Canadian Innovations in Naval Acoustics from World War II to 1967

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Innovation at Canada's two naval research laboratories advanced understanding of underwater acoustics to the benefit of researchers worldwide.

Introduction

Canada's two naval acoustics research laboratories conducted groundbreaking work in naval acoustics beginning in World War II and continuing to the present day. Early innovations included advances in acoustic mine and torpedo countermeasures, oceanography and acoustics of antisubmarine warfare, development of a variable depth sonar, and Arctic acoustics.

The motivation for early oceanographic and underwater acoustics research in Canada and worldwide was distinctly naval in nature, with the aim of detecting mines, submarines, and torpedoes (Muir and Bradley, 2016). Underwater acoustic research in Canada was spurred by Canada's entrance into World War II in September 1939; before that time, Canada did not have a specific defense research capability (Longard, 1993).

Figure 1. *Convoy assembling in Bedford Basin, Nova Scotia, Canada, in 1941 to be escorted by the Royal Canadian Navy (RCN) through the U-boat-infested waters of the North Atlantic. Approximately 25,000 merchant ship voyages were made by 12,000 men and women serving in Canada's Merchant Navy. It was dangerous work, with 1,500 Canadian lives and 59 Canadian-registered ships lost. Photo PA-128093 courtesy of Library and Archives Canada, Canada, Department of National Defence.*

By 1940, magnetically triggered mines had become a significant threat because they could quickly be deployed in large numbers by aircraft. The magnetic signature of a ship could be reduced by "degaussing," applying a current to coils installed on a ship that would offset its magnetic signature. Convoys of merchant ships (**Figure 1**) would gather in the Bedford Basin in Halifax, Nova Scotia, Canada, to be escorted by Royal Canadian Navy (RCN; see **Table 1** for list of abbreviations) ships across the Atlantic to resupply the war effort in England, and the RCN was responsible for degaussing all merchant ships bound to Europe from Canada (Longard, 1993).

In February 1940, Professors G. H. Henderson and J. H. L. Johnstone from Dalhousie University in Halifax were asked to help develop degaussing techniques. By 1942, degaussing "ranges" were established in the Bedford Basin, Sydney (Nova Scotia), Quebec City (Quebec), and Victoria (British Columbia). The routine work at the ranges consisted of measuring ships' magnetic signatures while underway and calculating the current required to offset them. With rising concerns about acoustically triggered mines, a combined acoustic-magnetic range, the Hugonin Range, was constructed in Halifax Harbour near McNabs Island.

The laboratory that began as the Anti-Magnetic Mine Office in July 1940 is now known as the Defence Research and Development Canada (DRDC) Atlantic Research Centre.

Table 1. *Abbreviations*

Term	Definition
CAT	Canadian Anti-Acoustic Torpedo
CCGS	Canadian Coast Guard ship
CFB	Canadian forces base
CRT	Cathode ray tube
DRB	Defence Research Board
DRDC	Defence Research and Development Canada
DREA	Defence Research Establishment Atlantic
DREP	Defence Research Establishment Pacific
F0	Pressure wave
FH	High frequency
FL	Low frequency
HMC	His/Her Majesty's Canadian
NRC	National Research Council
NRE	Naval Research Establishment
PNL	Pacific Naval Laboratory
RCAF	Royal Canadian Air Force
RCN	Royal Canadian Navy
RIP	Remote Instrument Package
RN	Royal Navy
VDS	Variable depth sonar

Initially, the laboratory was located in His Majesty's Canadian (HMC) Dockyard in Halifax (now Canadian Forces Base [CFB] Halifax). By January 1944, research had branched out into acoustic mines and submarine detection, and with a complement of about 50 staff, the laboratory was renamed the Naval Research Establishment (NRE) under the auspices of Canada's National Research Council (NRC).

In 1947, the NRE became one of seven research establishments absorbed by the Defence Research Board (DRB), formed to take over the defense research effort from the NRC. In 1952, the NRE moved across Halifax Harbour into a new building that was the largest structure and the first research establishment at that time in the city of Dartmouth.

