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EXPERIENCES WITH A COMMERCIAL ECDIS

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Abstract

The integration of accurate positioning and electronic charts provides an extremely valuable tool to the mariner when navigating under hazardous conditions. This paper describes the experiences of two organizations in Canada who work under such conditions. On the St. Lawrence River, the Canadian Coast Guard is using the PINS 9000, a commercial ECDIS, for ice breaking chores with few, if any, other aids and has demonstrated operational savings. Marine Atlantic, Inc., uses the same system for ferry navigation into and out of Port aux Basques, Newfoundland, where it not only assists in meeting a tight schedule, but also enhances safety when operating in difficult conditions.

EXPERIENCE WITH A COMMERCIAL ECDIS

1. Introduction

During the past fifty years, mariners have adopted a host of electronic navigation and positioning aids in a bid to make navigation safer and more efficient. Numerous systems designed for collision avoidance (radar, VHF radio-telephone) or enroute navigation (LORAN-C, GPS) are either currently available or, as in the case of GPS, currently being deployed. However, while various studies and specifications that have been produced in recent years demand that ships maintain a high degree of position accuracy while operating in confined waterways and harbours, the manual position plotting methods that are still commonly used today are not able to display this information without incurring significant delays and the possibility of human error. As a result, the position shown on the paper chart represents the ship's historical position rather than its

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current position. This delay effectively negates recent efforts to enhance the safety of vessels and prevent groundings by providing highly accurate position data through the use of microwave transponders, radar-assisted precise navigation systems, and the Global Positioning System (GPS).

By combining hydrographic chart data with position and orientation information obtained from the ship's gyrocompass and electronic navigation aids onto a video display in real time, Electronic Chart and Display Information Systems (ECDIS) provide a means to overcome many of the limitations of paper charts that are encountered in operational situations. By continuously and automatically plotting the current position, course, and track of one's own vessel relative to the nearby coastline, navigation hazards, and one's intended track in real time, electronic charts permit mariners to make optimal use of modern precise vessel positioning systems. No longer burdened by the repetitive (and potentially fatiguing) task of manual plotting, watchkeepers can devote more time and attention to other matters concerned with the safe passage of the ship.

The PINS 9000 (Precise Integrated Navigation System) is a second generation commercial ECDIS that was introduced by Offshore Systems Ltd. (OSL), in 1985. During the past five years, PINS 9000 systems have been installed aboard a variety of ships including icebreakers, ferries, oil tankers, research vessels, and several Canadian and U.S. naval vessels. A representative summary of PINS installations is given in Table 1. Feedback from users has been very favourable. PINS has been described as *'a master's dream when you have to manœuver in a confined area with no visibility'* [1] and, *'after the gyro and radar, ... the most useful instrument we have'* [2].

PINS was designed to support both conventional navigation tasks in coastal and inshore waters and more demanding activities including pilotage in confined waters, ice breaking, marine surveying, ship manœuvering trials, and coordination of underwater operations involving use of both tethered and autonomous vehicles. In this paper, we consider experience accumulated by the Marine Atlantic, Inc. (which operates two PINS-equipped ferries on a route between North Sydney, Nova Scotia, and Port aux Basques, Newfoundland) and the Canadian Coast Guard (which operates six PINS-equipped icebreakers on the St. Lawrence River between Lac St. Pierre and Quebec City). Those features which have contributed most to the success of PINS in operational situations are identified and discussed. Directions for future development are considered.

2. The Need for Electronic Charts

The speed, direction, and position of the vessel relative to navigation hazards is of primary concern to the master or pilot when guiding a vessel through coastal or inshore waters. Delays in processing incoming data into a form where this information can be extracted are critical. In the minute that it might take to transfer incoming data to a paper chart (and it would often take longer), a vessel moving at only 10 knots will have travelled over 300 metres. A vessel moving at 15 knots will have travelled a quarter nautical mile! Thus plotting on a paper chart can hardly be acceptable when most harbour and channel navigation plans [3, 4] require that large ships maintain positioning accuracy to between 8 and 20 metres.

Table 1 — Partial Summary of PINS 9000 Installations

Name	Length	Grt	Year	Client	Application
HMCS Cormorant Canadian Navy	245 ft	2350	1989	Dept. of National Defence	Route Survey/ Seabed Surveillance
CFAV Lady Alexandria CFAV Lady Joyce Canadian Navy	191 ft	1067	1989	Dept. of National Defence	Route Survey/ Seabed Surveillance
U.S. Navy Tracking Station			1989	David Taylor Labs, WA	Underwater Tracking of Submarines
CGCS Tracy	167 ft	963	1989	Canadian Coast Guard, Laurentian Region	Ice breaking and Buoy Tending
M/V R. Hal Dean MV Charles B. Renfrew	760 ft	44840	1988	Chevron International Shipping Company, San Francisco, CA	Channel Navigation and Docking of Tankers
R/V Oceanus	177 ft	297	1988	Woods Hole Oceanographic Institution, Woods Hole, MA	General Navigation
USS Ortolan, ASR 22 U.S. Navy	251	4570	1987	The Charles Stark Draper Laboratory, Cambridge, MA	Submarine Rescue Operations. Submarine and Surface Ship Tracking (Atlantic)
M/V Atlantic Freighter	495 ft	5466	1987	Marine Atlantic North Sydney, N.S.	Channel Navigation and Docking
CCGS Montmagny CCGS Sir Wilfrid Laurier CCGS Norman M. Rogers CCGS Pierre Radisson CCGS Des Groseilliers	137 ft 257 ft 275 ft 296 ft 296 ft	492 3812 4299 5910 6098	1987	Canadian Coast Guard, Laurentian Region	Icebreaking and Buoy Tending
Vancouver Port Office	—		1986	Van. Port Corporation	Harbour Management
USS Pigeon, ASR 21 U.S. Navy	251	4570	1986	The Charles Stark Draper Laboratory, Cambridge, MA	Submarine Rescue Operations. Submarine and Surface Ship Tracking (Pacific)
M/V Researcher	83 ft	128	1986	International Submarine Engineering	Tracking Display of Underwater Vehicles and Surface Vessel
M/V Chi-Cheemaun	347 ft	6991	1986/ 1985	Ontario Northland Transportation, Owen Sound, Ontario	Channel Navigation and Docking
M/V Caribou from M/V Atlantica	587 ft	27213	1986/ 1985	Marine Atlantic, North Sydney, N.S.	Channel Navigation and Docking
CFAV Endeavour Canadian Navy (2 systems)	236 ft	1560	1985	Defence Research Establishment Pacific	MCM Operations and Seabed Surveillance

