EXPERIENCE WITH HI-FIX HYPERBOLIC IN THE CANADIAN ARCTIC

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Early in 1962 the Canadian Hydrographic Service supplied a Hi-Fix chain for the airborne hydrographic surveys carried out in the Canadian Arctic Archipelago by the Polar Continental Shelf Project. It was used there in hyperbolic form for a survey by spot echo sounding through ice in Penny Strait during 1962, and in 1963 for the regular survey of Hell Gate (figure 1) by the helicopter-towed echo-sounding technique described elsewhere [1]. Normally, the Hi-Fix transmitter stations are manned by technicians or visited daily, but at Hell Gate the stations were run unmanned, and visited only for servicing at 1 to 2 week intervals.

This paper describes modifications to the standard equipment, installation for unattended operation, trials to determine maximum range, the stability of the patterns, accuracy and position plotting.

Although the Polar Continental Shelf Project has used Hi-Fix only for airborne surveys in the Arctic, the experience gained is thought to be relevant to hydrographic surveys by other craft and in other latitudes.

Where variable errors are discussed the largest likely figure is given, with perhaps 95 % probability that the actual error will be smaller. The reason for this is that a hydrographic surveyor is concerned that the maximum error in position of any sounding shall not exceed a prescribed limit. In this connection he does not consider the probable error, which is not applicable to the single observation for a sounding fix, and which should not be applied to the mean of all the fixes of a survey, since the mariner using the chart relies on every printed detail.

Equipment, installation and performance

The chain acquired in 1962 was a Decca Hi-Fix System, type B, with 25-watt transmitters. It was standard, except that the receivers had been successfully modified to cope with speeds of up to 70 knots, when the helicopter covers half a lane in the receiver time-sharing cycle of 1 second. Hi-Fix was used to determine the position of helicopters out to 75 km from the farthest transmitter station for the hydrographic survey of Penny Strait (76°30′ North, 97° West) between April and August 1962, and proved effective and reliable.

