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Better Accuracy from Sidescan Records: The Object-Chord Method

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Abstract: Sidescan Sonar has become a widely used and often indispensable tool for seafloor engineering and survey activities in the oil industry This acoustic technique has the ability to create a wide and continuous 'picture' of the 3-dimensional seafloor features and contours, and therefore permits quick and economical acquisition of seafloor information which is not readily available through other types of acoustic instrumentation.

The accuracy of mapped objects interpreted from this method has been limited by the fact that the fish is towed a distance from the vessel and its position is affected by different sea states and current conditions resulting in different feathering angles and layback distances.

Some present interpretation techniques do take into account the uncertain feathering angles of the fish, but they assume no errors in both the layback distances. The object-chord method takes into account both the feathering angle and layback errors and in certain circumstances, due to good field practices, eliminates them, resulting in more accurate positions mapped.

INTRODUCTION

Uses of Sidescan Sonar

Sidescan sonar is a widely used and often indispensable tool for providing seafloor information for surveying and engineering purposes. This acoustic technique has the ability to create a wide and continuous 'picture' of the 3-dimensional seafloor features, and therefore permits quick and economical acquisition of seafloor information which cannot readily be got by other methods.

The application of sidescan sonar is varied and includes the following:

Hydrographic Surveys
A sidescan sonar search is an essential precaution to make sure no anomalies lie between the lines of soundings.

Channel Clearance Surveys
Small man-made objects in critical areas in ports and harbours can cause expensive damage and delays; sidescan sonar does clearance surveys cheap and fast.

Geological Surveys
A systematic sidescan survey will map seafloor geological features in detail surpassed only by aerial photographs of land masses.

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Cable and Pipeline Surveys

Sidescan sonar pinpoints hazards and obstructions in proposed cable and pipeline routes, and can accurately and economically track installed lines as small as 5cm diameter cables at ranges up to 150 metres.

Searches

Has proven to be the most effective tool available for locating and identifying aircraft, vessels, well heads and many other objects.

Construction and Dredging Surveys

Used for selecting sites for jack-up rigs, power plants, and other offshores structures. Locates rock outcroppings and other dredging obstructions, and confirms total dredge clearance.

Pre-Drilling Hazard Surveys

Surface faulting, natural gas seeps, mud slides and most natural and man-made sea-floor hazards can be located and identified in a minimum of time.

Sidescan Transmission

The basic equipment consists of a towed fish and a ship-mounted paper recorder, linked together by a signal cable. The fish houses the twin, sideways looking transducers and amplication electronics. The special properties of sidescan, and the techniques for its interpretation, derive from the type of acoustic beam the transducers emit, with a wide vertical extent from above the horizontal on each side of the fish down to and past the vertical below it, but with a very narrow horizontal extent, so that the beam only sees objects exactly at right angles to the direction the fish is pointing (see artist's impression in Figure 1).

Sidescan Reflections

The seabed that falls within the acoustic beam gives reflections of varying character (see Figure 2). The character can be affected by the geometry of the feature. Objects that present a reflecting surface at a broad angle to the incident beam reflect most energy. Areas which are shielded from the acoustic beam, probably by higher ground closer to the fish, do not reflect any energy and will appear white in the records. Contrasting high energy and shadow areas are characteristic of sidescan sonar records given by sand ripples, anchor scours, pockmarks and boulders and will often identify man-made objects such as ship wrecks, platforms or pipelines (see Figure 3).

Fish Towing Options

The sidescan is normally deployed by towing the fish behind the vessel with the signal cable. The fish can be towed easily at the optimum height above the seabed of ten to twenty percent of the full-scale range selected, the height being adjusted by varying the cable length paid out, or the ship's speed. Towing the fish closer to the seabed will produce features with maximum shadow effect and is desirable where the seabed is fairly flat. Higher towing heights are desirable in rough terrain as broader coverage can be achieved, and there is less risk of damaging the fish. By towing the fish further astern of the vessel, it becomes decoupled from the rolling and heaving motion of the vessel and it is then possible to acquire good data

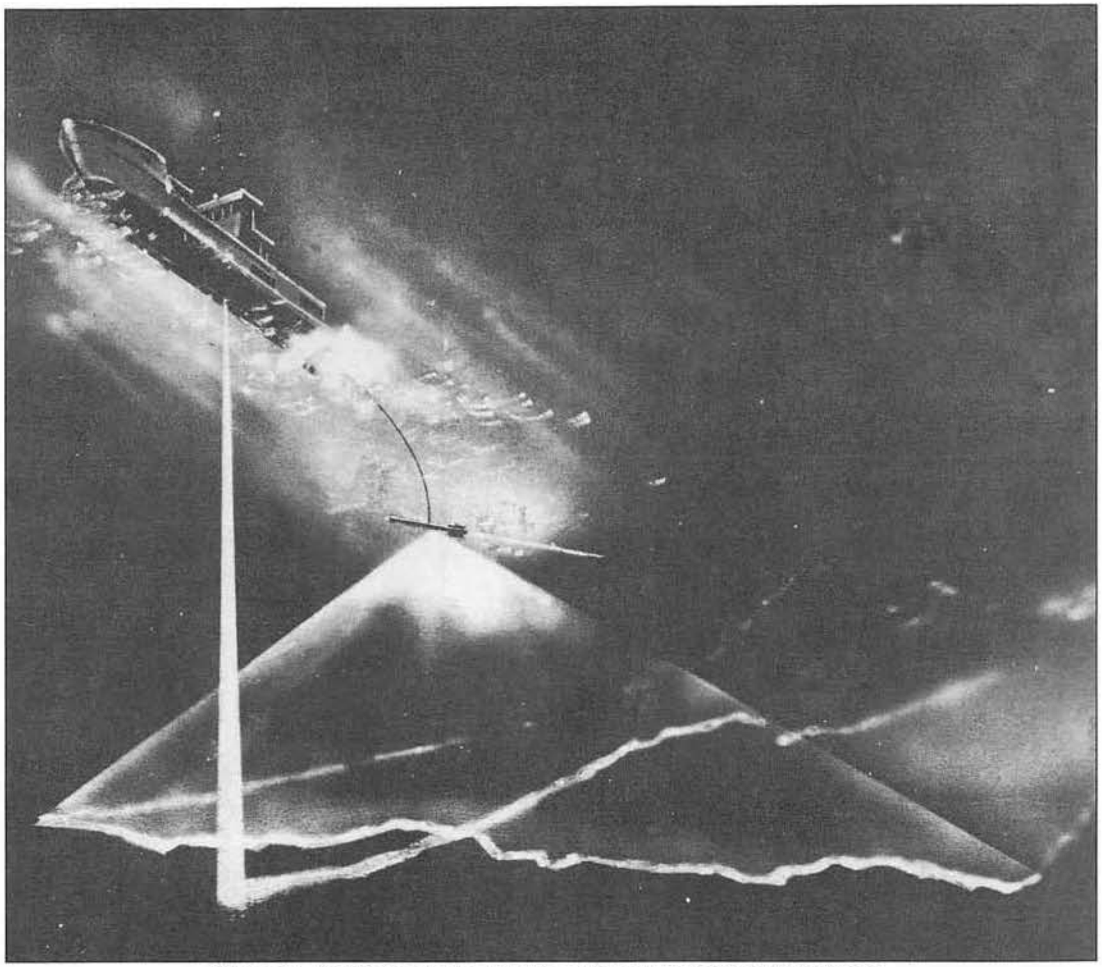

Figure 1: Artist's impression of basic equipment for sidescan transmission.