Much of the power of the electronic chart (and the feature which distinguishes them most from conventional chart plotters) comes from their ability to process data from a variety of sources and to detect and graphically show relationships between the data. This capability extends far beyond the use of a Kalman filter to integrate position data from various navigation aids and to generate an error ellipse on the chart display as an indication of the fix quality. For example, since an electronic chart combines one's position with chart information, it can be programmed to automatically warn of proximity to underwater hazards such as reefs or rocks. It would be extremely difficult (if not impossible) to detect such hazards using conventional collision or grounding avoidance systems such as radar or depth sounders. When failure to execute the planned route (as suggested by significant deviations from expected course, speed, cross-track distance, or water depth) is detected, the electronic chart can be programmed to generate various visual and audible alarms. By permitting one to overlay radar imagery onto the electronic chart display, the next generation of ECDIS will considerably ease the task of interpreting the radar display and distinguishing ship targets from land returns. These capabilities, coupled with a carefully designed and non-intrusive user interface, will enable electronic charts to play an effective and important role in the prevention of ship groundings and collisions during the 1990's. Some have described ECDIS as the most revolutionary advance in coastal navigation and pilotage since the introduction of the paper chart several hundred years ago.

In situations where vessels are required to navigate through narrow and poorly marked channels during conditions of poor visibility, the need for electronic charts in combination with precise positioning systems has been both obvious and immediate. Examples considered in this paper include large ferries using the harbour at Port aux Basques, Newfoundland, where poor weather can reduce visibility to near zero during critical phases of the harbour approach and Lac St. Pierre on the St. Lawrence River south-west of Trois-Rivieres where ice-breakers must clear an unmarked channel in mid-lake with broad shallows on either side. The PINS 9000 has also been used to solve similar precise navigation problems in the Great Lakes, U.S. Gulf Coast, Canadian Arctic, and the British Columbia coast with great success. Although electronic charts are particularly useful during periods of poor visibility, it has been found that electronic charts can provide valuable assistance to the mariner even in clear weather by warning of deviations from the desired track long before they can be detected by eye.

Unfortunately, the mariner transport industry is not yet making routine use of electronic chart technology. This may not be too surprising given that recent years have seen a wide variety of new devices (with their associated costs of procurement, installation, maintenance, and user training) imposed upon the industry in the name of safe navigation and safety of life at sea. Individual shipowners or operators may find it hard to justify an investment in additional equipment which is not required by law and with which they may be unfamiliar or have little experience. But other factors should also be considered by the industry.

The cost of a single mishap, whether a vessel is simply damaged and temporarily taken out of service or completely lost, is high and growing. Replacement costs for major marine transport vessels can range from \$50 million for a small passenger ferry to over \$200 million for a liquified natural gas (LNG) carrier. Drydock and repair bills for less serious incidents can typically range from $500 thousand to well over one million dollars.

Recent incidents, such as the grounding of the VLCC EXXON VALDEZ in Prince William Sound, Alaska, in March 1989, have dramatically shown that as the size and number of vessels transporting hazardous cargoes has grown, so have the potential environmental consequences of a single grounding or collision. In the aftermath of a disaster which have been prevented by use of appropriate technology, the power of public opinion should not be underestimated either. It has been estimated that Exxon Corporation will spend almost two billion dollars while attempting to clean up one of the costliest ship groundings in history.

In 1988, over 1000 shipping casualties involving commercial vessels of Canadian flag and foreign vessels operating in Canadian waters were reported to the Marine Casualty Investigation Branch of Transport Canada [5]. Of 1050 incidents, 615 resulted in grounding (the vessel touches bottom and remains stranded), contact (lateral or light impact with another object or vessel, touching bottom), or striking (hard impact with a stationary object or a vessel not underway); 596 of the incidents were attributed to operational mistakes and human error. Statistics for the previous year are similar. It seems likely that a large fraction of these accidents (including the grounding of the MV 'SIR ROBERT BOND' entering the harbour at Port aux Basques, Newfoundland, on February 8 1988 [6]) could have been avoided if an electronic chart in combination with a precise vessel positioning system, had been available to the master.

3. Background

Electronic chart and navigation display systems of various types have been proposed during the last twenty-five years. One of the first such systems, MANAV [7], was proposed in 1967 when Esso placed a contract with the British Ministry of Technology to develop a system to assist in ensuring the safe operation of its Very Large Crude Carriers (VLCC) which were then coming into service. Unfortunately, the computer technology and software engineering experience required to implement a workable and affordable electronic chart system were not available at that time. The introduction of commercial ECDIS was delayed until the introduction of affordable 16/32 bit microprocessors, mass storage and display hardware.

Offshore Systems, a supplier of precise navigation systems and related services to the offshore oil and marine transport industries in North America since 1977, introduced its first electronic chart system in 1979. Called the Precise Navigation System (PNS), it was designed for use by ice-breakers and supply vessels as they passed through the narrow dredged channels which connect the harbours at McKinley Bay and Tuktoyaktuk to the Beaufort Sea in the Canadian Arctic. Unlike previous aided port entry systems which merely provided an indication of the crosstrack distance and/or steering directions to the pilot, PNS also provided a monochrome graphics display which clearly showed the vessel's position with respect to the channel boundaries and nearby shoreline. An instant success, PNS was upgraded and improved several times before Offshore Systems Ltd. began developing the second generation PINS 9000.