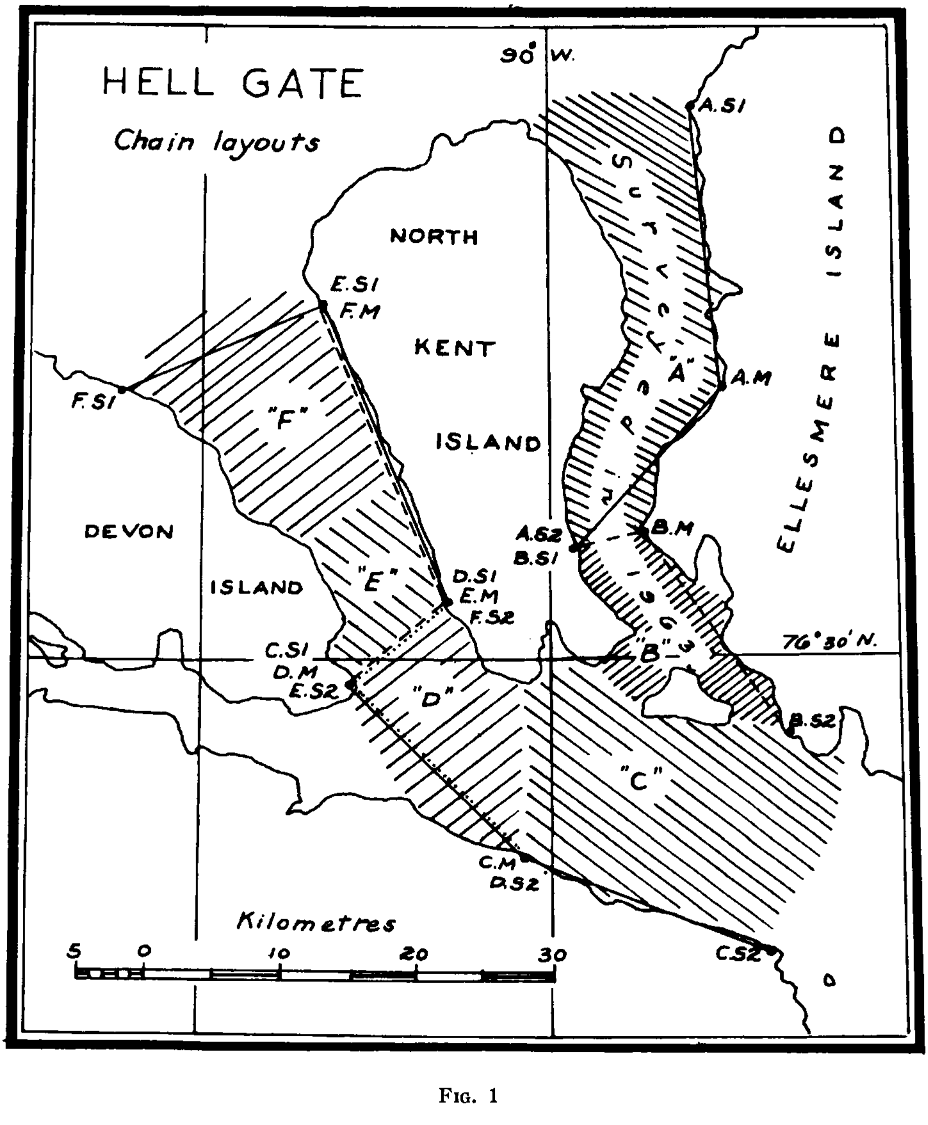

Fig. 1

Manning the Hi-Fix transmitter stations in the Arctic involves establishing and supplying camps by air, which is costly and reduces the mobility of the chain. During the winter of 1962-63 the following modifications were carried out by Computing Devices of Canada Ltd. to allow un-manned operation for the 1963 field season :

(i) The diesel generators supplying power at each station were modified so as to run for at least 14 days without attention.

(ii) Thermostatically controlled heaters and cooling fans were fitted to adjust the temperature of the electronic equipment at ambient temperatures between — 40° C and + 20° C. (Outside temperatures did not exceed + 5° C, but on windless days the diesel engine tended to overheat the tent housing the equipment.

(iii) 40-ft (12-metre) aluminum masts of triangular cross section were supplied. These were designed to withstand winds of 85 knots, and weighed only 40 lbs (18 kg). They were easily erected by two men using a 10-ft (3-metre) heel boom.

(iv) 75-watt transmitters were exchanged for the original 25-watt units, and were modified for single antenna operation. This dispensed with the separate receiving antenna.

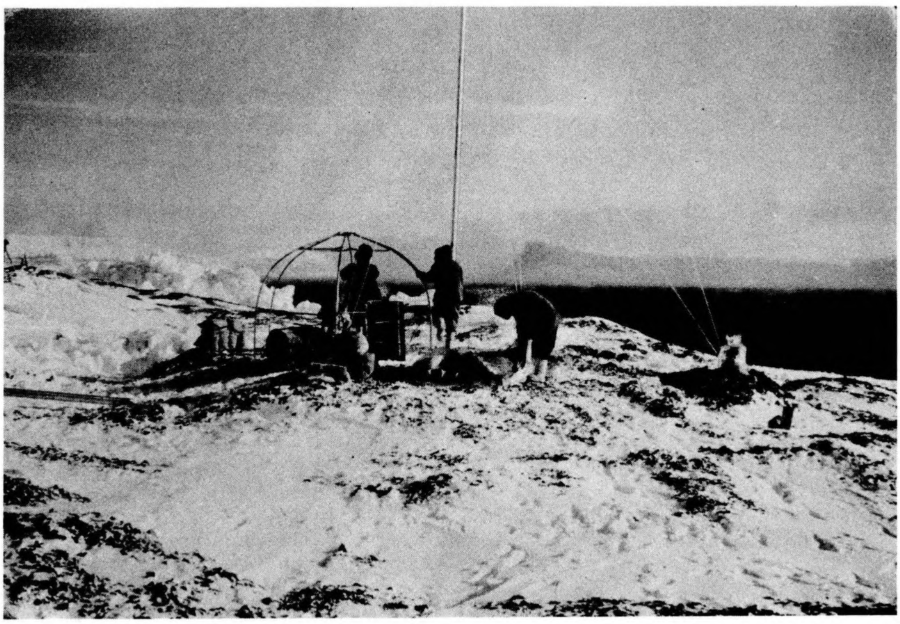

FIG. 2. — Building a Hi-Fix station (temperature about — 18° C).

