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AIRBORNE HYDROGRAPHIC SURVEYING IN THE CANADIAN ARCTIC

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This is a slightly modified and updated version of a paper entitled 'Chartmaking with LARSEN' presented at Hydro USA '86, the Second Biennial National Ocean Service International Hydrographic Conference, March 1986, Norfolk, Virginia, USA. It is reproduced below with the kind permission of the National Ocean Service/NOAA and the Hydrographic Society of America.

ABSTRACT

In August 1985 Canadian Hydrographers broke new ground by being the first to use airborne laser scanning techniques to locate and survey shipping channels through parts of the Southern Route of the Northwest Passage. This survey was a landmark event in hydrographic surveying as it signaled the first time that an active airborne sensor was used for chartmaking purposes. Laser soundings were acquired in two of the highest priority areas and the processed results are being used in the compilation of a new nautical chart in the area. In 1986 the airborne team returned to this area to continue the sweep through the entire Southern Route.

INTRODUCTION

Agencies of the Canadian Government and private industry have been working together for a number of years to develop and implement an airborne mapping system for use in surveying Canada's coastal areas. The system has been named LARSEN after the famous Canadian explorer Henry LARSEN (1899-1964).

Airborne systems similar in concept are also under development in other countries such as the United States, Australia and Sweden. The motivation for

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such development comes primarily from the anticipated cost savings such survey systems would make with respect to corresponding surveys using surface vessels. These savings come about due to the faster collection speed of the aircraft and to the fact that swath systems can survey along many survey tracks at once. In addition, LARSEN gives CHS an expanded survey capability allowing it to carry out surveys which were otherwise prohibitively expensive.

THE DILEMMA IN ARCTIC CHARTING

The Canadian Arctic is the storehouse of future wealth and prosperity for Canada. Beaufort Sea oil and gas reserves are among the largest in Canada, the

FIG. 1.— Transportation routes through the Canadian Arctic.

iron ore deposits on Baffin Island are among the most massive in the world and lead-zinc, asbestos, and other resources lie waiting there to be tapped.

Exploitation of these resources must deal with the economics of bringing them to the market places in the south. Very few options are available. Oil and gas could travel down the Mackenzie Valley by pipeline, but some may have to go by tankers or LNG's through the North West Passage. Bulk carriers and other surface craft will also use this route (see figure 1). In addition, drill-rig support vessels, barges, passenger-liners, and ice-breakers will continue to move throughout this area.

To prepare for the expected demands, CHS has been carrying out surveys along the Mackenzie River, in the Beaufort Sea and throughout the Northwest Passage. But, as one might expect, the Canadian Arctic waterways are not all surveyed to the requirements that this increased traffic warrants.

By its nature, chartmaking is a slow and expensive operation and some lead time is required before an area is suitably charted for commercial shipping. New charting demands, therefore, must be anticipated. Given the limited budget to carry out mapping, only areas requiring immediate attention can be surveyed. On the other hand, charting an area can have a positive effect on the economic viability of it by encouraging traffic to enter an area previously uncharted.

As it happens, priorities shift from year to year to move with the events and economic pressures of the time. (The 1985/86 boom/bust cycle in oil and gas exploration is one example.) It is therefore difficult to carve out the time and the resources to prepare for the long term demands which are certain to arise. Hence the dilemma : insufficient charting demand can lead to a lack of appropriate exploitation whereas charting an inappropriate area wastes precious survey resources and time.

A SPECIFIC PROBLEM

There are two routes which are generally referred to as the Northwest Passage. It is the Northern Route, which follows Parry Channel and Prince of Wales Strait, that is commonly considered the most likely route to be used by any large-scale commercial shipping and hence the area which CHS has been concentrating on.

Not all ships can travel this route, however. Heavy ice prevents ships lacking ice-strengthened hulls from working in this passage. The Southern Route, through Larsen Sound and Queen Maud Gulf, is where much of the lighter traffic will go. This passage will be used for service vessels from Beaufort Sea drilling operations as well as its current use for transportation of supplies to the many isolated communities in this area of the Arctic. The Southern Route has the advantage of being relatively free of ice, but is shallower than the northern passage and not as well surveyed.