4. PINS 9000 Overview

A pictorial diagram of the two major elements of a typical PINS 9000 installation is given in Figure 1. A block diagram showing the major functional components of PINS is given in Figure 2. The overlay of radar imagery is only available on the advanced PINS workstation. Mariners interact with PINS through an Interactive Display Console (IDC) that consists of a medium resolution 48-centimetre (19-inch) colour display with an antiglare screen, visor and a custom keyboard. In most PINS installations, the IDC (also called the navigation station) is mounted near the vessel's conning position on an overhead swivel and tilt shock absorbing mount. The rest of the PINS hardware (referred to as the executive station) including a Hewlett-Packard 9000 series 300 workstation, a 20-megabyte ruggedized hard drive and a 710k 3-1/2" floppy drive for mass storage, interfaces to various user-supplied positioning systems and navigation aids, a keyboard and monochrome display for system management, and an uninterruptible power supply (UPS) are mounted on a 19-inch rack in an equipment room or other available space near the bridge.

Much of the flexibility and power of PINS comes from the custom-designed multitasking executive under which the PINS display and positioning software runs. Depending on the system configuration, between ten and twenty-five software processes run simultaneously performing a variety of tasks involving data communications, data base manipulation, screen update, and position determination tasks. Use of a real time executive instead of a conventional program structure allows one to assign priorities to individual tasks depending on the required response time. The system provides a wide range of powerful features that are not found in simple chart plotters or many first generation ECDIS including:

- charts that are colour-filled to more closely resemble a paper chart,
- various chart display options including true motion, relative motion, north up, and ship's head up,
- user programmable automatic chart scaling to permit hands-off operation,
- multiple user-defined chart and text windows on a single screen,
- a hierarchical menu system driven by eight soft keys,
- sophisticated route planning, route execution, and fuel management tools,
- two-stage audible and visual alarms to warn of dangerous conditions including deviation from intended course or track and proximity to shallow water and other navigation hazards,
- software drivers and hardware interfaces to virtually any satellite, RF, microwave, or acoustic positioning system, and,
- optimal or adaptive Kalman filtering with least squares estimation,
- data logging (black box), playback, and data linking capabilities.

Many of these features are shown in the typical PINS displays presented in Figures 3 through 6. The display shown in Figure 3 is taken from a simulation of the events leading up to the grounding of the VLCC EXXON VALDEZ on

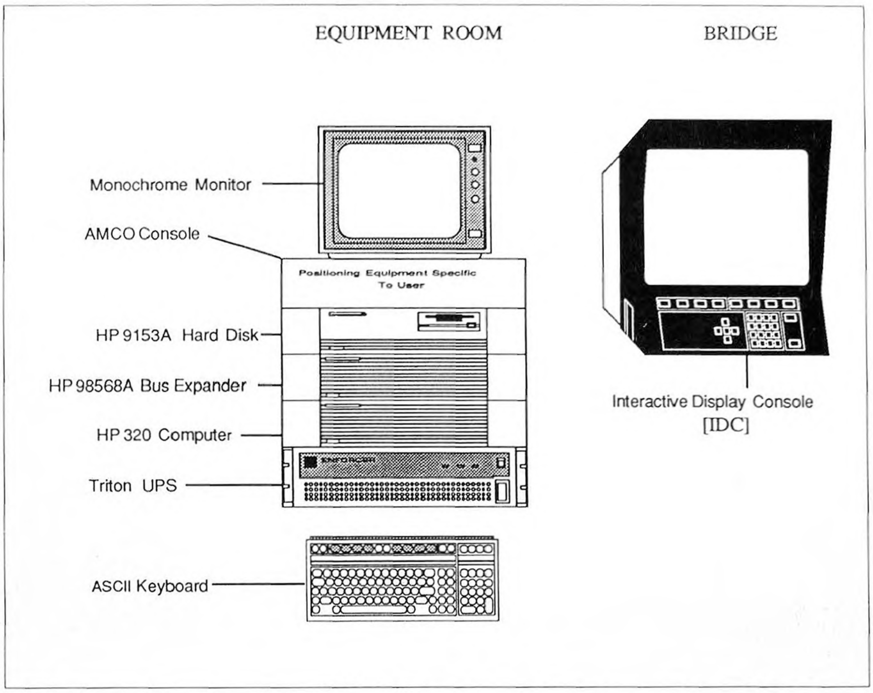

FIG. 1.— PINS 9000 — Interactive Display Console (IDC) and main equipment rack.

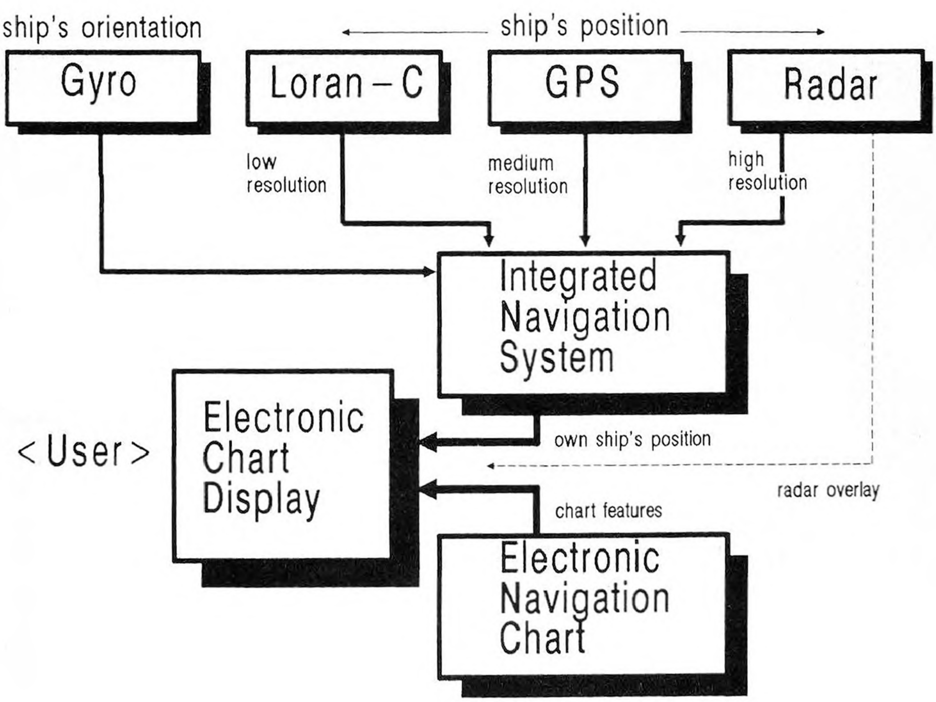

FIG. 2.— PINS 9000 / Advanced PINS — Functional block diagram.