In addition, a print-out from the Hi-Fix receiver was developed by Edo (Canada) Ltd. which automatically made a fix mark and printed the corresponding Hi-Fix reading on the sounding recorder paper at pre-set intervals.

At Hell Gate all equipment was moved from base camp to the transmitter station sites by Bell 47G2A helicopter. The 400-lb (180-kg) diesel engine was slung below the helicopter, and could be placed exactly where it was required. The diesel generator and electronic equipment were housed in an igloo-shaped aluminum-framed tent of about 8 ft (2 metres) diameter. Two men could have a station on the air within about 4 hours.

Once the pattern was adjusted, the station was visited every 10-15 days to refill the 45-gallon (200-litre) fuel reservoir. Transmissions were monitored at a manned camp on the shore of Hell Gate so that breakdowns could be detected immediately. Apart from one electronic and one mechanical failure, both the result of minor faults, the only interruptions occurred when the masts were blown down during gales; this trouble has since been overcome by the use of " gabian " wire mesh baskets filled with sandbags to anchor the masts.

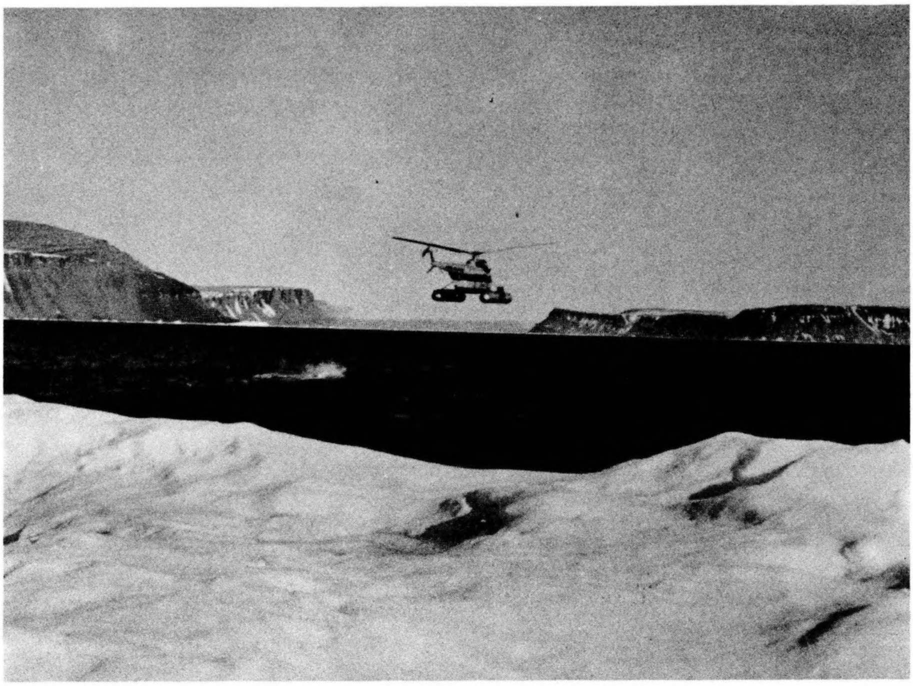

FIG. 3. — Sikorsky S 55 helicopter towing the echo-sounding "fish".

6-ft (2-metre) whip receiving antennas were fitted on the tail boom of the helicopters. Reception was good on the ground and in flight, but tended to be unstable when towing the " fish " containing the echo sounder transducer. It is thought that rapid changes in the proportion of the tow wire immersed in the waves may have caused this trouble by affecting the grounding characteristics of the helicopter. As a precaution against unnoticed lane loss, the receiver alarm light was modified so that instead of showing a momentary flash it stayed on after an alarm until cancelled, warning the surveyor to make an early visit to one of the lane check points established throughout the survey area.