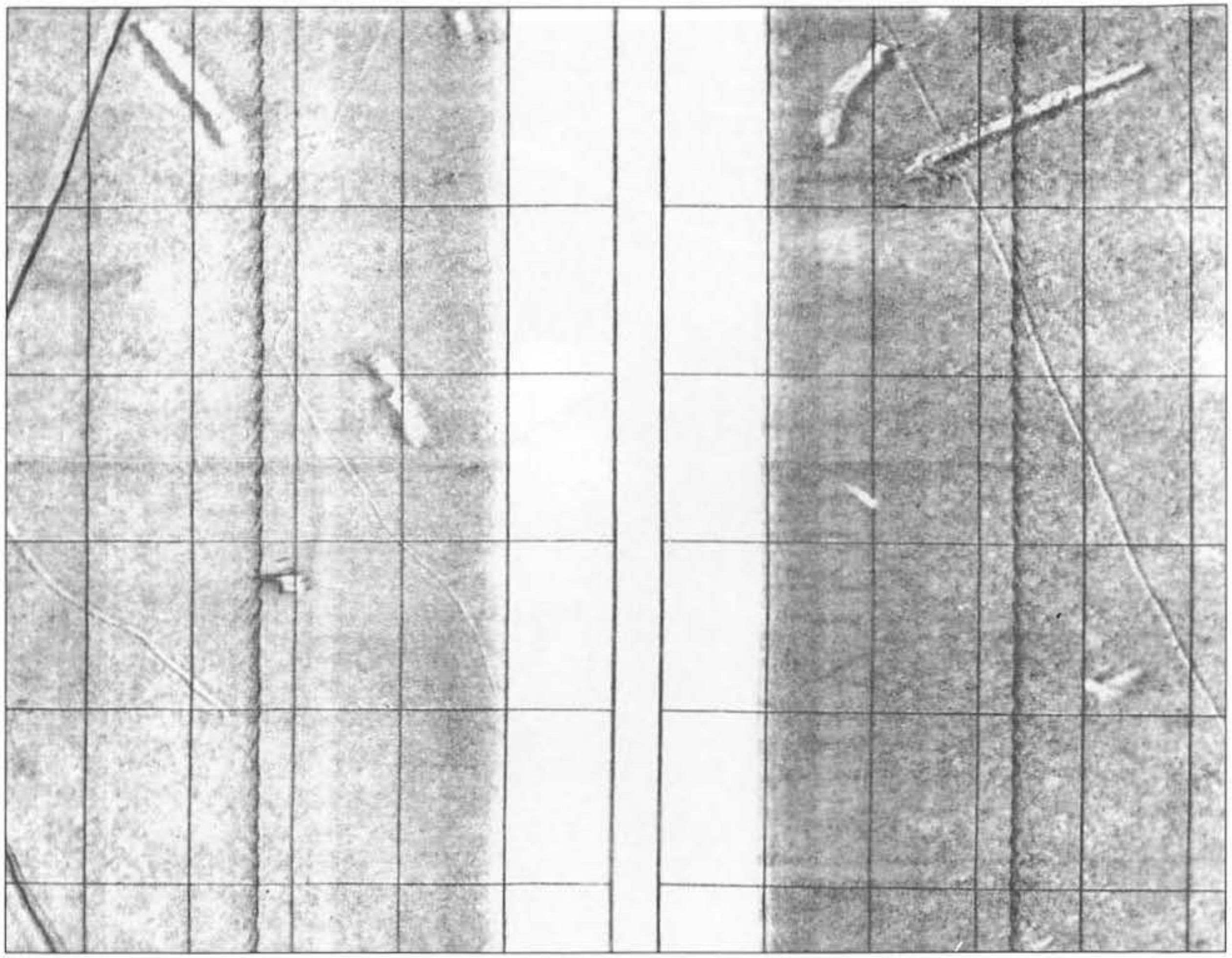

Figure 2 Sidescan reflections of varying character.