Conventional surveys carried out in this area are very expensive due to the unpredictable ice-free period. Survey ships must depart their base of operation weeks before and gamble on arriving on site at the right moment, neither too soon to face a continuous ice cover, nor too late to miss prime survey time in the short time window available.

THE SOLUTION

In general, the best inventions are not necessarily the cleverest, the most elegant, the most progressive or the most advanced ; they are the most timely. As it happens, the demand for more and more Arctic charting comes at a time when the survey resources remain limited. LARSEN's timely arrival provides a tool to help break out of this dilemma.

LARSEN's ability to survey areas which had been prohibitively expensive to do otherwise is perhaps its greatest feature. Improved Benefit/Cost ratios have provided a logical rationale for its development, but its ability to solve this high-demand/limited-resource dilemma is the real payoff for the time and money invested. LARSEN gives Canada a new strategic capability in Arctic Hydrography.

THE LARSEN SYSTEM

LARSEN has been described in detail elsewhere and the interested reader is referred to CASEY, O'NEIL, CONRAD (1985), CASEY (1984), O'NEIL (1980) for details. It was developed by OPTECH Inc. (Downsview, Ont.), the Canada Centre for Remote Sensing (CCRS, EMR, Ottawa, Ont.) and the Canadian Hydrographic Service (CHS, DFO, Ottawa). Data presentation and deployment strategies were developed along with TERRA Surveys (Sidney, B.C.). The Department of Supply and Services Unsolicited Proposal Fund contributed key portions of the source funding to bring the system to fruition.

LARSEN uses a laser sounder (Lidar bathymeter) to measure water depths, but this is but one of a large collection of components which provides depths, contours, shoreline and foreshore information. Together they comprise the LARSEN System.

Globally, there are three major subdivisions :

1. **The Airborne Component** contains the Lidar and its associated electronics, a guidance system for positioning, a video camera/video disc system for along-track imagery and a logger for the coordinated storage of all of the digital data.

LARSEN lays down a pattern of soundings beneath the aircraft as shown in Figure 2. At a flying height of 500 m, the spacing between the soundings is about 30 m. The spacing can be varied to suit the conditions (e.g. a tighter pattern in a known shoal area). Presently, fluctuations in aircraft speed, altitude and attitude can distort this uniform pattern. The design has allowed for the later installation of a controller to compensate for these effects. The Lidar can measure up to 90,000 soundings per hour.

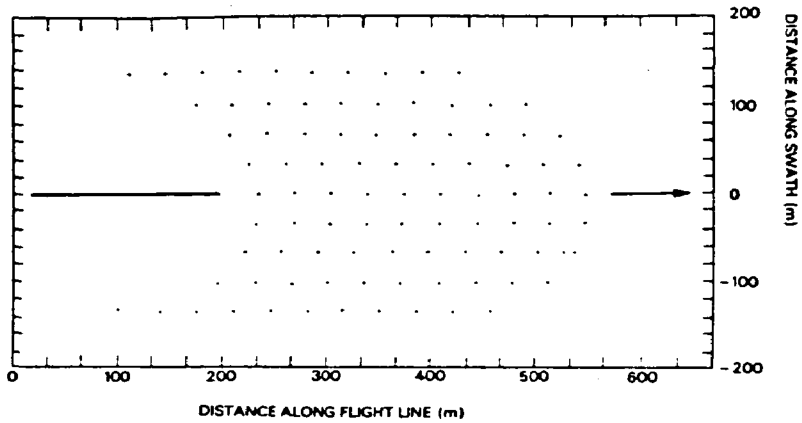

FIG. 2.— The LARSEN sounding pattern.