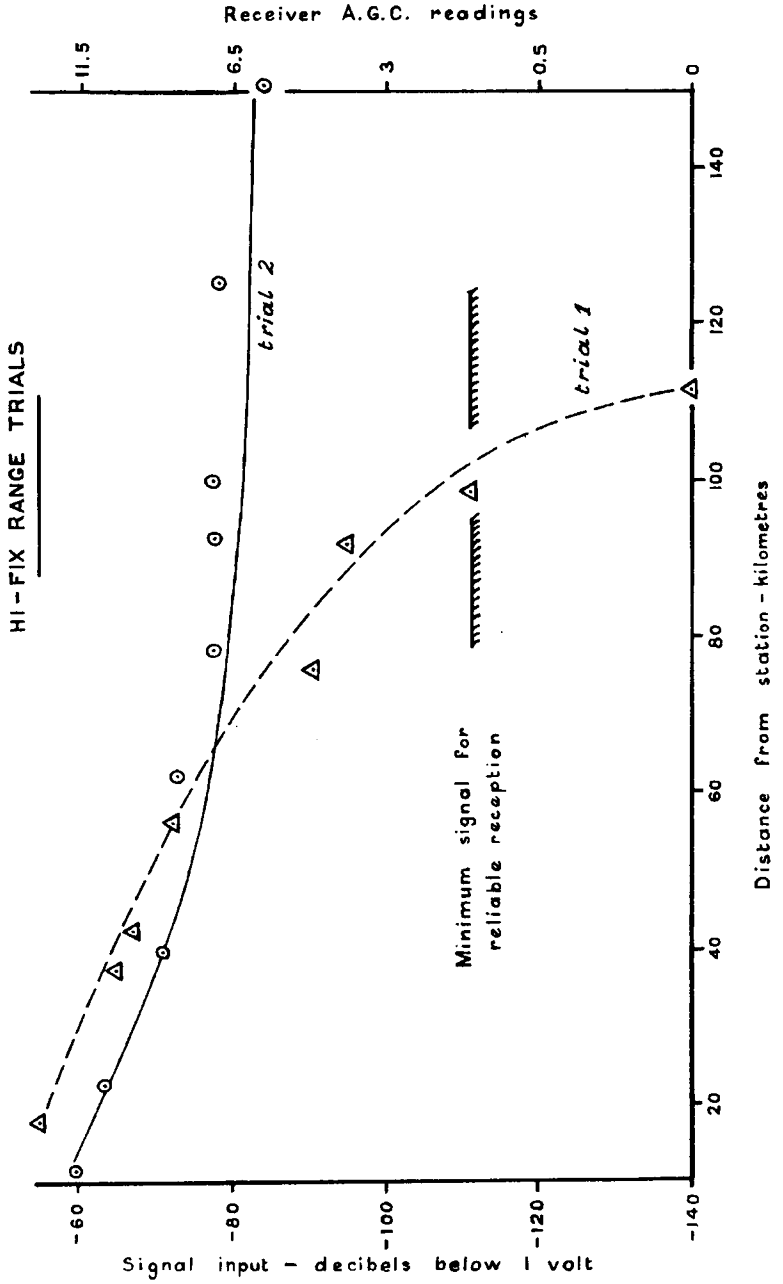
HI-FIX RANGE TRIALS
Receiver A.G.C. readings
11.5
6.5
3
0.5
0
trial 2
trial 1
Minimum signal for reliable reception
Distance from station - kilometres
20
40
60
80
100
120
140
-60
-80
-100
-120
-140
Signal input - decibels below 1 volt

FIG. 4

Range

The area which can be covered by a Hi-Fix chain is limited by the accuracy of the fix it affords, and by the greatest distance at which ground wave signals can be received reliably.

Two long range trials were carried out during the 1963 field season, to determine this maximum distance. The results were contradictory (figure 4). The trials were made within eleven days of each other under conditions as nearly similar as possible, using the same helicopter, receiver and antenna, and flying over sea with 10/10 ice cover.