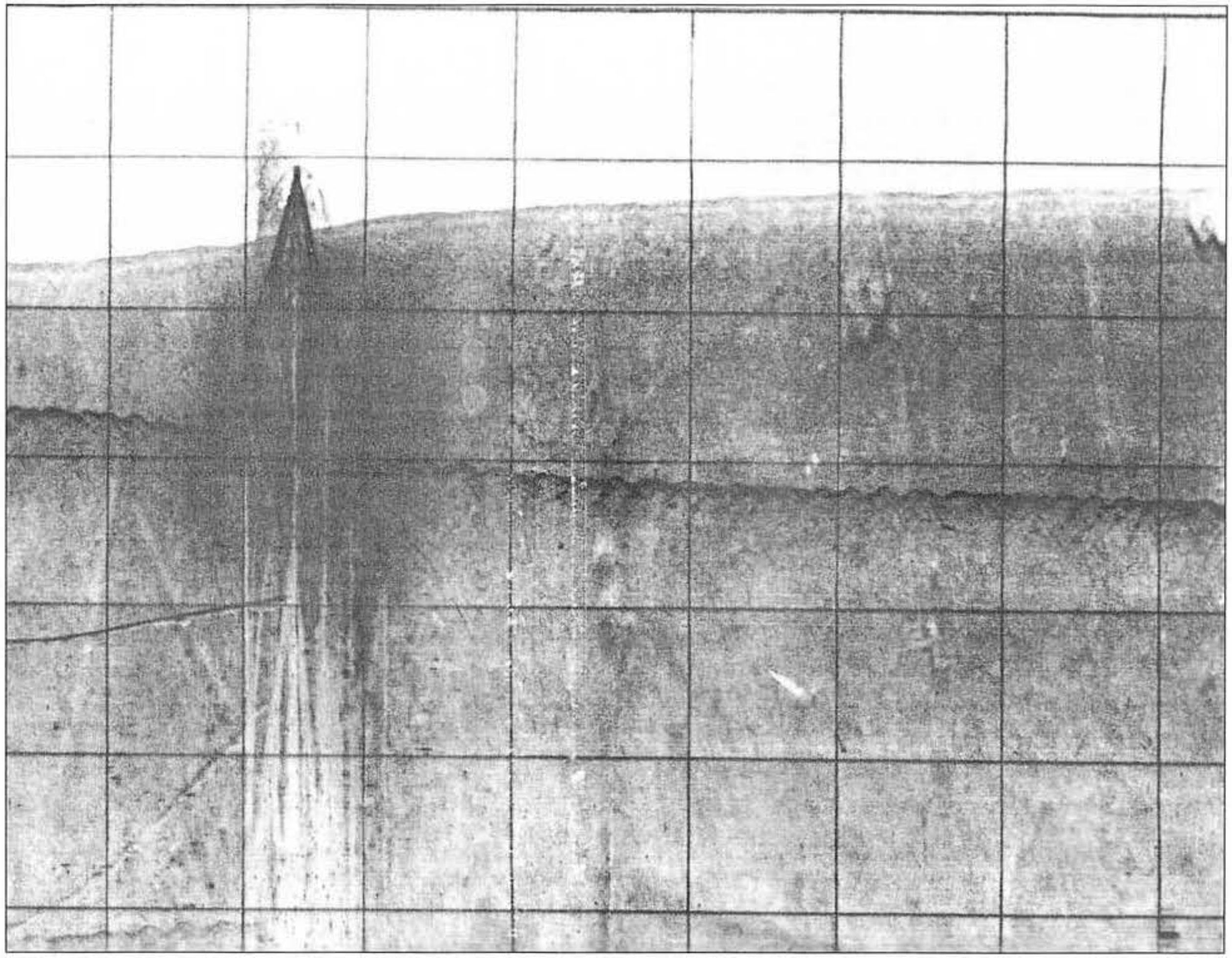

Figure 3: Contrasting high energy and shadow areas are characteristic of sidescan sonar records

even in quite poor conditions.

Errors and Uncertainties

The main disadvantage of a towed fish, particularly when towed at long stay, is that the position of the fish is not known accurately: its position is affected by uncertain feathering angles and by errors in the effective horizontal layback distance from ship to fish. Uncertainty in the position of the fish will result in errors in the positions of any mapped features; the size of these errors may be quite significant, so that the result of the survey may be invalidated.

How to Get Better Answers

There are two ways of solving this problem. Going to the root of the matter, it is possible to attach transponders on the tow fish; then, with additional hardware and software, the position of the fish can be known accurately. Such systems are expensive, however, and, in these hard times, not many clients will specify, and not many projects will warrant, these additional expenses. The second solution involves improved interpretation techniques: in certain conditions, it is possible to locate an object accurately without knowing the towfish position accurately, either in terms of feathering angle or layback. This solution does not involve any additional equipment (and consequent expense) and therefore recommends itself to many clients. The main thrust of this article is to explain this development in interpretation technique, which may be termed the object-chord method, and to make clear the conditions under which it will produce the most accurate results.

SOME METHODS OF INTERPRETATION

Conventional Basic Method

The simplest assumption with sidescan interpretation, taking no account of currents, is that the fish is towed directly behind the ship along a track representing the course made good,with a horizontal distance from the stern of the ship given by:

$$LB = \sqrt{(CO^2 - FD^2)}$$

Where

LB	=	horizontal layback distance from stern
CO	=	cable out from stern
FD	=	fish depth below the towing point

Because currents or tidal streams may cause the ship-cable-fish entity to be aligned at an angle (at slow speeds, often a large angle) to the course made good, this assumption will give large errors in fish position (see Figure 4).

A more valid assumption is that the difference between mean ship's heading and the course made good is due to current, and that the current affects ship and fish equally, so that the direction of the tow cable is the reverse of the ship's heading.

This still ignores wind, which will act on the ship but not on the fish.

Even if the direction the tow cable leaves the ship is carefully measured to allow for the

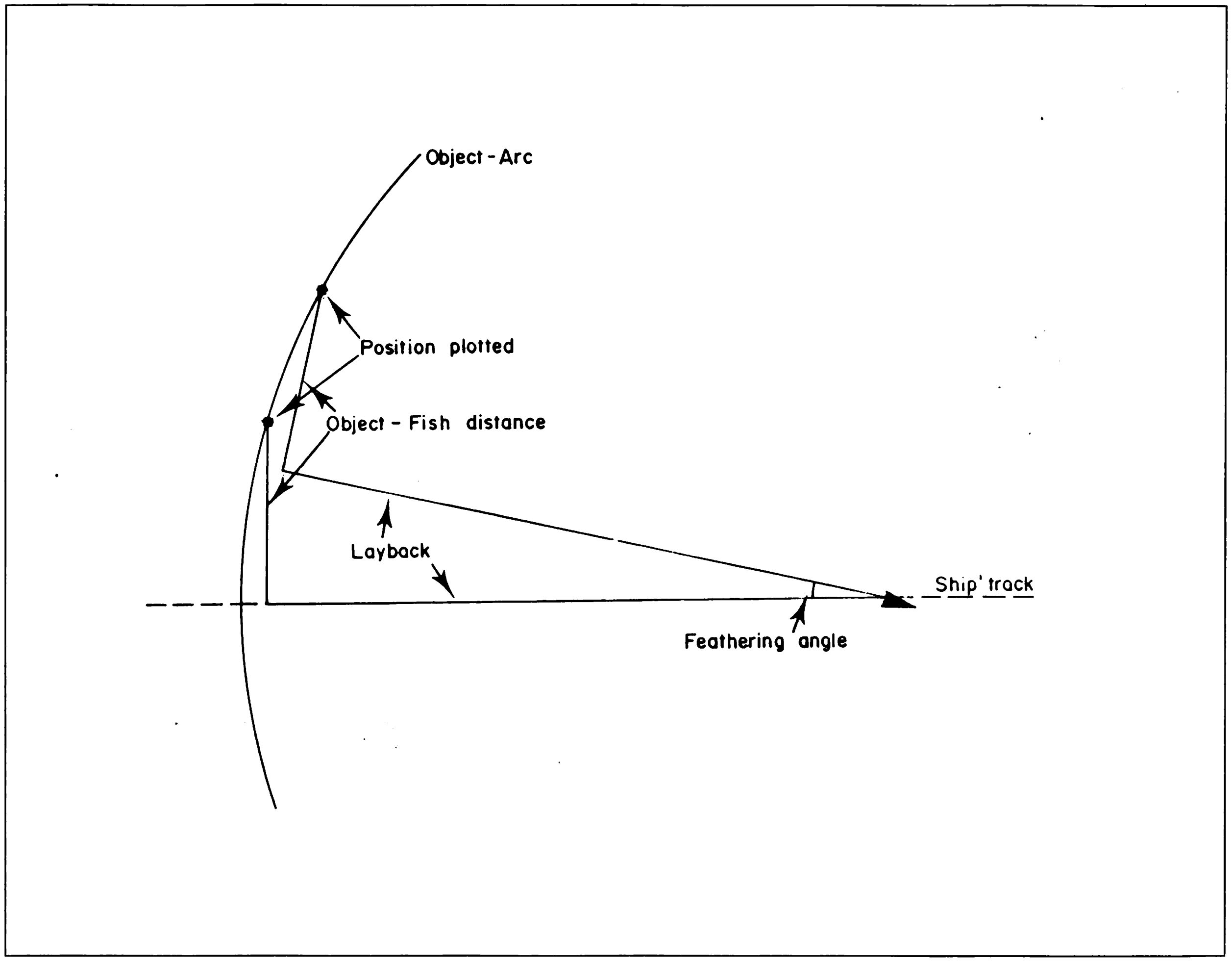

Figure 4: Conventional basic method.

effect of wind, imponderables remain: the cable will not run in a straight line to the fish, the feathering angle will change, results will still show 20, 30, 40 metre discrepancies.

