakers, will make it feasible to station the required ACV's in the Lakes.

Extension of the season would, of course, accentuate the usefulness of the ACV.

Finally, a few words on the social and environmental aspects of season extension and the use of the ACV. One of the social benefits would be of course, increased employment on board ships. Our Association employs about 5,000 seamen. Employment, now seasonal, would be year-round, with consequent substantial savings in unemployment insurance, and employment of additional personnel to cater for extended leave periods. As I mentioned before, labour unions are happy with the proposal, provided of course that satisfactory arrangements are made for safety equipment and winter working conditions generally. Disruption of the work force through seasonal operations has its own social and economic consequences.

Employment in ports throughout the system will also increase.

Energy conservation enters the equation, studies show that on a ton mile basis per gallon of fuel, lake ships are far more economical. The numbers being air 3.7, road 38, rail 200, pipelines 300, lake ships 500.

Environment aspects - which I suppose are a phase of the social aspect - do not appear to present significant problems. While I am told no comprehensive Canadian study on this subject has yet been made, a "draft environmental statement on the navigation season extension demonstration program" was published by the U.S. Army Corps of Engineers in June of this year. I will not attempt even to summarize the report, but one or two items, dealing with typical problems that will be encountered, may be of interest to you. The report studied in detail oil pollution problems associated with the extended season. Actual experience during the five year U.S. late navigation operations in newly formed ice showed minimum damage to vessel hulls. The greatest danger posed by ice damage appears to be in the premature movement of some 90 to 100 vessels. These are older U.S. ships ill-equipped to navigate in the lingering ice of late March and April which accounted for 95% of the ice damage incidents during the five years covered by the study. Fortunately, most of the incidents involved bow, propellor or rudder damage, and there was no pollution.

The authors of the report make the interesting observation that "extending the navigation season reduces the urgency to resume operations in the early spring". Improved weather and ice forecasting techniques will further minimize "premature navigation", they say. There is a lengthy discussion of the effect of cold weather on dealing with oil spills when they do occur. While conceding the obvious - that cold weather spills pose special problems for personnel and equipment engaged in the clean-up - the authors express the comforting view that such spills would not be as difficult to clean up as previously thought, because of some of the characteristics of oil in low temperatures and the movement - inhibiting qualities of ice.

Another problem that presented difficulties for the U.S. Authorities was the impact of season extension upon permanent residents of islands in the system. For example in the case of Lime Island in the St. Mary's River, open or ice floe filled vessel tracks prevented foot or snowmobile travel between the Island and the Mainland - a distance of three miles. The solution adopted by the U.S. Corps of Engineers was provision of an air-propelled combination boat and sled which could travel over snow, ice, water or broken ice-filled channels. Performance of this craft over the past three years was described, with a lower degree of enthusiasm than is normally found in such reports, as "somewhat satisfactory"! In any case this is one of the social problems that has been encountered and will no doubt arise in Canadian waters as the program progresses.

Generally the Canadian approach has been to work out an inventory of problems that will be encountered in the environmental field, and ensure the answers are ready. For example, if dredging is required (as it will be in the course of some aspects of the season extension program) the normal procedure developed by Environment Canada over the past few years will be followed. Dredged material will be tested, and if it is polluted it will have to be dumped into disposal compounds specially prepared for the purpose.

To sum up, Gentlemen, the view of our industry is that season extension will come, that will be on a balance beneficial to Canada, that social - environmental problems can and will be resolved, and finally that the ACV appears to have an important if not vital role to play in the program.