During trial I, radio communications were poor at 5 Mc/sec over distances of 300-500 km, but the records of the Ionospheric Station at Resolute Bay, 250 km away, indicate that skywave conditions at the Hi-Fix frequency of 1.7 Mc/sec were slightly better during trial I than during trial II. Pattern stability was observed on shore for five minutes at the 150 km point of trial II, and showed a variation of ± 0.02 lanes; this alone probably rules out any likelihood that skywave contributions account for the markedly higher signal strengths observed on trial II than on trial I.

Experience has shown that range is drastically reduced over land.

Pattern stability

Once the chain was on the air and the pattern adjusted, the slave settings were left unaltered.

The readings of the receiver at the Hi-Fix monitor camp were recorded continuously on a strip chart at a scale of 0.01 lane = 0.6 cm and 1 hour = 2 cm. The following table compiled from this record shows the pattern stability which can be expected from such an un-manned chain, under stable atmospheric and meteorological conditions :

TABLE 1
Summary of Monitor Records

(1) Chain	S. Hell Gate		N. Hell Gate	
(2) Pattern	1	2	1	2
(3) Days of Monitor records	23	19	18	21
(4) Lane number of baseline bisector	26	108	117	87
(5) Mean monitor reading when chain set up	47.15	06.41	23.18	162.55
(6) Mean monitor reading when chain closed down	47.13	06.41	23.19	162.57
(7) Average divergence of daily mean from (5)	± 0.01	— 0	± 0.01	± 0.01
(8) Average daily maximum divergence from (5)	± 0.04	± 0.03	± 0.03	± 0.03
(9) Maximum divergence from (5) recorded excluding days of heavy ice cover	± 0.06	± 0.06	± 0.03	± 0.04
(10) Maximum divergence from (5) recorded	± 0.06	± 0.06	± 0.04	± 0.07

The divergence from the original setting shown at line (7) perhaps represents the probable variation, and the average daily maximum divergence shown at line (8) is roughly the variation at the 95 % probability level.

Accuracy

The error of a Hi-Fix reading is represented by the difference between the computed and the observed reading at a point. The shift in position of a fix resulting from a Hi-Fix error depends on the expansion of the lanes as the hyperbolic position lines diverge from the baseline, and on the angle of cut between the hyperbolae of the two patterns.

Lanewidth at a point equals lanewidth on baseline multiplied by the cosecant of half the angle subtended between master and slave stations.

Angle of cut of hyperbolae equals half the angle subtended between the slave stations.

A diamond of error can be constructed using these formulae, or further formulae may be derived which give the length of the longer diagonal of the diamond directly. If the same error is assumed to exist in each pattern, the derived formulae can be used to draw up accuracy limit lobes, within which the maximum shift caused by the assumed error will not exceed a specified limit. Examples of such lobes for Fram Sound are shown on figure 5.

Error calibration

During the 1962 and 1963 field seasons considerable effort was put into calibration to determine Hi-Fix error. The most noteworthy finding of the 1962 survey of Penny Strait was the degree to which the amount of sea ice on the master-slave baselines affected the propagation velocity, computed from lanecounts. A selection of the results is given in table 2.

TABLE 2

Velocity from Baseline Lanecounts

Pattern	Date	State of Sea Ice on Baseline	Velocity (km/sec)
2	3 May	Unbroken heavy ice	299 230
1	2 May	Unbroken ice with polynias (open pools) indicating that the ice was relatively thin	299 550
2	22 June	2/10 ice	299 650
1	18 July	No ice	299 700

Hell Gate (figure 1), scene of the 1963 survey, is a sinuous channel 50 km long and 2 km to 10 km wide, bordered by cliffs 200 metres high for much of its length. Overland path could only be avoided by setting up separate chains for every 10 km of the channel; as the arctic survey season is short, it was decided to cover the area with only two chains, accepting a reduction in accuracy and attempting to evaluate the errors by calibration. At the end of the season calibration was also carried out over Fram Sound, the southern approach to Hell Gate, in preparation for its survey the following year.