The Object-Arc Method

An improvement in sidescan interpretation became possible with the development of the object-arc method, first published in the Hydrographic Journal in 1984. This method does take into account uncertainty in the direction from cable to fish. It can be seen that, because of different feathering angles, possible true positions of an object can vary along a locus defined by an arc of radius R where,

$$R = \sqrt{(LB^2 + D^2)}$$

Where LB = horizontal distance from the towpoint to the fish
D = horizontal distance of the object from the fish.

This arc is known as the Object-Arc; with at least two of these arcs from different lines, it is possible to obtain an intersection which will represent the object location (regardless of the feathering angle). This method assumes no error in the layback distance to the fish and because the object-arcs often intersect at a narrow angle, small inaccuracies in the layback distance can give rise to large errors and sometimes ambiguities, in position. This is particularly the case when parallel runs are made in opposite directions (perhaps for an as-laid survey): the object-arcs for an object between the runs will tend to be nearly parallel.

Layback Errors

Inaccuracies in layback distances will certainly arise because the catenary of the towed cable is not a straight line but a 3-dimensional curve in dynamic equilibrium with response to hydrodynamic conditions during towing. Other inaccuracies do occur because of errors in the length of cable being deployed. These may arise because of bad tagging on the cable, retermination of the cable without remeasuring, slippage at the measuring block during deployment of the fish in bad weather or simply human error in reading the cable length!

Keeping the Layback Constant

If the amount of cable deployed and the towfish depth are kept unchanged, we can assume that the speed through the water and the catenary of the tow cable remain generally unchanged, and that the layback errors are therefore constant. This assumption has most validity when current and sea conditions show no marked change: so the three or four sidescan runs past a single target that are needed to determine layback errors are best done within a short time span, and repeated when conditions change. How this is done is the subject of this paper, and is called:

THE OBJECT–CHORD METHOD

Two intersecting object arcs (from two sidescan passes) generate an object-chord which is the line joining the intersections of the object-arcs (Figure 5). The object-chord method makes use of the fact that whereas object-arcs are the locus of posible target positions as the feathering angle varies, object-chords are the locus of the intersections of object-arcs as the

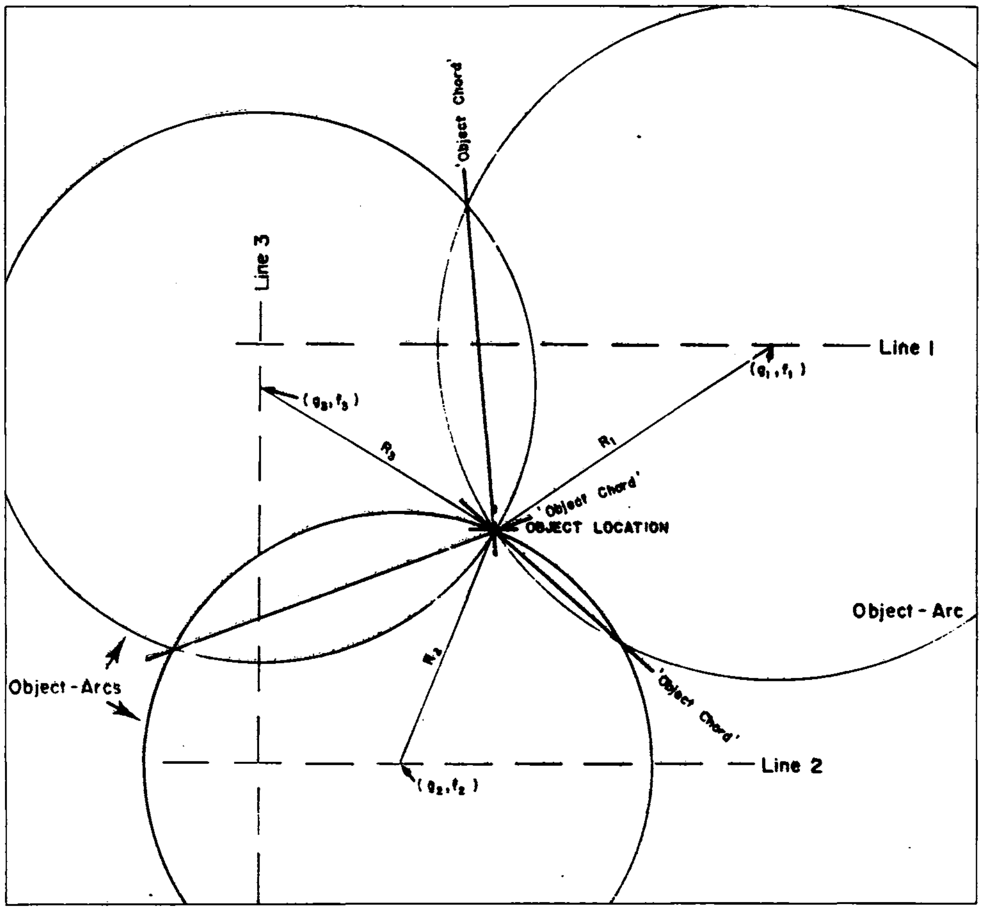

Figure 5: The object chord method.

layback error varies. An object-chord is therefore a position line, corrected for both feathering angle and layback uncertainties, that passes through the "true" position of the target. Two intersecting object-chords define the "true" target position; once this is known, the layback error can be determined, and so can the actual feathering angles for the line directions run. While these two values remain known and constant, the simpler interpretation methods are valid. One well-defined target can therefore be used to determine feathering angles and laybacks valid over quite a large area of survey.