Additional establishments created by the DRB included the Pacific Naval Laboratory (PNL) in 1948, located in the HMC Dockyard in Esquimalt (now CFB Esquimalt) near Victoria, British Columbia, Canada. The PNL was charged with examining naval problems not handled by the NRE and problems specific to the Pacific Ocean. Starting in the late 1950s, the PNL undertook a significant research program in the Arctic. Thus the NRE and PNL were considered "sister laboratories" studying naval acoustic problems in Canada's three oceans.

In 1967, as part of a DRB drive to unify the laboratories through name changes, the PNL became the Defence Research Establishment Pacific (DREP) and the NRE became the Defence Research Establishment Atlantic (DREA; Turner, 2012). Most Canadian naval research was consolidated at the DREA after closure of the DREP in 1994, with only a small contingent of materials scientists remaining at the "Dockyard Laboratory Pacific" in Esquimalt (but organizationally part of the DREA). In 2000, the DREA became part of a new agency, Defence Research and Development Canada (DRDC), and the laboratory was renamed DRDC Atlantic. On March 31, 2018, the Dockyard Laboratory Pacific was closed, with the remaining materials science work being transferred to the DRDC Atlantic Research Centre. In early 2018, the staff of the DRDC Atlantic Research Centre was moved to a new building on the same site in Dartmouth as the original building from 1952, which was then demolished.

Over the years, research areas at the former NRE have remained relatively stable: mine countermeasures, harbor defense, antisubmarine warfare, torpedo defense, ship signatures and structures, and materials science, with the later addition of maritime command and control and information warfare.

Mines, Torpedoes, and Countermeasures

Underwater sound radiated from a ship consists mainly of engine and propeller noise, which can easily be detected by hydrophones and used to trigger acoustic mines. Acoustic mines were first deployed by the Germans around the British Isles in 1940 (Moffatt, 2005). Consequently, acoustic minesweeping devices were developed to trigger the mines from a safe standoff distance; essentially, these were very loud noisemakers. One widely used type was the "parallel-pipe" noisemaker that was developed by trial and error in naval dockyards in the United States and Canada. It consisted of two 6-foot (1.88-m)-long pipes connected by a bridle and towed in the wake of a minesweeper oriented at right angles to the flow of water (Longard, 1993). The vortices produced between the pipes as they struck one another repeatedly resulted in broadband noise.

During the course of the war, the two magnetic ranges in Halifax Harbour were outfitted with hydrophones, filters, and recording equipment. Based on intelligence reports, the initial frequency bands of interest were 170-340 Hz for German acoustic mines and 20 kHz for German wake-homing torpedoes. Eventually, the Hugonin Range was equipped to cover frequencies from fractions of a hertz to 256 kHz (Longard, 1993). The frequency bands were referred to by their British Admiralty-style abbreviations of FL (low frequency: 1-100 Hz) and FH (high frequency: 8-200 kHz) and what the NRE called F0 (the pressure wave induced by the passage of a ship).

For both the FL and FH ranges, a Rochelle salt hydrophone was bottom mounted on a tripod near the center of the degaussing range. For the FH range, the output was directed to banks of analog electronics and then displayed on an array of twelve 3-inch (7.5-cm) cathode ray tubes (CRTs). The CRT traces were photographed simultaneously on slowly moving film (**Figure 2a**). For the FL range, recordings were initially made on a gramophone disc of wax on glass. Analysis required repeatedly replaying the signal through a filter called a Wien Bridge, a device that could only be used to analyze one narrow band at a time. The process was so fraught with difficulties that Ed Lewis and Oscar Sandoz redesigned the measurement system entirely, building a bank of filter amplifiers whose output was displayed on CRTs and photographed (as in the FH range). Several hundred ships were ranged at the FL and FH ranges by Lewis, Sandoz, and Bruce French, resulting in statistical summaries that related observed frequencies to ship size and type, engine type, and