The positioning systems used are the Del Norte Trisponder Model 540 and the Global Positioning System (GPS). Both have worked very well. The GPS was supplied by NORTECH Surveys (Calgary, Alt.) and used a cesium clock, an OPTECH Model 501 Altimeter and a Texas Instruments model TI4100 Receiver. This data, along with NORTECH hardware and software, provides real-time 3D positioning using as few as two satellites. Position and attitude information is acquired for the calculation of (x, y) coordinates for each Lidar sounding.

These systems along with a Litton LTS 90 INS were interfaced to a HP 9826 computer which provided flight-line guidance information at 5 Hz. This was displayed for the pilots and operators and showed along-line progress on one screen, and general area progress on another. The guidance computer also provided quality control information on the positioning. The guidance function was under the control of the hydrographer.

The nadir-looking video camera is high resolution and its imagery is sampled at regular (programmable) intervals and stored on the video disc. The frame number of each image is stored along with the appropriate time, position and attitude file. This allows for images to be accessed by time or by position.

The logger was custom built to carry out the Lidar-transceiver/scanner control as well as the data logging.

2. **The Data Reduction System** includes all aspects of the hardware and software necessary to carry out functions from the stripping of raw tapes to the presentation of the data at field sheet scale. Its design and implementation are beyond the scale of this paper but some words are appropriate about the Editor as it is the key component.

The Editor employs a colour graphics terminal to verify and edit the Lidar soundings. Figure 3a shows a portion of an area sounded by the LARSEN. The depths are plotted as integers and colour-banded by depth. At this scale the numbers merge together to form a raster-like image. One can enlarge any portion of the screen to a scale at which the soundings become distinct (Fig. 3b). Note the encircled 14.5 m sounding surrounded by the much deeper soundings. Any question-

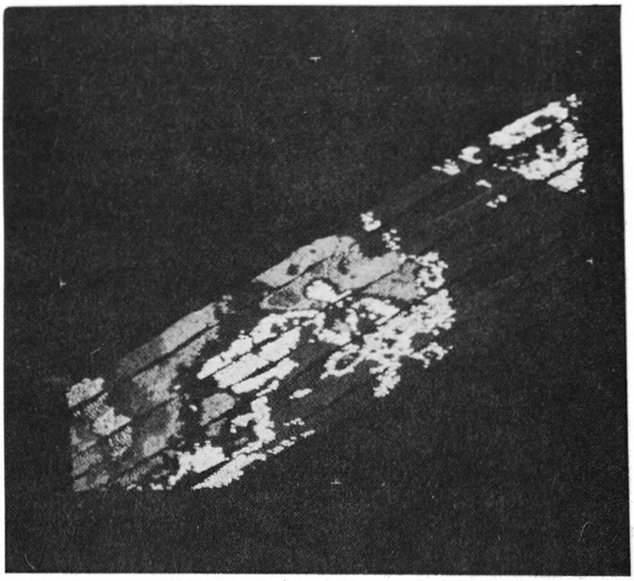

FIG. 3a.— Image of LARSEN data showing soundings plotted in various colours according to depth.