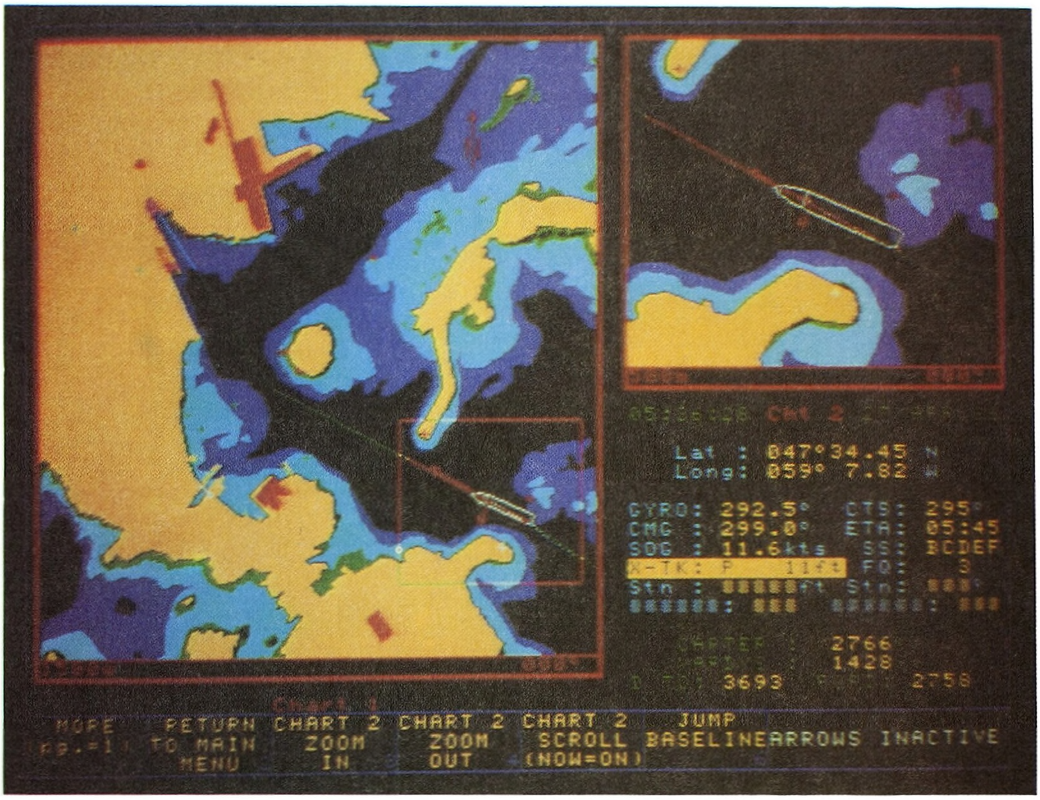

FIG. 3.— PINS simulation of the EXXON VALDEZ in Prince William Sound, 1989.

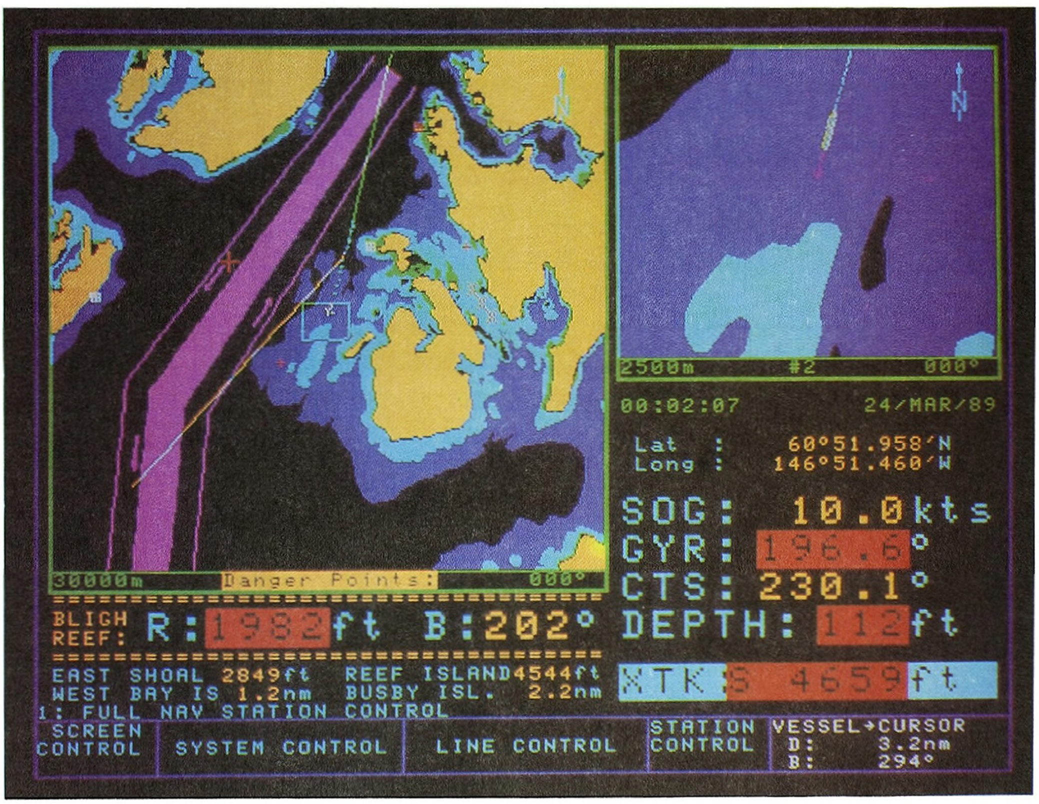

FIG. 4.— PINS display of an ice-breaker in Lac St. Pierre.

FIG. 5.— PINS display of M/V CARIBOU entering the harbour at Port aux Basques, 1986.