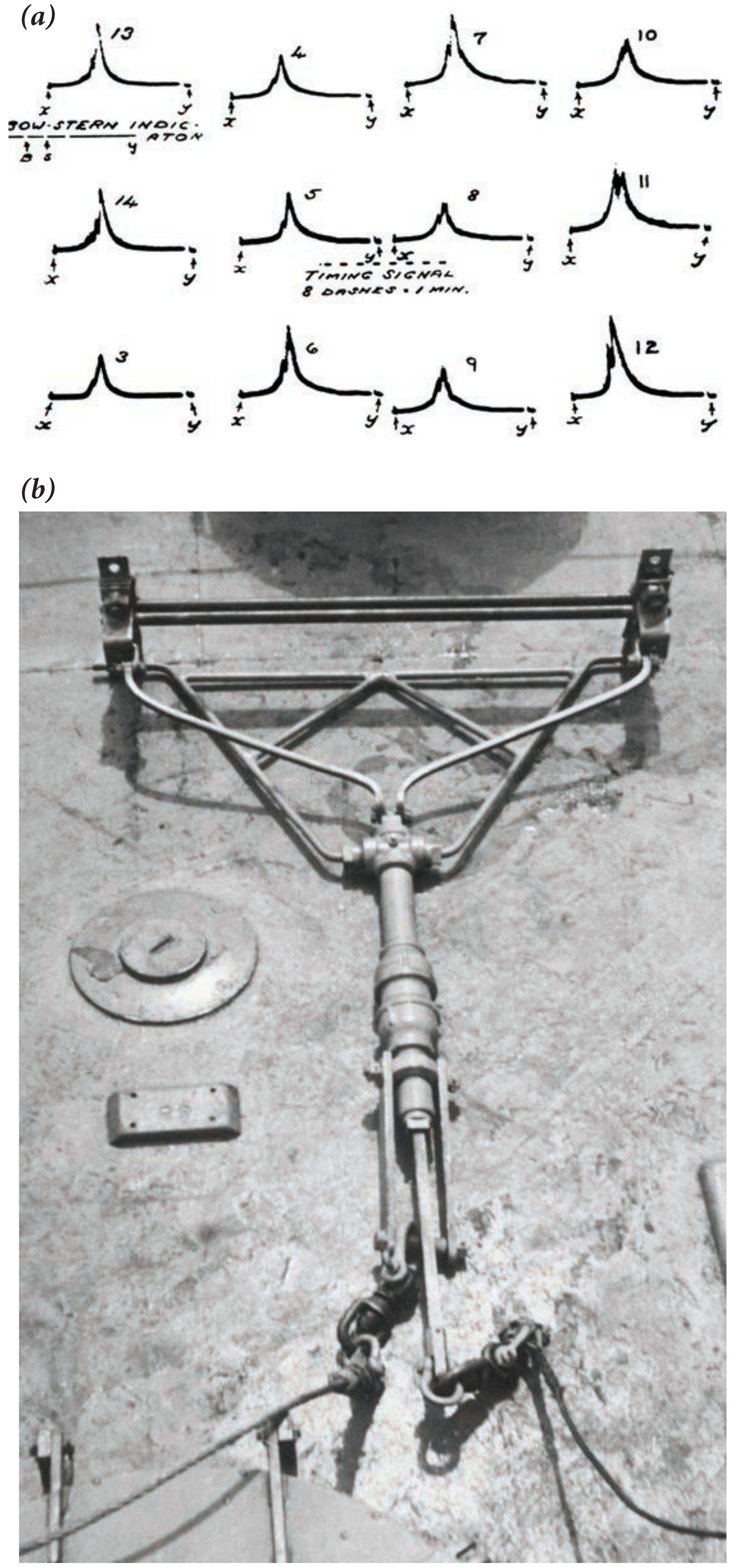

***Figure 2. a:** Ship noise recorded on 12 one-third octave bands (8-128 kHz indicated by numbers 3-14) at the high-frequency (FH) range. Traces begin at x and end at y, with the bow-stern aspect indicated below band 13. Peaks tend to occur at or just after passage of the stern. The timing signal dashes are visible in the center. **b:** Canadian Anti-Acoustic Torpedo (CAT) gear. **Top:** parallel pipes; **bottom:** towing lines. Photo courtesy of Canada, Department of National Defence.*

number of propellers (Longard, 1993). The same report included what was likely the first direct observation of the line spectrum of the vibration of a ship's hull (Longard, 1993), a phenomenon still used to identify individual ships.