In taking calibration observations the Hi-Fix fitted helicopter was fixed by simultaneous radio-controlled intersection from theodolites on triangulation stations. On the first calibration series observations were made at each position with the helicopter on six headings around the compass. The results showed that variation in heading had no effect provided that the receiving antenna on the tail was used as the sighting point, and thereafter only four fixes were obtained at each position. For the longer sights of Fram Sound the main rotor mast was used for sighting, and a correction applied for the displacement of the receiving antenna; lack of precision in this correction may have caused discrepancies of up to 0.03 lanes. Each fix was computed separately by the method of semi-graphic intersection on the transverse mercator projection; the side of the triangle of error was generally about 1 metre. The theoretical Hi-Fix reading for the fix was then computed, assuming a propagation velocity of 299 700 km/sec, and compared with the reading observed in the helicopter to obtain the Hi-Fix errors. The four errors obtained at each position generally agreed to within ± 0.02 lanes.

Analysis of errors

The errors in Hi-Fix reading found on two chains are shown on figure 5. Calibration positions north of the double pecked line between Fram Sound and Hell Gate were observed on the South Hell Gate chain. The figures in brackets against positions B, E and F of the South Hell Gate chain give the shifts resulting from the three worst combinations of a large error with bad pattern geometry. The arrows through each position show the directions of the intersecting theodolite rays.

The errors found on the Fram Sound chain are tabulated in table 3.

Pattern 2 of Fram Sound shows errors which vary in proportion to lane number, and are zero in the vicinity of the baseline bisector. Considering the formula for computing a Hi-Fix reading :

$$\text{Reading} = \frac{\text{Baselength} + \text{Master Distance} - \text{Slave Distance}}{\text{Wavelength}}$$

it can be seen that a reduction in velocity of propagation, and hence in wavelength, would decrease readings on the master side of the baseline bisector (where Master Distance < Slave Distance) and increase readings on the slave side. This offers an explanation of the errors in pattern 2, whose master-slave baseline includes about 25 % land of low conductivity. A slightly different form of the formula for the Hi-Fix reading can be used to find, by least squares, a value for the velocity which will reduce this proportional error to a minimum. The final column of table 3 shows the residual errors on pattern 2 after such manipulation.

TABLE 3

Errors in Hi-Fix Readings, Fram Sound

Calibration position	Pattern 1			Pattern 2		
	Lane number of position	Error (Observed reading minus computed)	Difference from mean error	Lane number of position	Error (Observed reading minus computed)	Residual error after velocity adjustment
A	177	— 0.10	+ 0.01	7	— 0.04	+ 0.06
B	158	— 0.13	— 0.02	9	— 0.09	+ 0.01
C	130	— 0.08	+ 0.03	20	— 0.05	+ 0.04
E	76	— 0.13	— 0.02	60	— 0.09	— 0.04
F	71	— 0.06	+ 0.05	60	— 0.08	— 0.03
G	57	— 0.09	— 0.02	70	— 0.11	— 0.07
H	54	— 0.12	— 0.01	79	— 0.08	— 0.04
				Baseline bisector at lane number 114		
I	41	— 0.12	— 0.01	128	+ 0.02	+ 0.01
J	39	— 0.12	— 0.01	143	+ 0.04	+ 0.02
K	36	— 0.11	0	155	+ 0.03	0
L	32	— 0.13	— 0.02	167	+ 0.04	0
N	11	— 0.12	— 0.01	195	+ 0.07	0
O	7	— 0.08	+ 0.03	210	+ 0.11	+ 0.03
	Mean error	— 0.11				

Pattern 1 of Fram Sound shows a roughly constant error, which indicates that the velocity adopted (299 700 km/sec) is correct for overwater paths. The source of this error can be traced to the method adopted of setting up the patterns: using the receiver at slave 2 as a monitor, pattern 1 was adjusted until the receiver showed the reading computed for slave 2; the process was reversed to set up pattern 2. The opposite slave station is a poor choice for the position of a chain set-up monitor, since it is generally a long way from the baseline bisector of the pattern concerned, and the use of an incorrect velocity in computing its Hi-Fix reading will introduce a relatively large error. However the velocity appears to be correct in this case, and it can be shown that land on the path from the master station to slave 2 is again the cause of the trouble. Following the rule that land on the master path causes a positive error (and land on the slave path a negative error), pattern 1 should have been adjusted so that the receiver at slave 2 showed the computed reading plus the land path error, say $R + e$. In fact it was set so that the receiver showed the computed reading (R), and thus a constant error of $R - (R + e) = - e$ was introduced into pattern 1.