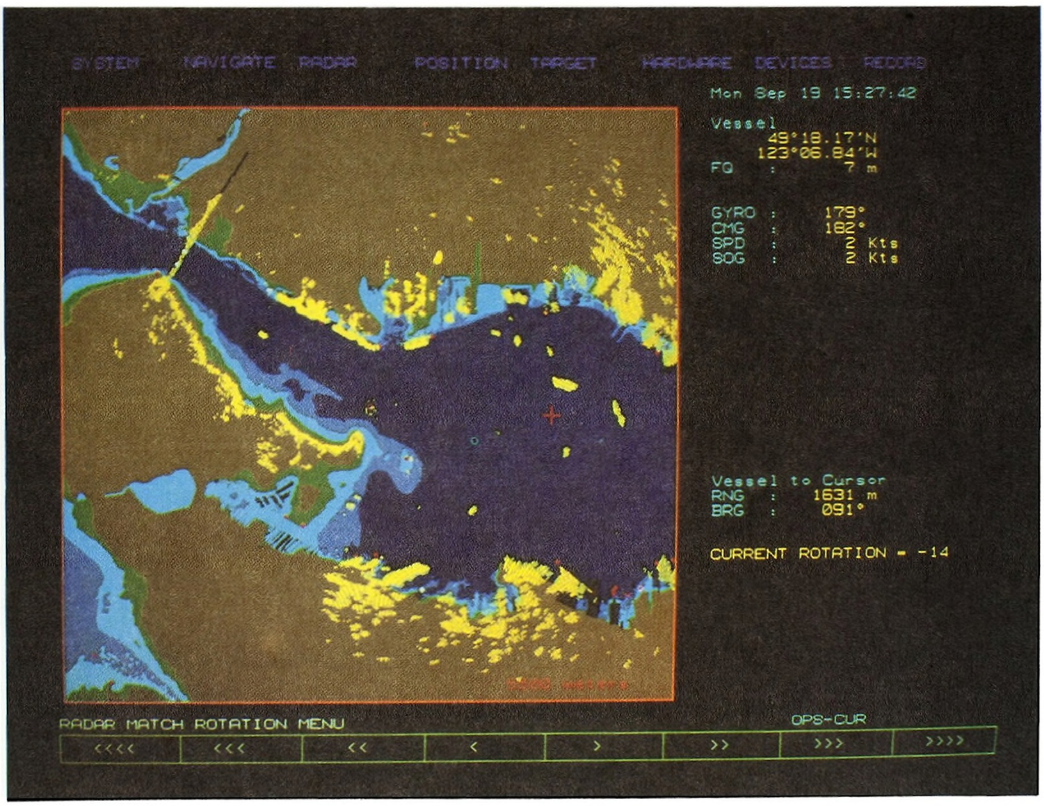

FIG. 6.— Advanced PINS display of Vancouver Harbour.

Bligh Reef in Prince William Sound in March 1989. Large and small scale chart displays are shown in adjacent windows. Visual alarms (black characters on a red background) warn of a potentially dangerous deviation from the vessel's intended track. Labels for soft keys are displayed at the bottom of the screen. The remaining displays are generated from actual data collected in the field. The display in Figure 4 shows the Marine Atlantic ferry M/V CARIBOU entering the harbour at Port aux Basques, Newfoundland. The PINS display in Figure 5 shows a Canadian Coast Guard ice-breaker operating in Lac St. Pierre on the St. Lawrence River. A prototype version of an advanced PINS display is shown in Figure 6. The screen shows part of Vancouver, B.C.'s inner harbour with a radar overlay. Since the screen resolution has been increased from 512 × 390 pixels to 1280 × 1024 pixels, relatively fine text and symbols can easily be displayed on the chart itself if desired.

5. Aided Port Entry at Port aux Basques

When used in combination with highly accurate electronic navigation charts and a precise positioning system, the PINS 9000 can assist in channel navigation and docking from the initial harbour approach until the first berthing line is thrown ashore. The need for such a capability is particularly acute at Port aux Basques, a harbour situated on the south coast of Newfoundland near the southwest extremity of the island and an important transfer point for goods and passengers between Newfoundland and Nova Scotia. Poor weather including fog and blinding snow can suddenly reduce visibility to near zero while large ferries operated by Marine Atlantic, Inc. (formerly CN Marine) are negotiating the hazardous harbour approach.

Several generations of ferries have plied the 96-mile route across Cabot Strait during the last ninety years but it was the introduction of the 200-metre M/V CARIBOU (shown in Figure 7) that made it necessary for Marine Atlantic to assume a pioneering role in the application of electronic chart technology. The CARIBOU and its soon to be operational sister ship M/V JOSEPH and CLARA SMALLWOOD are Canada's largest passenger ferries and the largest vessels ever to manœuver in Port aux Basques harbour on a regular basis. The PINS display in Figure 5 shows both the harbour and an outline of the CARIBOU to scale. It confirms that clearance in the harbour is extremely limited. As can be appreciated by inspecting the view from the bridge of the CARIBOU shown in Figure 8, the low lying topography of the land surrounding the harbour does not lend itself to the generation of the solid and distinctive radar returns required for safe radar navigation.

In December 1984, Offshore Systems installed a prototype version of the PINS 9000 aboard the M/V FREDERICK CARTER which was the largest ferry in use in the Gulf of St. Lawrence at that time. During the next 12 months, an intensive development effort saw OSL developers working with Marine Atlantic personnel to prepare both the PINS 9000 and a network of microwave transponders for use by the CARIBOU. The close interaction between the developers and the end users during this period contributed greatly to the success of PINS at Port aux Basques.