The F0 system was developed by Ken Newbound to measure the decrease in pressure underneath a passing ship, which was thought to be a potential trigger for German "oyster" mines. However, the measured maximum negative pressure was comparable to that of background sea swell, suggesting that a pressure mine would require a second influence device to avoid being falsely triggered (Longard, 1993).

In 1943, the NRE scientists received a message that the Germans were using torpedoes capable of homing on a ship's propellers. That very evening, Lewis, John Longard, and Commander A. F. Peers designed a decoy that became known as the Canadian Anti-Acoustic Torpedo (CAT) gear. It was thought that a suitable noisemaker towed well astern of a ship could attract the torpedo and run it to exhaustion so they redesigned the minesweeping parallel-pipe noisemakers to operate around 20 kHz. The long parallel pipes were replaced with 30-inch (75-cm) steel rods, and the gear was assembled from other scraps and bolts found around the laboratory (**Figure 2b**). The next day, Olga Mounsey drafted proper drawings and the CAT gear went into production, and within 17 days, it was being fitted on Allied ships (Veterans Affairs Canada, 2017). Eventually, the CAT gear was copied by the United States, where their new noisemakers with rods of the same length (30 inch) also included the "much oversize bolts" from the NRE drawing (Longard, 1993).

Oceanography and Antisubmarine Warfare

Mine and torpedo acoustics occur at short enough ranges that sound essentially travels in a straight line. However, vertical variations in the speed of sound in water (which depends on temperature, salinity, and pressure) result in a lensing effect that redirects the sound upward or downward. Therefore, over the longer distances required for detecting submarines, the sound may interact many times with the rough ocean bottom and surface, resulting in scattering and losses. In deeper waters, sound may be refracted downward and away from a surface ship's sonar system, drastically reducing the detection range against a submarine.

During World War II, the RCN observed that in Canadian waters, U-boats could escape detection simply by diving. To increase understanding of the ocean's thermal structure off Canada's East Coast, the NRE undertook multiple survey programs beginning in 1943. On the West Coast, oceanographic surveys were initiated by John P. Tully of the Pacific Oceanographic Group in 1936 and continued jointly with the PNL staff beginning in 1948. Oceanographic surveys and trials to understand the effects of ocean conditions on sonar performance were undertaken in the Pacific Ocean, Bering Sea, and Western Arctic (Chapman, 1998; Canadian Meteorological and Oceanographic Society [CMOS], 2014).

Figure 3. *Operation CABOT staff. Naval Research Establishment (NRE) staff included (**left** to **right**) Norbert Lyons, John Longard, William Mackasey, Bill Ford, Bryce Fanning, and two others (names unknown). Photo courtesy of Canada, Department of National Defence.*

In 1950, W. L. Ford led a team aboard the NRE ship HMCS *New Liskeard* (**Figure** 3) that was part of a six-ship survey of the northern boundary of the Gulf Stream known as Operation CABOT, a joint undertaking with several American research groups. The considerable dataset acquired on the survey (700 bathythermograph slides and 800 water samples on the *New Liskeard* alone) greatly increased the understanding of Gulf Stream dynamics (Ford et al., 1952; Stommel, 1965).

The surveys resulted in NRE memoranda produced for the RCN and the Royal Canadian Air Force (RCAF) on water conditions off the East Coast of Canada. Longard also developed an extension to the 1942 US Navy code used to describe the ocean temperature structure to accommodate the stronger gradients observed in Canadian waters. The codes could be plotted on a map to give a three-dimensional picture of water conditions. Longard's extended code was adopted around 1948 by the US Navy under the name "NRE code" and used for about 10 years (Longard, 1993).