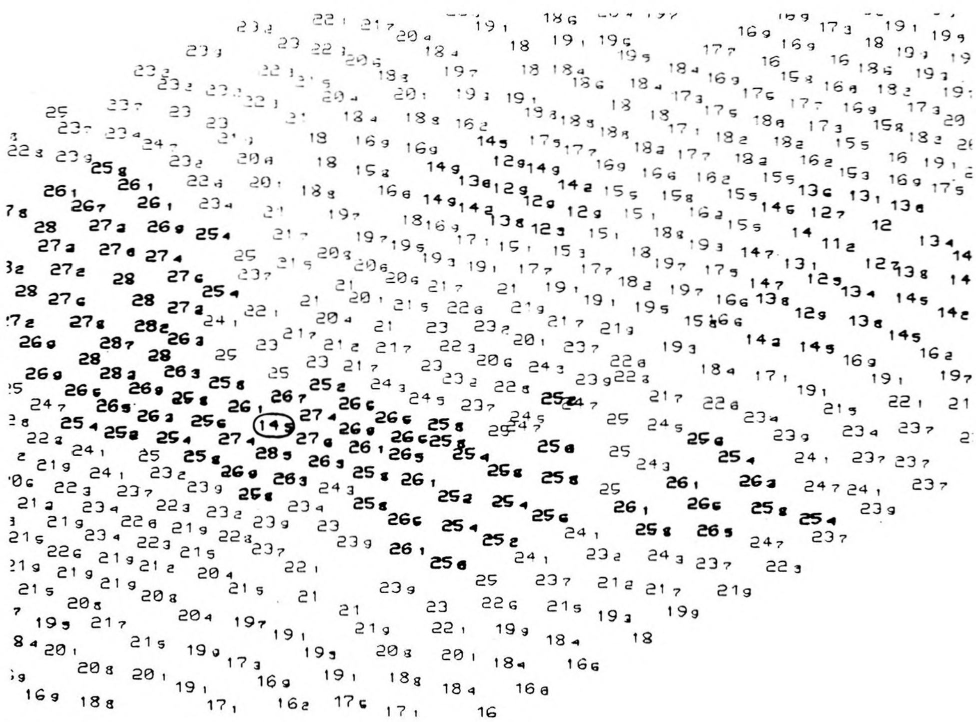

FIG. 3b.— An enlargement of the image shown in figure 3a.

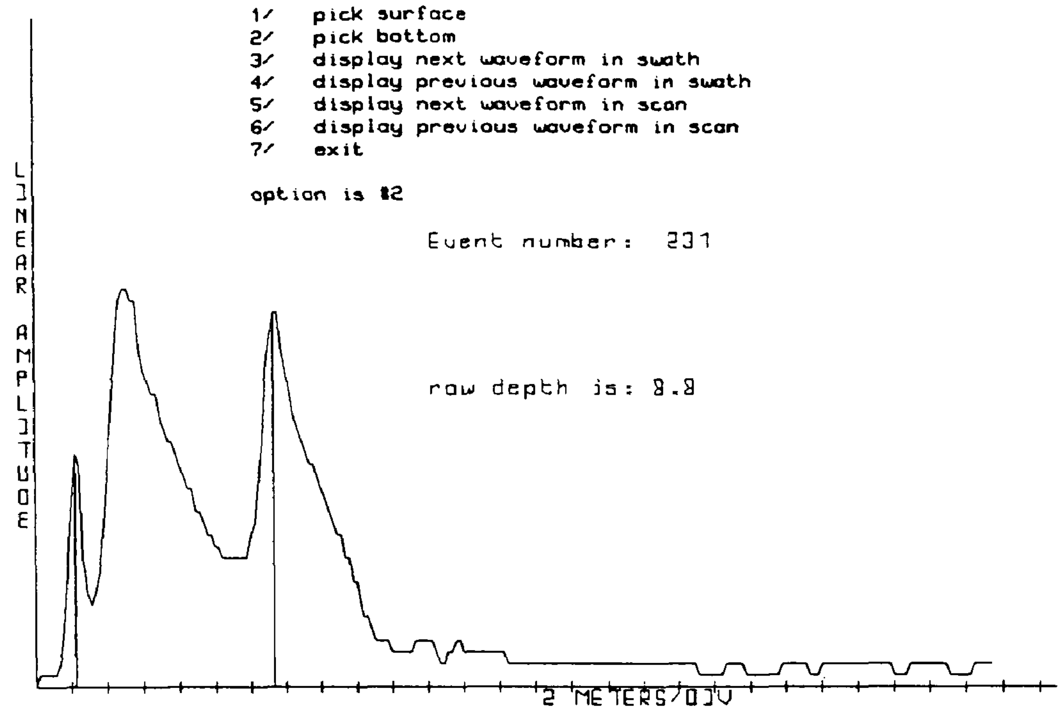

FIG. 3c.— A lidar waveform showing timing registration mark, surface return and bottom return respectively (photo taken from display screen).

able sounding like this can be examined for its particular details such as its time-of-measurement, position error ellipse, etc. In addition, one can also display the entire lidar return waveform (Fig. 3c). With this feature one can see at a glance whether there was a legitimate return from something in the water or whether there was a fault in one of the digitizing or data processing stages. The Larsen thus provides the most thorough quality control system available for any bathymetric sensor.