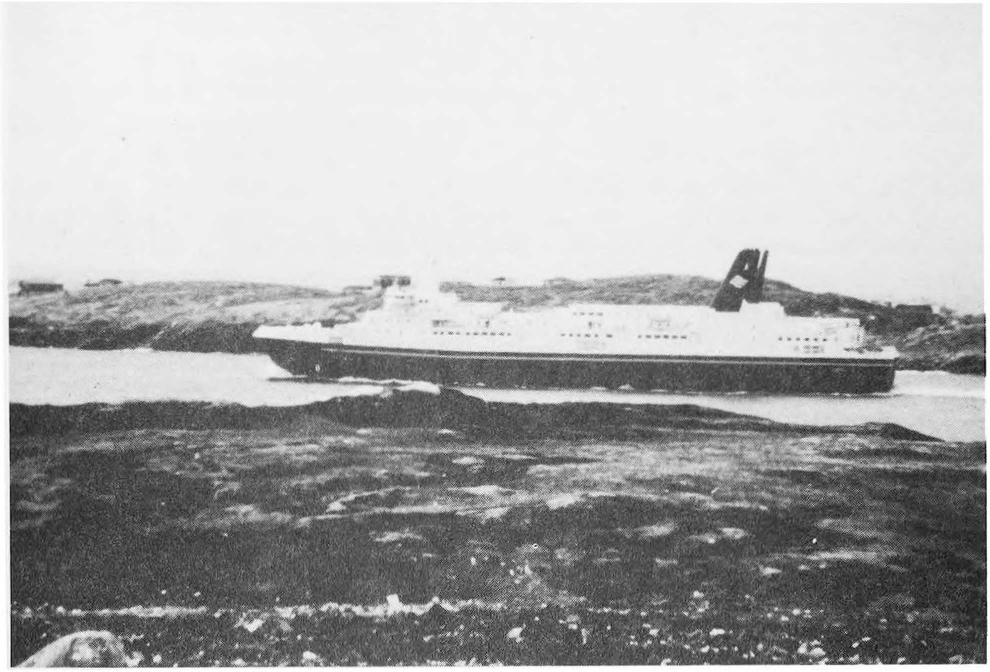

FIG. 7.— M/V CARIBOU.

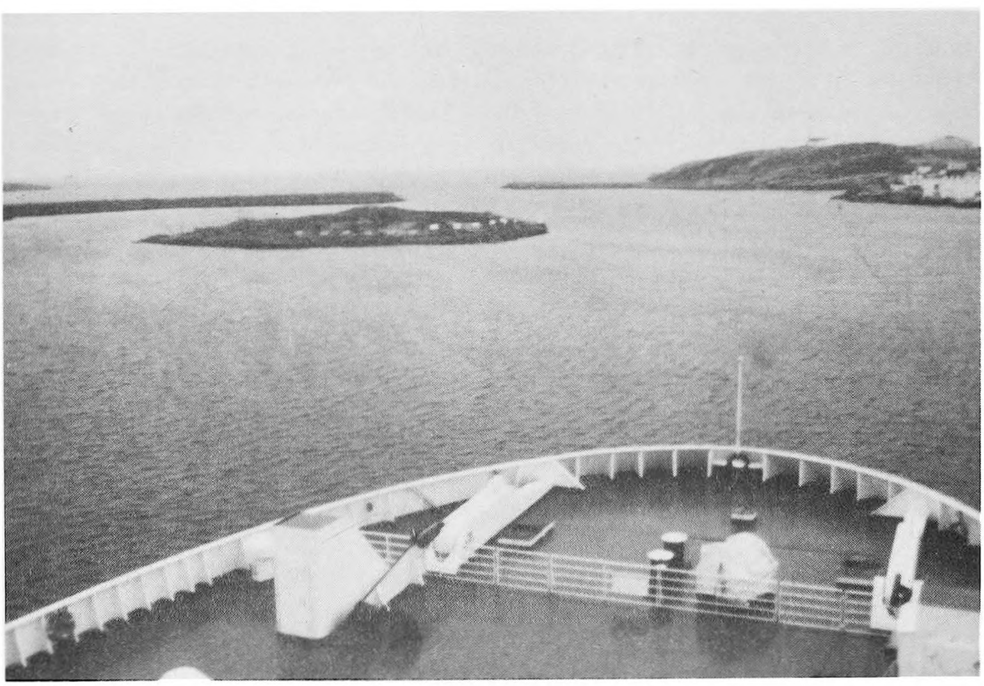

FIG. 8.— Approach to Port aux Basques Harbour as seen from the bridge of M/V CARIBOU.

An incident late in the first year of regular operation soon provided Marine Atlantic with vivid proof of the value of the system. On December 7 1986, as CARIBOU began entering the outer harbour and became committed to completing the passage, a blinding snowstorm suddenly reduced visibility to near zero. The PINS display shown in Figure 4 was generated from data recorded at the time. Although several lookouts with portable radios were deployed along the ship, they were unable to see anything ashore until the ship was nearly alongside its berth. As a result, the master was forced to rely exclusively on PINS during the entire transit of the harbour including the 180-degree turn north of Vardys Island and the back up into the berth. Thanks to PINS, a potentially costly grounding was avoided. Other vessels entering the harbour under similar circumstances, but without a PINS system, have not been as fortunate [6]. Since then, a PINS system has been installed aboard the M/V ATLANTIC FREIGHTER, a 150-metre cargo ferry on the same run. In 1990, a third PINS system will be installed aboard the M/V JOSEPH AND CLARA SMALLWOOD. The success of PINS has led to serious consideration of installations in other harbours and aboard other Marine Atlantic vessels in the future. Considering the number of port entries and departures they have made, using PINS, over the past five years, Marine Atlantic bridge officers may well have accumulated more operational experience with electronic charts for port entry than anyone else in the world.

6. Ice-breaking in Laurentian Region

The Canadian Coast Guard (Laurentian Region) is responsible for ice-breaking, related aspects of flood control, and providing assistance to shipping along the St. Lawrence River between Quebec and Montreal. One of their main tasks is to keep the St. Lawrence ship channel open along the route. They employ three R-class heavy ice-breakers, two medium ice-breaker/navy tenders, and two light ice-breakers for ice management activities.

Operating conditions are extremely harsh. The ice-breakers work in ice up to six metres thick. They must spend a great deal of time manœuvering in close quarters and confined waters. Low visibility and high winds are common and currents can reach up to six knots in places. Ice jams, a serious problem on the St. Lawrence at the best of times, were extremely troublesome during the winter of 1985. At one point, the Coast Guard were forced to use three or four ships working 24-hours per day for almost a month to break a jam on Lac St. Pierre. Although there were no accidents, there were at least a few close calls.

With the previous winter's experience firmly in mind, the Coast Guard began to install PINS 9000 systems abord their ice-breakers in 1986. A microwave transponder-based positioning system which had been installed several years before to assist in collection of sounding data was pressed into service as a real time positioning system for use with PINS. The CCGS TRACY, the sixth and most recent ice-breaker to have PINS installed, is shown in Figure 9. By 1991, all seven ice-breakers in the fleet will be outfitted with PINS.