Variable Depth Sonar

In 1948, Longard postulated that the cold intermediate water layer between the two warm layers on the Scotian shelf would form a "sound channel" at the depth of the sound speed minimum and that a transducer lowered to this depth should detect a target in the same layer at long ranges (Longard, 1993). As an initial test, an existing sonar capsule was fitted with a bridle and cable designed to be lowered from a stopped ship. Trials in 1949 and 1950 demonstrated very long detection ranges with both the transducer and submarine target at the depth of the sound channel. With the concept demonstrated, the focus turned to the engineering required for an operational system: the development of appropriate cables and a tow body, transducer, and a display system.

Measurements and theory of cable drag indicated that the length of cylindrical cable required to achieve desirable tow depths and speeds would be too large for practical handling. The solution was to use a faired cable (one with a streamlined cross section) to reduce the drag and thus the required cable length. The final cable design consisted of a formed rubber section fastened by U-shaped metal clips that turned easily on the cable. The first tow bodies were simply torpedo bodies fitted with UK "Type 144 Asdic" (i.e., sonar) transducers. Over six years of development were required to develop a suitable tow body, and the final design based on the Royal Navy (RN) 100-inch sonar dome was known as TRILBY. The experimental "variable depth sonar" (VDS) using the TRILBY body become known as the CAST/1.

The increased operational depth intended for the CAST/1 allowed for a higher power output than the modified steel-quartz transducer from the Type 144 Asdic could provide. Thus, the CAST/1 used the new high-activity low-impedance piezoelectric ceramics being developed at the NRE at the time. Small concentrations of cobalt added to barium titanate ceramics resulted in a large reduction in dielectric loss at a high electrical driving power. The optimal mix was determined by Schofield and Brown (1957) and this "NRE-4" ceramic (the fourth of seven concentrations tested) was used in the CAST/1 transducer.

The electronics and display equipment were designed in conjunction with the Defence Medical Research Laboratory (now the DRDC Toronto Research Centre), who provided "human engineering" advice. The combination of high-quality audio signal replay and visual presentation resulted in "unusually good target classification" (Longard, 1993).

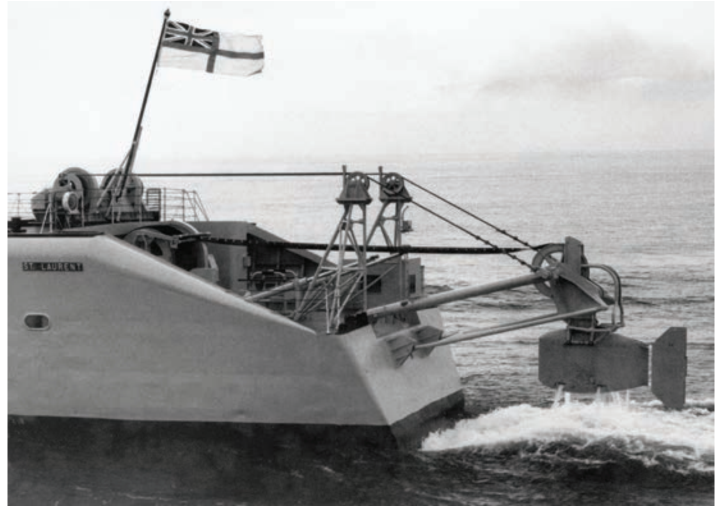

***Figure 4.** Operational variable depth sonar on the HMCS* St. Laurent. *Note the Royal Navy (RN) White Ensign (flag) that was the Canadian Naval Ensign at the time. The TRILBY tow body containing the transducer is visible (**far right**). Water streaming out suggests that it is being recovered. Photo courtesy of Canada, Department of National Defence.*

In March 1958, the CAST/1X electronics (an experimental version of CAST/1) and TRILBY body were tested by the RCN on the HMCS *Crusader*, with the resulting recommendation that it be accepted with as few modifications as possible to expedite production (Longard, 1993). The CAST/1X demonstrated its superiority in trials when comparing its performance to that of the British experimental medium-range Asdic. As a result, the RN stopped development of their Asdic and adopted the Canadian design. The operational variant of the VDS (**Figure 4**) was known as SQS-504 by the RCN and Type 199 by both the RN and the Royal Australian Navy and is on display in the Canadian War Museum in Ottawa, Ontario.