MATHEMATICAL BASIS OF THE METHOD

Fundamentals

The mathematical basis of the object-chord method can beverified by using the equation of a circle. Let us consider three circles (or object-arcs) each with a centre representing the towing point and a radius R representing the horizontal distance from the towing point to the object location (see Figure 5). The three circles can be represented mathematically by the general equation of a circle, as:

$$X^2 + Y^2 + 2g_1X + 2f_1Y + C_1 = 0 \quad (1)$$

$$X^2 + Y^2 + 2g_2X + 2f_2Y + C_2 = 0 \quad (2)$$

$$X^2 + Y^2 + 2g_3X + 2f_3Y + C_3 = 0 \quad (3)$$

The constants g and f represent the centre co-ordinates (easting and northing respectively) of the individual circles, and hence the co-ordinates of the towing points. The constant C can be expressed by the general equation,

$$C = g^2 + f^2 - R^2 \quad (4)$$

By subtracting equation (1) from (2), the equation of the line (or chord) joining the intersections of circles 1 and 2 can be derived, and represented by:

$$Y = \frac{(g_2 - g_1)X}{(f_1 - f_2)} + \frac{(C_2 - C_1)}{2(f_1 - f_2)} \quad (5)$$

This is the equation of the object-chord. It can be simplified into the general form of a linear equation, given by:

$$Y = M_1X + A_1$$

Similarly, two other equations for the object-chords can be derived from the other combinations of the equations of a circle.

From any two of the equations of the object-chords, we can derive an intersection point between the object-chords.

Using $Y = M_1X + A_1$ and $Y = M_2X + A_2$,

we can derive $X = \frac{(A_1 - A_2)}{(M_1 - M_2)}$

and Y can be derived by substituting X into any one of the two equations of the object-chord.

The co-ordinates X, Y therefore represent the object location.

Each sidescan pass will yield one object-arc. Two arcs will yield one object-chord. Three arcs will yield three object-chords, which will meet at a point (the third chord being derived from arcs that have already defined the first two chords). Four arcs will yield four independent points at which three chords intersect. This means that we now have redundant information, and the agreement of the four points is a measure at the validity of the result.

Proof of the Object-Chord Method

It remains to be shown that the object-chord lies in the same place if a constant layback error exist.

The horizontal distance from the towing point to the object position, denoted by R, is equal to:

$$R = \sqrt{(LB^2 + D^2)} \quad (6)$$

or

$$R^2 = LB^2 + D^2$$

where LB = horizontal distance from the towing point to the fish position, and
D = horizontal distance from the fish to the object.

and the sidescan beam is assumed to be at right angles to the direction from fish to tow point.

Term D can be measured or calculated accurately from the sidescan records and is assumed to contain no error. If the layback contains error the equation therefore becomes:

$$R^2 = D^2 + (LB + \Delta LB)^2 \quad (7)$$

The equation of the object-chord has been shown to be:

$$Y = \frac{(g_2 - g_1)X}{(f_1 - f_2)} + \frac{(C_2 - C_1)}{2(f1 - f2)} \quad (8)$$

It is also accepted, by definition, that

$$C = g^2 + f^2 - R^2$$

Therefore it is clear that errors in the equation of the object-chord will be due to errors in the terms g, f and R. Errors in the terms g and f are solely due to navigation, cannot be eliminated by sidescan interpretation technique and will not be discussed in this article.

It has also been shown that any error in R can be assumed to be due to errors in LB, the layback distance.

If we re-define the term $(C_2 - C_1)$ taken from equation (5) by expanding equation (4) and substituting equation (6), we have

$$(C_2 - C_1) = (g_2^2 - g_1^2) + (f_2^2 - f_1^2) + (D_1^2 - D_2^2) + (LB_1^2 - LB_2^2) \quad (8)$$

The above equation contains no layback error. Where there is error in the terms LB, substituting equation (7) instead of (6) gives:

$$(C_2 - C_1) = (g_2^2 - g_1^2) + (f_2^2 - f_1^2) + (D_1^2 - D_2^2) + (LB_1^2 - LB_2^2) + (\Delta LB_1^2 - \Delta LB_2^2) + 2(LB_1 \Delta LB_1 - LB_2 \Delta LB_2) \quad (9)$$

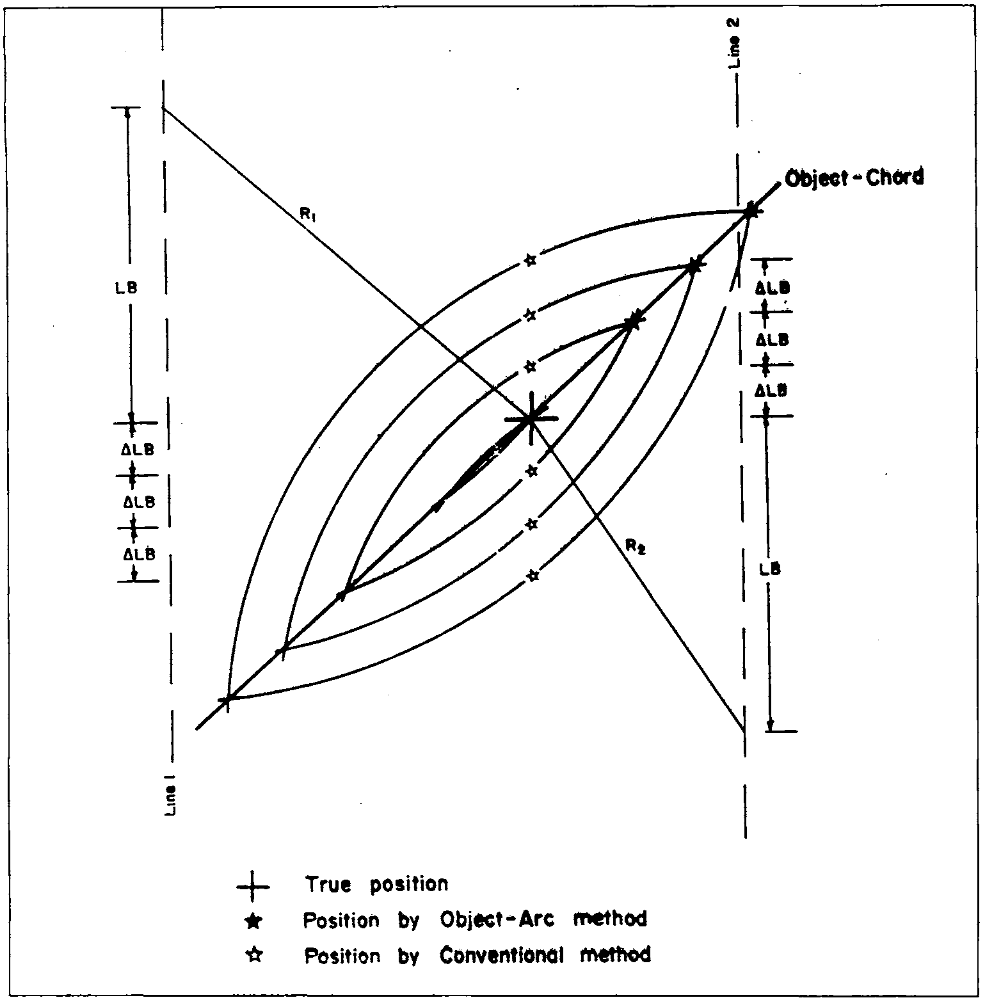

Figure 6: The chord is a straight line that passes through the position of the object.