On the South Hell Gate chain, calibration results at positions with overwater paths from the transmitting stations are similar to those for Fram Sound, but with smaller errors. Positions with overland paths show that large errors can be expected under such conditions; it would have been preferable to have used several more chain shifts to cover Hell Gate, and the layout for the rest of the area (figure 1) reflects this lesson.

It appears that the distance of the receiver from the land on the path has some effect on the size of the error. At South Hell Gate position E, 0.5 km from a 200-metre cliff, a very large negative error on pattern 1 is caused by a comparatively small proportion of land on the path to the slave; at G, 2.5 km from the cliff the pattern 1 is less than one third of that at E, although the proportion of land on the path is only slightly smaller. It was often noticed that signal strength dropped abruptly under such circumstances, giving warning to expect errors.

From comparison with nearby offshore values it appears that points onshore within a few metres of the water's edge such as stations 254 and 256 and the Hell Gate Monitor give errors representative of those to be found over adjacent waters.

Calibration for towing error

The possibility that the towgear used with the echo-sounding "fish" caused error in Hi-Fix reception by the towing helicopter was investigated by taking simultaneous fixes by Hi-Fix and by theodolite intersection from shore, while the helicopter was in flight and towing. 33 fixes were observed on each of the two types of helicopter used. Analysis of the results indicated that the towing error is proportional to the amount of the Hi-Fix lane covered by the spread of the tow system; the displacement of the hyperbola was generally about 10 metres.

Plotting positions

In 1962 and 1963 accurate hyperbolic lattices were used to plot the positions of sounding fixes. The production of a precise lattice is a laborious business; the Fram Sound lattice, for instance, involved the calculation by electronic computer of about 40 000 points where integral hyperbolae intersected U.T.M. grid lines, the plotting of these intersections, and the painstaking drawing in of the hyperbolae by spline and french curve. The draughting took about 130 man hours, and however carefully it was done there was a possibility that a line would be 0.5 mm out of position; two such errors at a 40° angle of cut could shift a fix 1.5 mm, which, at the survey scale of 1/50 000, represents a displacement of 75 metres. Interpolation between hyperbolae when plotting sounding fixes introduces a further source of error.

This expensive lattice, with its virtually unavoidable weakness where the angle of cut is fine, will be used to plot between 1 000 and 2 000 fixes. It is plain that it would be cheaper and more accurate simply to compute the position fixes in terms of the projection, and plot them by rectangular coordinates, and this approach is being used on later chains.

The surveyor needs a rough lattice of plane hyperbolae to plan and control the sounding coverage. This can quickly be produced by a simplified version of the graphical method of concentric circles [2]; the graphical construction is weak over the widely-spaced hyperbolae adjacent to the baseline extensions, but it is a simple matter to compute a small number of hyperbolae in x and y co-ordinates originating at the intersection of the baseline and its bisector, using the following version of the equation of a hyperbola :

$$y^2 = (x^2 - a^2)\,\frac{d^2 - a^2}{a^2}$$

where :

$2d$ = baselength;
a = distance along baseline between the bisector and the intersection of the required hyperbola.

A lattice covering an area of 30 cm by 50 cm was produced by this method in about 10 hours, by a man without previous experience of such work; it differed from a precise lattice for the same area by no more than 1 mm.

References

[1] Eaton, R.M. : Airborne Hydrographic Surveys in the Canadian Arctic. *International Hydrographic Review,* Vol. XL, No. 2, July 1963.