Surface Reverberation

When attempting to detect active sonar echoes from a target in the ocean, there are two main sources of interference: ambient noise and reverberation. Ambient noise consists of all the sounds one is *not* interested in, and in the case of anti-submarine warfare, it consists primarily of noise from wave breaking, shipping, biological sources, and ice. Reverberation consists of the diffuse echoes arising from large numbers of spatially separated scatterers, primarily the ocean surface and bottom, and scatterers suspended in the water column.

In the modern day, it easy to explain the sources of noise and reverberation, but in the 1950s and 1960s, each of these terms was being examined in detail. At the NRE, Robert P. (Bob) Chapman led many studies using explosive sound sources to provide acoustic measurements over a wide frequency band (400 Hz to 16 kHz). Chapman was unable to participate in sea trials, and he thus relied on collaboration with others (Merklinger and Osler, 2015). In March 1961, Jim Harris organized a sea trial to measure surface reverberation using explosive sources north of Bermuda, which had a deep isothermal surface layer in the wintertime. Wind conditions varied from 0 to 30 knots (0-15 m/s) during the experiment, covering all the wind speeds of interest.

Chapman's initial analysis showed that time of day and wind speed were perfectly correlated, and thus it could not be determined which was the cause of the observed changes in scattering strength. However, Harris had collected an initial "test" dataset on a day with completely different wind conditions, but he had omitted it from the original plots because it was not part of the "official" dataset (he had used only two hydrophone depths). When the test dataset was included, it became clear that the surface scattering did primarily vary with wind speed. When Chapman presented the paper at the 1961 Fall US Navy Symposium on Underwater Sound, the data were plotted in several octave frequency bands, and an audience member suggested plotting it all together to elicit greater understanding. On his return to the NRE, Chapman did just that and then asked Anne Robison to calculate the nonlinear curve fit that is now known as the Chapman-Harris equation that relates the surface-scattering strength to wind speed and frequency (Chapman and Harris, 1962).

The same *Journal of the Acoustical Society of America* (*JASA*) paper by Chapman and Harris noted the time-of-day variation in scattering strength that was ultimately attributed to volume reverberation. In later years, using a 3.5- to 6-kHz echo sounder on the HMCS *New Liskeard,* they were able to identify several volume-scattering layers, some that migrated and some that did not. These "deep scattering layers," now known to be found worldwide, are predominantly biological in origin, and most of the scattering was due to fish swim bladders (Chapman et al., 1974).

Early Arctic Acoustics

Arctic underwater acoustics in Canada began at the PNL in 1958 when Al Milne was inspired by stories of the Canadian Army's Operation Muskox and tales of the Beaufort Sea trials. In 1959, Milne organized *Paclabar* (**Pac**ific **Lab**oratory **Ar**ctic), the first of what were to be numerous Arctic trials. The trials (*Icepack 1-8* and *Polarpack 1-3*) took place in locations across the Arctic Ocean, including Barrow Strait, Prince Gustav Adolph Sea, M'Clure Strait, Prince Regent Inlet, Viscount Melville Sound, and Mould Bay (Milne, 1998).

The trials followed the same general formula. First, by some combination of airlift, ship, sled, and helicopter, the team would arrive at a suitable location on the ice with appropriate scientific and survival equipment, a nontrivial task. Next, they drilled a hole through the ice through which they lowered a hydrophone. A small "shooting party" traveled by sled or helicopter 1-2 km away, drilling or blasting a second hole through the ice through which to make oceanographic measurements and then set off explosive charges at some depth in the water while at the first hole, the hydrophone signal was being recorded. Then the shooting party would navigate farther away and repeat the drilling-oceanography-blasting process (Milne, 1998). Through this series of experiments, the teams (including Milne, Tom Hughes, John O'Malia, and John Ganton among many others) made measurements of noise and reverberation under the Arctic sea ice (e.g., Milne, 1964; Milne and Ganton, 1964; Brown and Milne, 1967) and the sound speed in the bottom (Milne, 1966). One interesting series of measurements explored the stability of the sound transmission medium under land-fast ice over short and long ranges (Ganton et al., 1969).