Under the condition that $LB_1 = LB_2$ and ΔLB_1 -ΔLB_2, which is assumed to be the case where the cable length deployed and the fish depth are kept unchanged, $(C_2 - C_1)$ in equation (9) will be exactly equal to $(C_2 - C_1)$ in equation (8), the additional terms in equation (9) being self-cancelling.

It is clear then that the equations of the object-chord with and without layback error are identical. The chord is therefore a straight line that passes through the position of the object, regardless of the size of the layback, provided it is constant (see Figure 6). This is the proof of the validity of the object-chord method.

EXAMPLES

Two theoretical examples are presented to illustrate the advantages of the object-chord method.

First Example (see figure 7)

In this example, the layback distance is similar for all three lines. We have induced also an equal amount of error in the layback. The position derived from the object-chord method remains accurate despite the presence of these layback errors.

The positions from the object-arc method have drifted quite a lot due to these errors and the rather acute angle of cut between the object-arcs.

The positions from the conventional method have also drifted because of layback and feathering angle errors.

Second Example (see figure 8)

In this example, lines 1 and 2 are acquired with the same set of layback distance and error while lines 3 and 4 share a different set of layback distance and error. This situation may happen if cross lines are done when all the main lines have been completed, possibly a day or deployed may be different. Sea conditions may have changed and the ship's speed and cable deployed may be different.

The advantage is that the object-chords from lines 1,2 and lines 3, 4 will intersect at correct position despite the different acquisition parameters.

The positions derived from the object-arc method have drifted. In this example, which of the object arc intersections would be quite subjective, and may differ with different individuals. This ambiguity is one of the main advantages of the object-arc method.

The positions by conventional method have also drifted due to errors in layback as well as feathering angles.

Third Example (see Figure 9)

An example from recent fieldwork is also presented.

In this example three sonar lines were available for interpretation. The survey was performed for an as-laid pipeline and our objective was to check and map out the pipeline. An object with a known position was present in all records and gave us an opportunity to test our finding.

As expected the object-chord method gives the best result, with its position only 2 metres due south of the correct position.

The result from the object-arc method gives a mean position which is 11 metres, 015 degrees from the correct location. Standard deviations are 7 metres in both easting and

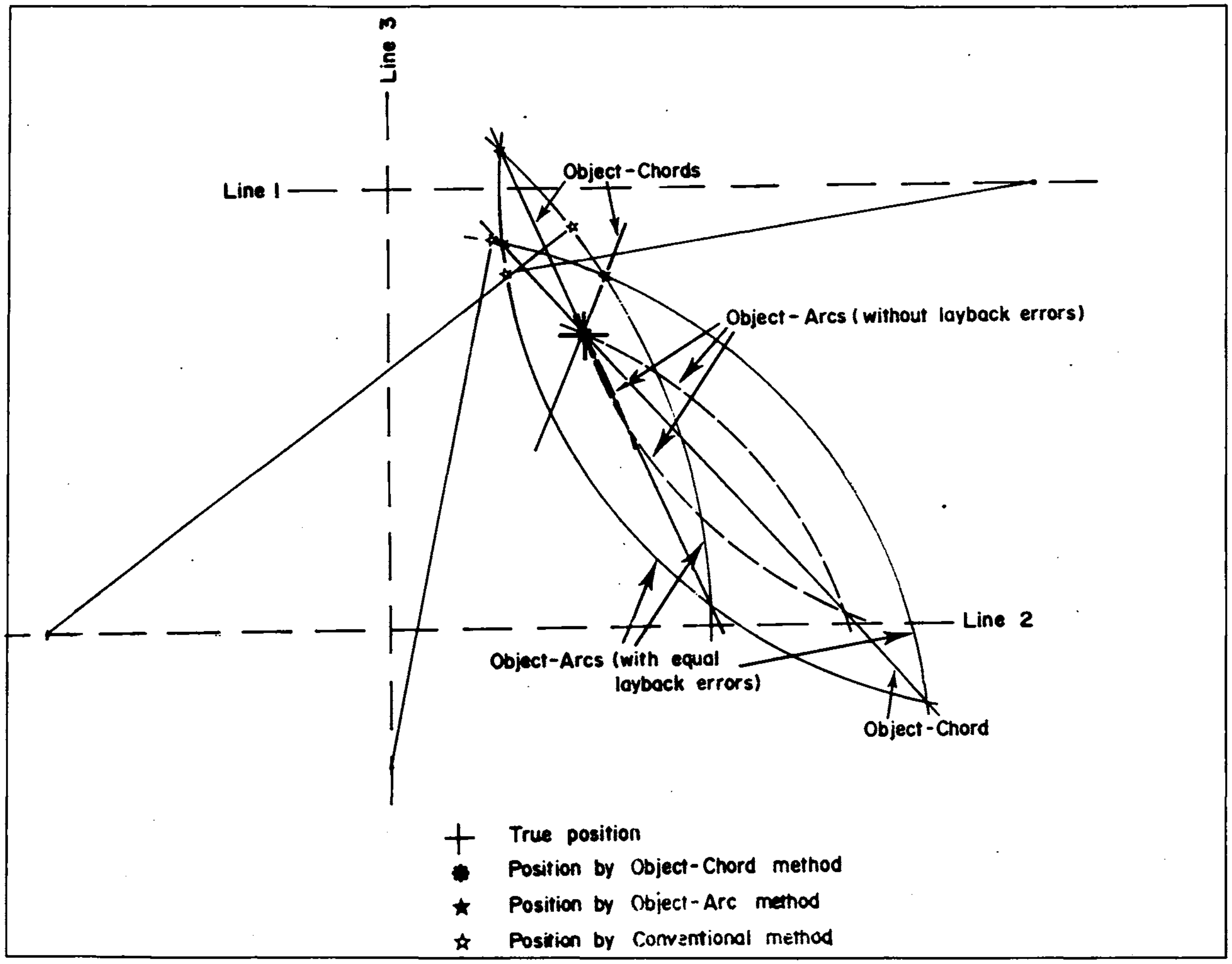

Figure 7: First example to illustrate the advantage of the object-chord method.