A typical PINS display as it would appear during regular operations is shown in Figure 4. Lac St. Pierre is located in the St. Lawrence River appro-

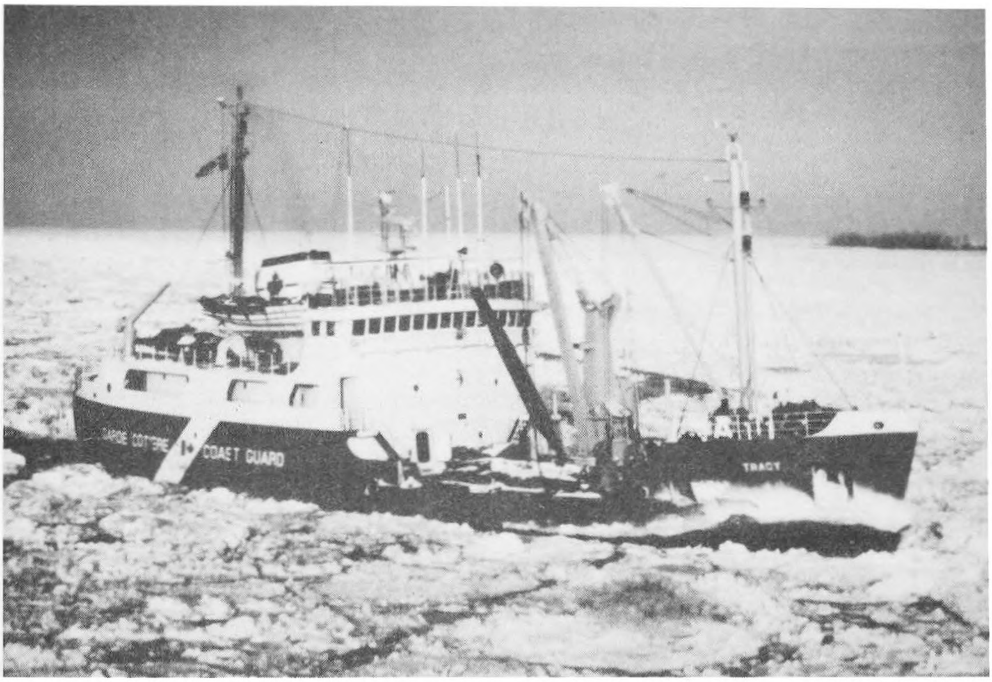

FIG. 9.— CCGS TRACY.

FIG. 10.— Laviolette Bridge on the St. Lawrence River with Lac St. Pierre in the background.

ximately half-way between Quebec City and Montreal near the town of Trois-Rivières. This naturally shallow lake is about 16 miles long and 6 miles wide. A narrow dredged channel about 245 metres wide and 10 metres deep can be seen running through the lake in the small scale north-up chart shown in the upper right window of the display. A close-up view of the vessel is shown in the large scale ship's head up chart in the upper left hand window of the display. Here the vessel is demonstrating how it can move outside the standard channel to clear ice in perfect safety.

PINS has provided many increased capabilities to the Coast Guard ice-breaking fleet and achieved great popularity amongst Coast Guard bridge officers [8]. Vessels can position themselves over buoys hidden by ice thus avoiding the need for time-consuming searches during buoy recovery. Significant time is saved now that ice-breakers can make 180-degree turns within the narrow ship channel instead of being forced to go to a turning basin. Vessels can break ice in deep water contours outside the channel which allows them to keep the channel open for traffic while ice-breaking continues upstream. And, of course, since the bridge officers know their exact position relative to shallow water and other navigation hazards, ice management operations can be conducted at any time in any weather. This helps prevent serious jams by permitting action to be taken early and, by increasing efficiency, it allows the Coast Guard to use fewer vessels for a given job than they might have required before PINS.

7. Discussion

The success of OSL's PINS 9000 electronic chart can be attributed to a number of factors. First, much attention was paid to human factors during the development of PINS. The system was designed to be simple to operate and use only a limited number of controls. The special PINS keyboard and a directed syntax menu system were adopted because they are far easier to use in a busy bridge environment than a conventional ASCII keyboard. PINS permits the user to easily configure the display with multiple windows containing independently scaled charts and text displays with user defined formats to suit individual needs. In practice, watchkeepers usually prefer to operate with large scale displays in order to see greater chart detail. However, small scale displays are often used to look ahead for long range tactical purposes or general orientation and route planning. Users often configure PINS to display large and small scale charts in adjacent windows. Once a suitable format or layout has been obtained for a given application, users rarely find need to change it. Although some ECDIS proposals call for multiple screens for displaying text and graphics, PINS users have indicated that they prefer to have all the information integrated onto a single monitor screen.

Second, PINS has earned the confidence of the masters and pilots who rely on the system. This was accomplished partly by ensuring that both the hardware and software components of the system were reliable and robust. However, it is also necessary to provide a real time indication of the health of the system. To this end, PINS provides the mariner with a dynamic measure of the quality of the displayed position fix including both a scalar quality factor in the text window and an error ellipse display superimposed on the vessel outline in the chart window.

Finally, OSL recognized early on that new users wouldn't fully appreciate the capabilities of electronic chart display systems and would initially be rather conservative in specifying their needs and requirements. While these needs and requirements were invariably satisfied, masters soon began to suggest new features and modifications to existing features that would make PINS even more useful to them. In anticipation, the PINS software was designed from the outset in such a way that new features requested by users could be added easily. One of the most important user requested features (and the one that was most difficult to achieve) is completely automatic start-up and 'hands-off' operation including automatic chart scaling during harbour approach and docking. Other user-requested features have included wind speed and direction vectors, for use during docking and velocity vectors, for use during turns in mid-channel. The results of the close interaction between user and developer have been extremely satisfying for both.

Widespread use of electronic charts by the marine transport industry will be as dependent on the establishment of a suitable infrastructure for the production and distribution of chart data and the availability of training for the prospective user as it will be on the technical sophistication of ECDIS hardware and the quality of the user interface. Some electronic chart manufacturers have resorted to the use of scanned paper charts images in place of a true electronic navigation chart data base. Since one loses most of the advantages of the electronic chart in the process, this is not a viable solution in the long term. However, until government hydrographic agencies are able to make certified electronic chart data available to users on a routine basis, use of electronic charts will probably be restricted to special purpose and niche applications and the true potential of the electronic chart will not be realized.