The PNL team developed numerous innovations for transportation and survival in the Arctic (Ganton, 1968). The drill used for ice 5-7 feet (1.5-2.1 m) thick had a triangular bit to drill holes 9 inches (23 cm) in diameter; for larger holes, several "dry" holes were drilled in a circle and a central "wet" hole was filled with explosives that were then detonated. They then faced the problem of how to keep the holes ice free; an inflatable neoprene balloon was a simple solution that worked for up to a week. For longer deployments, they used the "rope trick." A 7-inch (18-cm)-diameter plastic cylinder was wrapped with nylon rope embedded in silicon rubber. Instrument cables were threaded through the cylinder and the whole apparatus was allowed to freeze into the 9-inch (23-cm) hole. To recover the instruments, the rope was easily unspooled from the outside of the cylinder, and the freed cylinder was recovered, with the cables frozen inside.

Survival and navigation also required innovative solutions. Regular compasses were useless near the magnetic pole, so wayfinding was achieved with a combination of a sextant, radio fixes, and bamboo poles with black flags marking their route. The Army-issued Arctic clothing used for the first trial was insufficient; on subsequent trials, it was enhanced by additional liners and newer materials such as L19 Ventile cloth (Milne, 1998). Heavy steel sleds and wooden wannigans (insulated sheds) were replaced with lightweight aluminum sleds and wannigans whimsically named *Empress*, *Frontenac*, and *Royal York* (after three grand railway hotels in Canada). Graeme Dennison designed a lightweight fabric shelter that was manufactured in the HMC Dockyard sail loft out of double-layered nylon with batts of Dacron between for insulation. An insulated floor completed the four-person shelter that included a kitchen box, space heater, and snow melter. A smaller shelter carried for emergencies was called the "instant igloo"; its two floor segments unfolded with the tent between them (somewhat like a bellows), and it could be set up in under a minute, even in wind.

Ships used for field trials included the Canadian Coast Guard ship (CCGS) *John A. Macdonald* and CCGS *Labrador*, Canada's first icebreaker and the first warship to transit the Northwest Passage (coincidentally, with 10 scientists from the DRB on board; Piggott, 2011). Through collaboration with American colleagues, the PNL team undertook the joint trial *Polarpack 1* in 1962 to study sound transmission between ice islands more than 1,000 km apart, and they sailed on the USS *Staten Island* during the *Polarpack 3* trial in 1965. While embarked on icebreakers, they were frequently diverted from scientific work to assist ships in distress, provide icebreaking escort services, or helicopter support. On one interesting diversion in 1967, the CCGS *Labrador* was diverted to the Eureka weather station to provide helicopter assistance to a joint National Geographic-US Wildlife Service project rounding up yearling musk oxen for relocation to Alaska (Milne, 1998).

Long-Term Under-Ice Measurements

Eventually, the PNL team wanted to design a recording system capable of being deployed in the Arctic for a year to measure underwater ambient noise during freeze-up and under early winter ice. Over the relatively short period of 15 months between the initial concept and deployment, they designed and built the "Remote Instrument Package" (RIP) recording system that was customized in every way to long-term measurements in cold ocean waters (Ganton et al., 1970).

The RIP consisted of a square frame with two battery packs on opposite corners, the electronics package in the center, and a spherical DREA barium titanate hydrophone mounted above one corner. Digital recordings were made through a preamplifier followed by a bank of 6 one-octave analog filters covering frequencies from 10 Hz to 16 kHz. The bands were sampled sequentially in time for an averaging period of four minutes, with timing provided by a Bulova mechanical timer. The skepticism surrounding the digital recording system was evidenced by the inclusion of an independent analog system that recorded the 150- to 300-Hz band on a paper chart recorder. In fact, the digital tape recorder had mechanical problems when it was tested on delivery, but the short time frame for deployment required that the problems to be fixed in-house rather than waiting for procurement of a different recorder (Ganton et al., 1970).