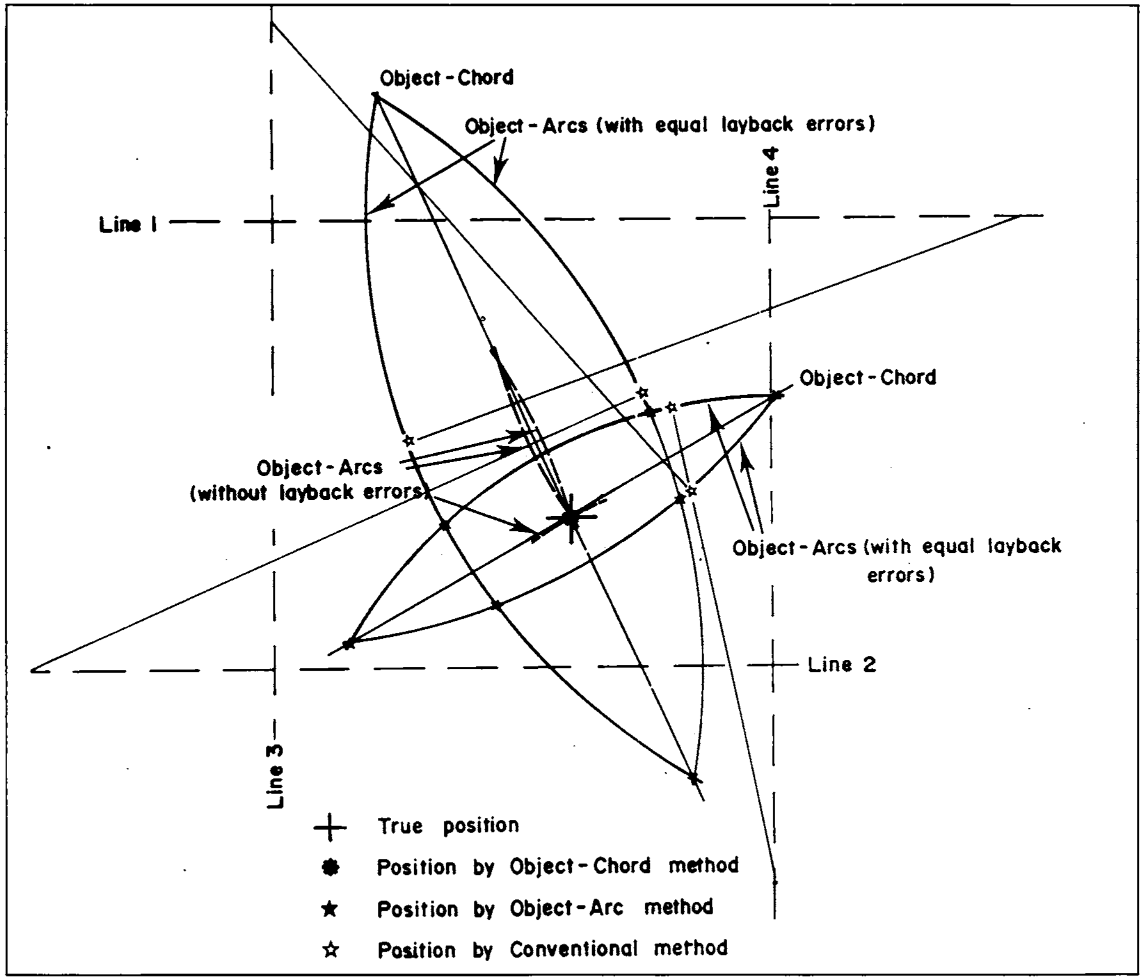

Figure 8 Second example to illustrate the advantage of the object-chord method.

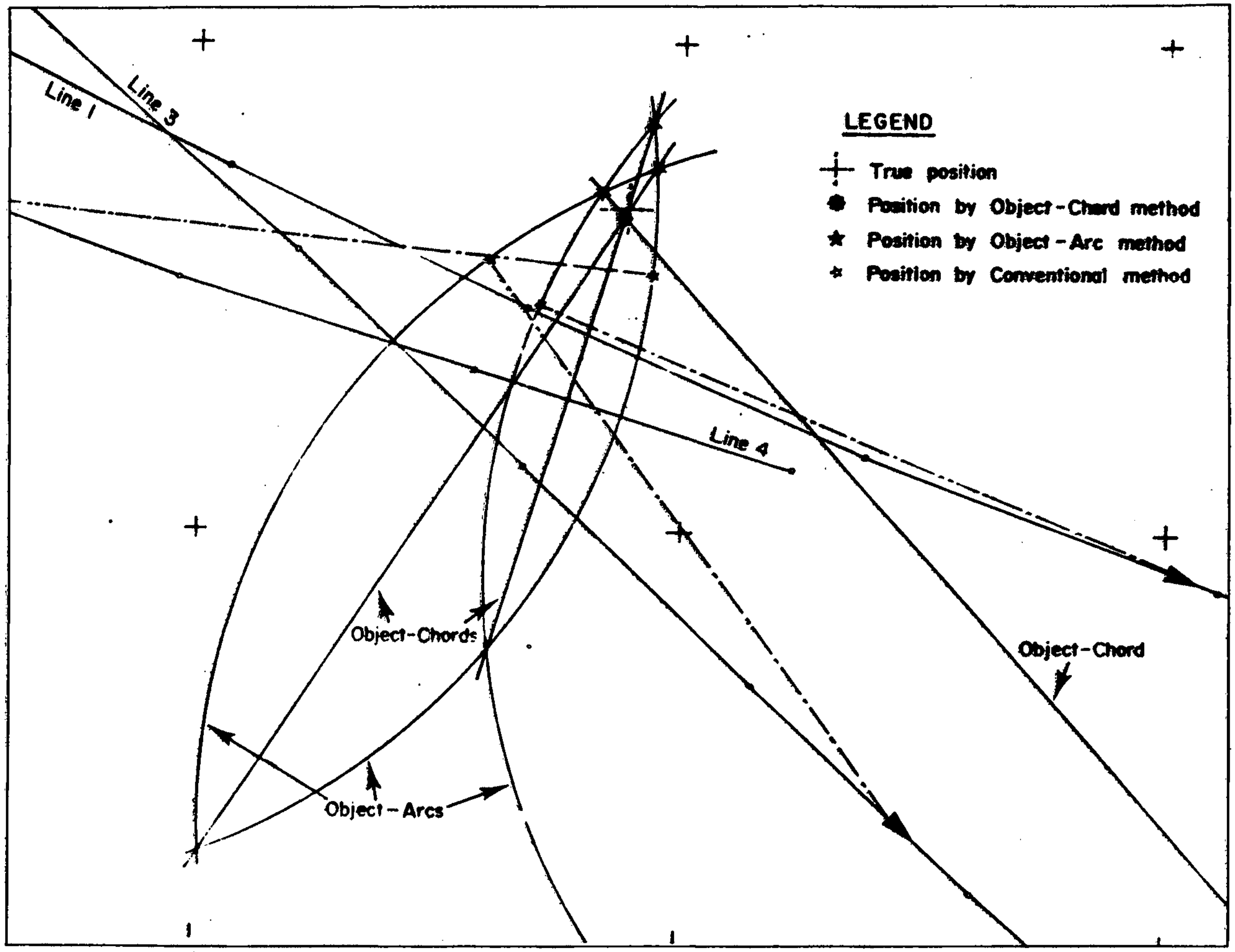

Figure 9: An example from recent fieldwork.

northing. This result is less than satisfactory, the layback error being 7 metres only.