2. **The Video Mapping System** is an off-line device which takes the (analog) video imagery and uses the position and attitude information to provide a mechanism for extracting controlled shoreline and foreshore information. This tool is also used for quality control as it provides total photo coverage of the survey area.

The system consists of a small computer complete with graphics boards, high resolution monitor, screen copier, tablet for cursor control and a video disc player. It accesses the processed position and attitude data files. The imagery undergoes a first-order geometric correction for aircraft attitude and all pixels on the image can be referenced to absolute (x, y) coordinates. It is used to extract unmapped shoreline features, isolated rocks, etc. The system is under development by Photo-Compilation PMSinc. (Quebec City, P.Q.).

DEPLOYMENT

Optimum field deployment strategies have been dealt with elsewhere (MALONE *et al.*, 1983, CASEY, 1984) and will be briefly summarized here. The strategy turns on LARSEN's key factor for success — the 220 Kph speed of the aircraft.

An analysis of survey statistics for operations carried out in remote areas shows that the most productive strategy is to exploit the short good weather period to the maximum. The speed advantage of the aircraft is threefold :

1. It allows for quick deployment from its southern base to the survey base camp.
2. It allows for the survey to be completed in the minimum time on site.
3. It allows for the survey to move from site to site in a very short time to take advantage of changing conditions.

Exploiting this advantage effectively calls for a survey plan with great flexibility. In particular, a number of potential survey areas must be included in the overall plan. Horizontal and vertical control must be in place. Shoreline plots must be available for all of the areas. Ground truthing (i.e. verification soundings) must be established. Clearly the GPS is the ideal positioning system for this work.

THE NORTHWEST PASSAGE LARSEN SURVEY

Five areas were identified for inclusion in the survey (see Figure 1) :

1) Simpson Strait
2) James Ross Strait
3) Requisite Channel
4) Victoria Strait
5) Cambridge Bay.

Control for the Trisponder was established early in 1985 at the Simpson Strait and James Ross Strait sites. In 1986 control was established for Requisite Channel and Victoria Strait.

Cambridge Bay, N.W.T., was the base of operations. Cambridge is an Inuit settlement of approximately 800 people and offers relatively good airport facilities, hotel and stores.

The survey team was comprised of individuals from two government agencies and four private contractors. TERRA was the chief contractor. The co-author (VOSBURGH) acted as the hydrographer in charge. In the 1985 season the team arrived in Cambridge August 1 after confirmed reports of the ice departure from Cambridge and Simpson Strait. In 1986, a bad year for ice, the team did not arrive until mid-month.

Ice cover in James Ross Strait and Requisite Channel have prevented these areas from being surveyed. Given these conditions the team decided to concentrate on the approaches to Cambridge Bay and Simpson Strait which were ice-free. We were fortunately able to get off to a good start in 1985 and by the evening of August 2 had surveyed approximately 20% of Simpson Strait.

The survey was not without its problems. Several of the LARSEN components required unexpected servicing in the field. Data communications between the GPS processor and our own led to a premature end to the use of GPS. The venerable DC-3 blew a piston in its port engine on take-off and required a major engine repair. Major system enhancements which we had designed, based on our 1985 experiences, were not sufficiently well tested and led to unexpected delays.

Despite these problems, the data poured in, the tapes accumulated and the plotters and printers ran on through the night. In 1985 all first-level data reduction to the plot stage took place in Cambridge. In 1986 however we decided to take a minimum of processing equipment to the site and shipped the data back to TERRA's facilities on regularly scheduled flights.