Figure 5. Photo of the Remote Instrument Package (RIP) in Lancaster Sound, Baffin Bay, Nanavut, Canada, before it was raised to the surface. The hydrophone is in the cage at the top of the package. Batteries and electronics are in the pressure vessels. The winch carrying the recovery rope is visible at the back. Photo courtesy of Canada, Department of National Defence.

The recovery system consisted of an explosive bolt that released a custom-milled syntactic foam float that brought to the surface a light polypropylene line spliced into the wire recovery line. To assist in locating the float, there was a pop-up radio transmitter and a dye capsule that ejected bright green dye. An ingenious hook system to release the lines on deployment was devised so that the system could be lowered into position. The RIP was protected from corrosion through the use of a zinc anode and liberal amounts of Vaseline. It was designed for deployment in up to 2,000 feet (610 m) of water and its mechanical components were designed for a lifetime of 2 years (Ganton et al., 1970).

In mid-August 1967, Milne, Ganton, Bill Burrows, and R. H. (Dick) Herlinveaux (of the Pacific Oceanographic Group) and their cargo were flown in an RCAF C-130 Hercules to meet the CCGS *Labrador* at Resolute, Nunavut, Canada. At each deployment location, bottom cores were taken to determine whether the bottom was hard enough to trigger the line release mechanism. The ship's helicopter was sent to nearby shore locations where two rock cairns were built and portable radio transponders were placed to aid navigation on recovery. After each RIP was deployed, a photograph was taken of the ship's radar display to allow accurate navigation to the same location the following year (Milne, 1998).

During the year between deployment and recovery, Milne became concerned about the possibility of the release system failing and arranged to rent the *Pisces 1* manned submersible from International Hydrodynmaics Ltd. at a cost of $150,000 (CAD). To raise the necessary funds, a collaboration was undertaken among the PNL team, Herlinveaux, Bernie Pelletier (Bedford Institute of Oceanography), and Carlton Ray (Johns Hopkins University). In mid-August 1968, an RCAF C-130 Hercules flew 25,000 pounds of gear and personnel, this time to Thule, Greenland, to meet the CCGS *Labrador*.

When the team arrived in Baffin Bay, they found a 53-m-high iceberg with an estimated weight of 45 million tons grounded on the 430-m-deep knoll where the RIP had been deployed. The iceberg was rocking with a two-minute period, and they quickly realized there was no way to safely recover the RIP. The remaining four RIP recoveries went like clockwork, including the one in Norwegian Bay with 5-feet (1.5-m)-thick 10/10ths ice cover. Before they triggered the explosive bolt to initiate the Norwegian Bay recovery, the icebreaker first had to break a path to the RIP location and then break up ice in a quarter-mile (450-m)-diameter area to allow for the float and dye to be spotted. They also went ashore in Grise Fjord and Pond Inlet and recorded underwater sounds from narwhals from a small boat (Watkins et al., 1971). Using the *Pisces*, they were able to photograph one of the RIPs while it was still on the ocean bottom (**Figure 5**). Although the grounded iceberg eventually left Baffin Bay, a heavy swell prevented the safe launch of the *Pisces* to inspect the RIP deployment site. Thus the fifth RIP was never recovered. The RIP systems worked extremely well despite component failures that limited the recording periods to 3-11 months (Ganton et al., 1970).

Summary

The stories told in this article about acoustic mine and torpedo countermeasures, oceanography and the acoustics of antisubmarine warfare, development of a variable depth sonar, and Arctic acoustics are only a few of the dozens of interesting stories arising from Canada's two naval acoustics research laboratories, the NRE and PNL. Other scientific stories include corrosion prevention by cathodic protection, hydrofoil vessel development, computational acoustic models for reverberation and transmission loss, and explosive echo ranging (in collaboration with the RCAF and other maritime air forces worldwide). Oceanographic studies with direct bearing on naval acoustics included fluid dynamics research on turbulent microstructure and internal waves, temperature and salinity surveys, and drift bottle studies of surface currents. Essential to the success of the work was the feeling of camaraderie and excitement about working toward a common goal, a sentiment that persists to this day in the remaining Canadian naval acoustics research laboratory, now called the DRDC Atlantic Research Centre.

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BioSketch

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