The mean position obtained by the conventional method is 18 metres, 225 degrees from the correct position. Standard deviations are 17 metres in easting and 5 metres in northing. The result is the worst.

SUMMARY

Field Technique

In order to use the Object-Chord method effectively, it is important to keep the amount of cable deployed and fish depth, and hence the speed through the water, unchanged so that the catenary of the cable remains generally constant. These are acquisition conditions that must be met if the object-chord method is to be available to the interpreter.

Data acquisition is best done in fairly constant current and sea conditions. At least three lines are needed to derive a position using this method, and a minimum of four lines are required for redundant data to allow a check on the validity of the result.

Where it is not practical to acquire at least three lines in similar sea and current conditions (and so normally within a short span of time), two pairs of line are required, the two lines of each pair meeting the conditions.

Sets of three (or four) lines should be so planned to give a good angle of cut between the object-chords through selected well-defined objects.

Determining True Position of Selected Objects

For each contact, the following procedure is recommended:

(1) Using the calculated layback distance, plot the towing and the fish, assuming the cable bearing is the opposite of the ship's head.
(2) Plot the contact position from the fish in the usual manner taking into account the slant range.
(3) Draw an arc centred on the towing point with radius equal to the distance from the contact position to the towing point.
(4) Repeat the above procedure for the contact from other lines.
(5) Join the object-chords at the intersection of the arcs.
(6) The true position is at the intersection between these object-chords.

Determination of correct layback distance and feathering angle by graphical means
(see Figure 10)

For each line, the following procedure is recommended:

(1) Draw a line between the towing point and the true position of the contact.
(2) Bisect the line. With the half-way point as the centre, draw a semi-circle through the true position and the towing point. The fish will be on this semi-circle.
(3) Draw an arc with radius equal to the horizontal distance from fish to contact (reduced from the records), centred on the true contact position, and intersect the semi-circle. This will give the true position of the fish.

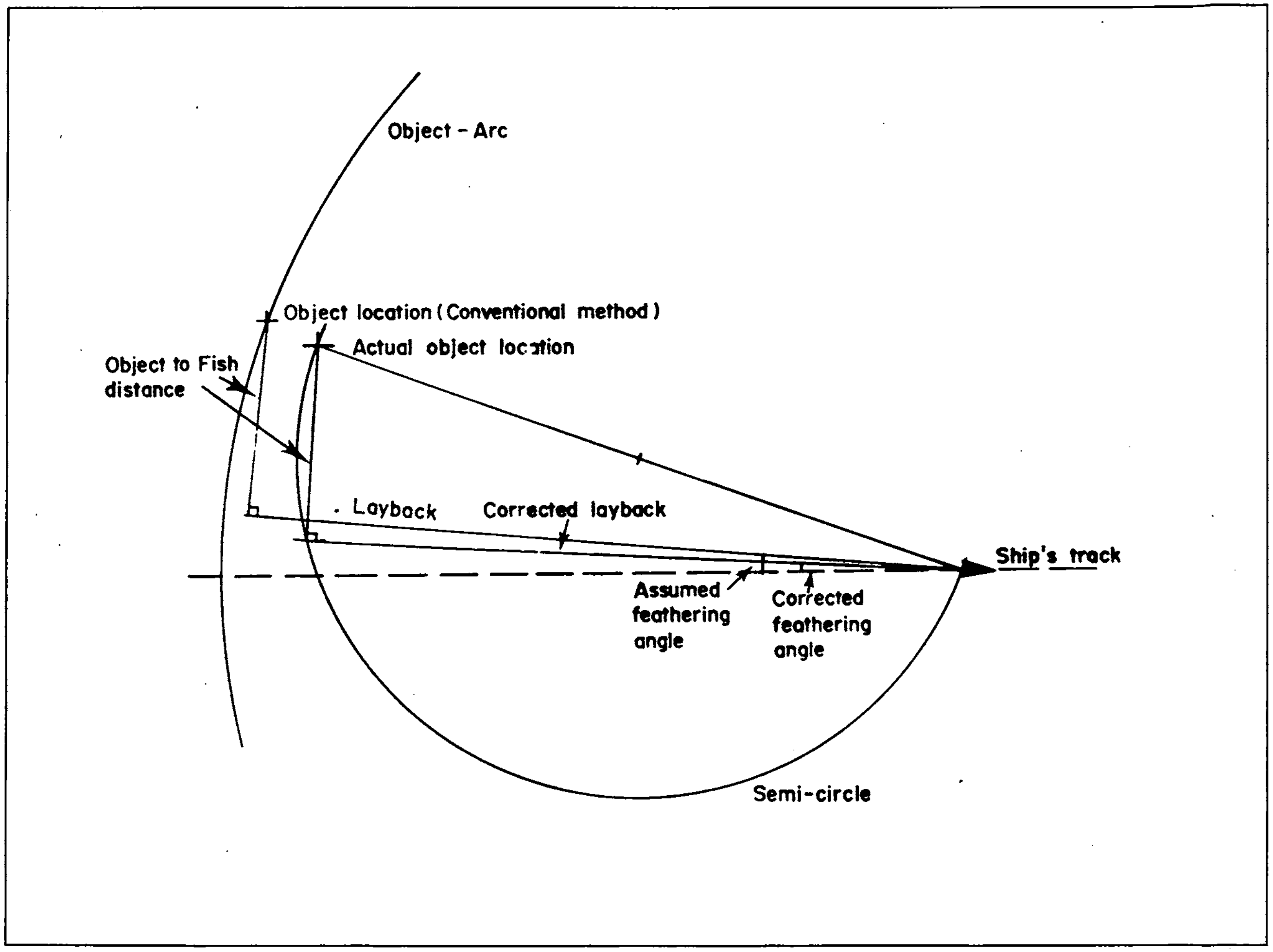

Figure 10: Determination of correct layback distance and layback angle by graphical means.

(4) The distance from the fish to the towing point represents the true layback distance and the angle between this line and the ship's track represents the feathering angle.
(5) These values may be used to ensure accurate interpretation along the lines for which they were determined, provided acquisition conditions remained stable.

CONCLUSION

In our recent experience with sidescan interpretation, the object-chord method has proved a valid method of providing accurate results. It identifies and overcomes an important weakness in the object-arc method.

The method is inexpensive, and needs no special equipment. It is flexible, and can be used to the extent that the interpreter judges to be necessary.

Its successful use does depend on an appropriate survey layout being specified at the planning stage, and the use of proper acquisition techniques.

ACKNOWLEDGEMENT

Since reading this paper, the authors have read a letter in the July 1984 issue of *The Hydrographic Journal,* from B.E.G. Bizzell, in which the concept of object-chords is suggested.

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