In general, for every hour of lidar sounding it takes approximately three hours to process the data and plot it on a graphics monitor, the depth values shown in colour, banded by depth. A screen copier is used to make hard copy plots. Plotting on the large pen plotter takes another three hours-per-hour and is only done once the day's data is fully processed.

Depth penetration in this area was excellent and depth measurements greater than 35 m were common. Ground truth measurements were made at a number of locations using a Zodiac launch equipped with an echo-sounder and Trisponder positioning system. The soundings were compared as a form of quality control. Approximately 600 coincident soundings were used to evaluate the differences between the two systems. A mean of 0.1 m and a standard deviation of 0.3 m were determined as the sample estimates for the sounding differences.

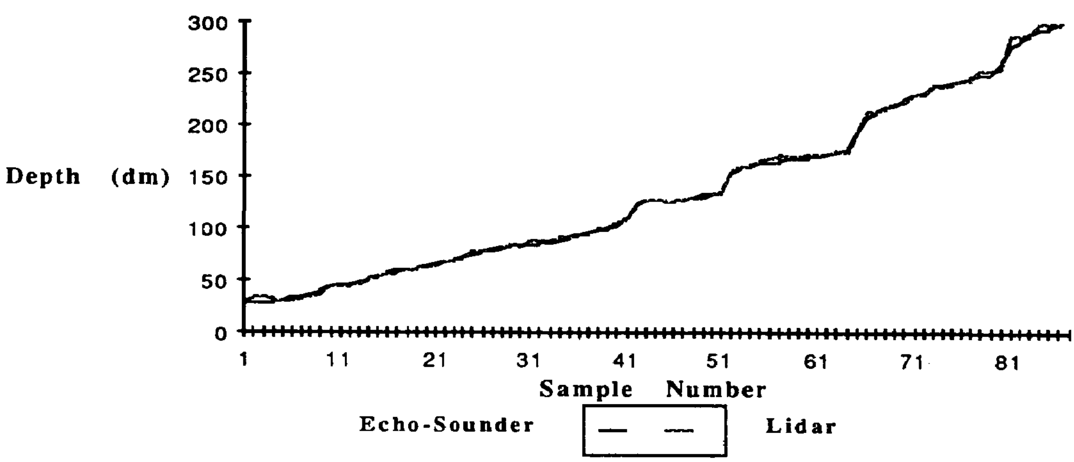

FIG. 4.— Lidar versus Acoustic. Once the surface and bottom returns have been identified, a raw depth estimate can be obtained using the formula depth = (txc)/z, where t is the time separation between the surface and bottom returns and c is the speed of light in water.

A portion of the depth difference variance can be attributed to the echo-sounder as well as the laser-sounder. Figure 4 is a plot of a sample profile of echo-sounder and laser-sounder over a depth range of from 1.5 to 31.0 metres. If one assumes a standard deviation of 0.2 m for the echo-sounder, then the standard deviation of the laser-sounder is approximately 0.22 m, or not significantly different. A comparison of any two independent sounding systems would be difficult to do rigorously under operational conditions due to the vagaries in the individual positioning systems and the roughness of the bottom.

Each surveyed area was 'optically swept' from one coastline to the next. With this technique the aircraft flies over deep as well as shallow water areas. In areas where the laser will not reach the bottom, the signal is searched to see where the signal drops into the background noise. In this way 'no bottom at ....' soundings are inferred and the deep water limits defined.

The survey not only resulted in the capture in a tremendous volume of new and valuable sounding data but also provided us with the first opportunity of using LARSEN under the rigours of the real world. The equipment and techniques are currently being refined, based on the experience gained.

CONCLUSION

The LARSEN coastal mapping system has ushered in a new era in hydrography. Its design gives survey managers a new tool to use in areas traditionally considered too expensive and time consuming to survey. Many areas in the Arctic Archipelago fall into this category. LARSEN promises greatly increased levels of productivity but it also gives Canada new ability to seek out, explore and survey alternative shipping channels in Canada's frontier areas and this is perhaps its strongest feature.

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