Various agencies including the International Hydrographic Organization (IHO) and International Maritime Organization (IMO) have begun to address the host of problems involving electronic navigation chart production, maintenance, updating and even issues of copyright and legal status that have not yet been solved. The Canadian Hydrographic Service has taken a leading role in the solution of these problems through such initiatives as the development of MACDIF (Map and Chart Data Interchange Format) and promotion of the development of ICOIN (Inland Waters, Coastal, and Ocean Information Network) [9]. ICOIN is a proposal to develop a comprehensive parallel data base of environmental, economic, resource, and social information to support maritime activities. A data base of this type used in conjunction with an optical disk, the MACDIF data interchange format, and a suitable data communications system would carry ECDIS far beyond the paper chart in the quest to provide mariners with fast and easy access to the information they require.

Although the potential of the electronic chart is undisputed, the question of whether the electronic chart will actually replace the paper chart has been a source of controversy for nearly a decade. However, just as the introduction of office automation did not result in a paperless office, it is doubtful that ECDIS will result in a paperless bridge. It is clear, however, that an ECDIS equipped bridge will be both safer and more efficient than its traditional counterpart.

8. Radar Assisted Precise Navigation

The usefulness of an electronic chart such as PINS is dependent on the accuracy of the position data available to it. When it is provided with low resolution ($\pm$ 100 metres) position data from either a Loran-C or standard GPS receiver, PINS can assist in route planning and execution, fuel management, and general navigation in coastal and offshore waters. When it is provided with high resolution ($\pm$ 2 metres) position data from a microwave transponder-based system, a radar-assisted precise navigation system (such as OSL's RANAV [10]), or a differential GPS receiver (after 1994), PINS can plot and electronically monitor a ship's course accurately enough to permit blind pilotage in narrow channels, harbour approaches, and harbours.

Microwave transponder-based positioning systems similar to those used by Marine Atlantic at Port aux Basques and the Canadian Coast Guard on the St. Lawrence River are commonly used to provide very accurate position fixing to a small number of users operating in a relatively small area such as a harbour. Although they are extremely cost effective when used for short periods of time in small areas, maintenance and repair problems often reduce their effectiveness when they are used in permanent installations. The transponders require a local source of power and contain sensitive circuitry. As a result they are expensive to install, particularly at remote sites, and are prone to failure. Failures due to lightening strikes have been particularly troublesome at a number of installations. Although microwave systems can be made to work if one is willing to expend the occasionally considerable effort required to maintain them, an alternative to microwave positioning which eliminates some of these difficulties while providing the desired 2-metre positioning accuracy would be most desirable.

In 1987, OSL, with funding and support from Transport Canada's Transportation Development Centre and Marine Atlantic, began developing a radar assisted positioning system (RANAV) to provide position data accurate to within a few metres in critical areas such as harbours, harbour approaches, and narrow channels. The system is based on the automatic measurement of the range and bearing to passive reflectors located in precisely surveyed locations ashore. Since it uses passive targets in place of active transponders, RANAV virtually eliminates the hardware reliability problems which plague conventional transponder based systems. In addition, RANAV can be used by any number of casual users without penalty.

The first operational RANAV system was used for channel navigation and docking/berthing by the 150-metre cargo ferry M/V ATLANTIC FREIGHTER at Port aux Basques, Newfoundland, on a daily basis from May 1989 until January 1990 when the vessel was taken out of service for routine maintenance. This successful demonstration prompted Marine Atlantic to request that RANAV systems be installed aboard the M/V CARIBOU and M/V JOSEPH AND CLARA SMALLWOOD.

9. Conclusions

The 1980's were an exciting period of research, development, and demonstration of electronic chart technology. The advantages of using electronic charts to present precise vessel position information in real time to masters and pilots during critical manœuvering in restricted waters such as narrow channels, harbours, and harbour approaches were proven in a number of operational situations. It was generally recognized that ECDIS can play an important role in reducing the workload on bridge crews (especially routine but repetitive tasks such as frequent position fixing and chart plotting that can either fatigue or distract the watchkeeper) and can help eliminate accidents such as groundings and collisions that are caused by human error in estimating position by visual signs or interpreting raw data from navigation instruments.

Although numerous chart plotters and other simple ECDIS-like instruments are used by fishing vessels and pleasure craft, electronic charts are not yet found on board the majority of ferries, freighters, and tankers that routinely use North American ports. A number of factors may be relevant. Some have suggested that because ships have sailed without electronic charts in the past and international regulations do not yet require them to be carried, it can be difficult to convince conservative and cost-conscious shipowners that ECDIS is now a necessity. If this is indeed the major factor limiting acceptance of ECDIS, it is most unfortunate given that the cost of a single mishap, whether it results in complete loss of the vessel or just the loss of its use while it is being repaired, is many orders of magnitude higher than the cost of even the most expensive and full feature electronic chart system.

Others have suggested that since electronic chart technology is still quite new, many mariners are still unfamiliar with the intended role of ECDIS. Experience with OSL's PINS 9000 seems to bear this out. Masters and pilots who have a great deal of experience with PINS are generally quite enthusiastic about its role in providing assistance during coastal navigation and pilotage. In contrast, those who do not have much experience tend to be much more cautious and guarded in their appraisal. The present situation should gradually correct itself as ECDIS becomes more widely used and ECDIS training becomes established at fleet schools and marine training institutes.

As hardware becomes even more sophisticated and capable, as experience is accumulated, and as precise navigation systems capable of providing position data that is accurate within several metres (such as differential GPS and OSL's RANAV) become widely available in the 1990's, it is expected that the market for electronic chart systems will grow tremendously. Thanks to the farsightedness displayed by the international hydrographic community during the 1980's, it appears certain that the technology and infrastructure that will be required to meet the challenge of producing, distributing and updating certified data for electronic navigation charts on a routine and regular basis will be in place in the not too distant future. In the meantime, users and developers must continue to work together during the design and development process to ensure that ECDIS will continue to meet user requirements.

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