[2] International Hydrographic Bureau : Radio Aids to Maritime Navigation and Hydrography. *Special Publication No. 39.*

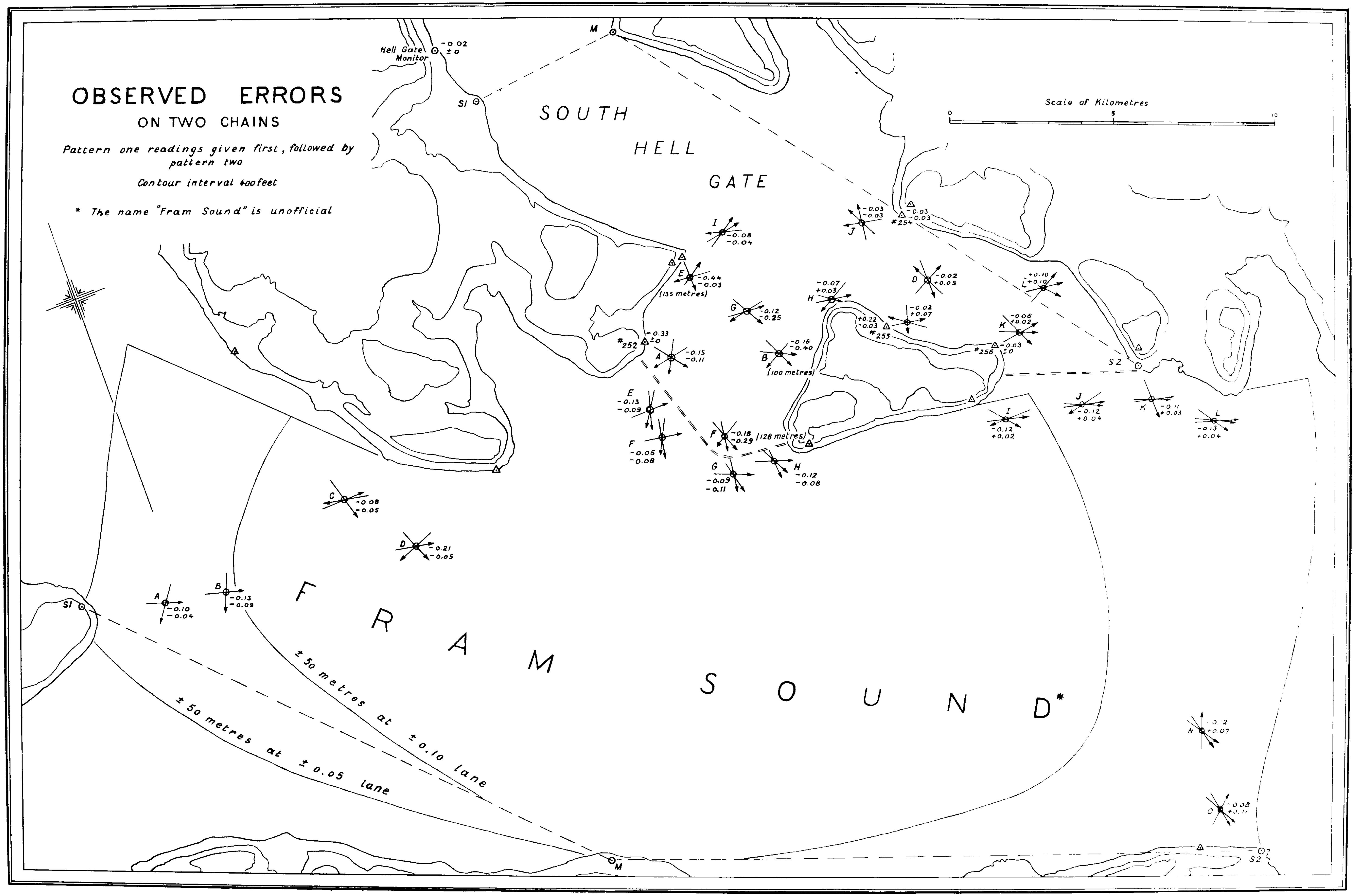
OBSERVED ERRORS
ON TWO CHAINS
Pattern one readings given first, followed by pattern two
Contour interval 400 feet
* The name "Fram Sound" is unofficial
SOUTH
HELL
GATE
Hell Gate Monitor
Scale of Kilometres
0
5
10
FRAM SOUND*
± 50 metres at ± 0.10 lane
± 50 metres at ± 0.05 lane
(135 metres)
(100 metres)
(128 metres)
#252
#254
#255
#256
M
S1
S2

Fig. 5