The tables have been laid out to give a convenient pattern to the calculations, even at the cost of some repetitive tabulation. For instance, versines are effectively tabulated twice over, once in Table 2 and again in Table 3. The device of expressing versines in sexagesimal notation, as degrees and minutes, ensures that even the weariest and most harassed navigators will not try to add the wrong figures together. Possibly these are the reasons for the long-sustained popularity of these tables.

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An Examination of Criticisms of Automatic Radar Plotting Systems and their Advantages in Relation to Manual and Semi-auto Systems

A. Harrison

MUCH of Captain Wylie's note (this *Journal*, **27**, 111) is undoubtedly correct, particularly the part headed 'automatic versus manual', which restates the strong operational requirement for automatic plotting. The earlier part, however, contains some truth, some error, and shows a notable omission. A detailed analysis would take far too much space, so I will deal with three points only.

First, the opening sentence is nearly correct; I could accept it if 'supposed' is omitted, and 'plotting' reads 'predicting'. With regard to the next sentence, I must recommend a re-reading of my paper[1] (Capt. Wylie's ref. 3). May I re-quote my first conclusion. 'The "classical" technique of manual plotting for 3 or 6 minutes gives a predicted C.P.A. whose accuracy varies within wide limits. The accuracy is adequate at long range for a fast approach, or at shorter range for a slow approach, so the method is operationally satisfactory in that adequate warning time is available in either case.'

So the criticism *does* state that the errors affect all methods of plotting, but goes on to say that because of differences in procedure (programme) made clear in the paper, the errors of prediction from manual plotting are acceptable in operation.

Second, the first paragraph on page 112 implies that the errors arise only when the ship rolls, and concludes, "The steadiness of the ship contributes to a reduction of radar bearing error.' A generality; but let us, as recommended on the previous page, descend to the particular and ask 'how much?' My calculations (ref. 1) supported by experimental evidence[2,5] indicate that the error in

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bearing, which is responsible for almost all the predicting error, can be well over ½ degree in a near calm. This is certainly only some 60 per cent of its magnitude in a sea state which causes ±10 degrees of roll, but it is still a large error.

Third, the references quoted from the I.E.E./I.E.R.E. Conference omit what I believe to be almost the only valid experimental evidence available. I refer to the paper presented at the same conference by Shuffleton and Evans of A.S.W.E.[3] in which the C.P.A. of a large number of 'targets', as predicted by computer, is compared to the actual C.P.A. obtained by an independent method. Their observations show that

(a) Using a simulator target, the standard deviation of C.P.A. is about 3 per cent of the range at which the prediction is made (for ranges over 4 miles).

(b) With the radar still firmly on shore, but observing ship targets, this error rises to about 9 per cent. The increase is argued to be due to 'variations in the shapes of ships' echoes', i.e. to target glint, which is absent from the constantly repeated shape of the simulated targets in (a). To improve the bearing accuracy, predictions were made in which each bearing fed to the computer was the average of eight separate observations, i.e. an integration time of 20 sec. Theoretically, this should reduce the errors by 65 per cent. It achieved 35 per cent, i.e. the standard deviation of C.P.A. dropped to about 6 per cent of range.

(c) With the radar mounted aboard ship, observing ship targets (63 ships tracked in various sea states) the errors remained at about 9 per cent. Unexpectedly, averaging hardly affected this figure. It was concluded that the errors due to own ship's motion were cyclic, and of longer period than the 20 sec. integration time, so that this smoothing was ineffective.

My paper shows that these cyclic bearing errors have periods from about 30 sec. up to several minutes. The error in a prediction made from data acquired during part of such a cycle is unlikely to be noticed, since there is no independent standard of comparison. (Note that the trial target check, available on some equipment, uses a simulated target, to give results as in (a) above.)

The position is therefore quite clear. Automatic plotting of all the 'historical' data, on all the targets, available in for example the Kelvin Hughes 'Situation Display', is a facility which can be of considerable assistance to the ship's Master. If and when the data is subject to errors, particularly cyclic errors of the type described, the observer's mental prediction, made from the average of a track a mile or two long, does not overstrain the accuracy of the data, and the errors become negligible, as with manual plotting. Averaging *will* improve the bearing accuracy, provided the average extends over a sufficient number of cycles of error. Here is the dilemma for the designer of an auto-tracking system. Accuracy can be achieved, but only at the expense of a time lag, which delays both the prediction and the observation of a target manœuvre (ref. 4). Thus, a predicted C.P.A. derived from currently available radar and gyro installations, and processed in a predictor using a short-time programme, is likely to be subject to errors which are hidden by the clear presentation.

Of course, these errors can be significantly reduced if attacked at source; e.g. a vertical reference gyro to correct the tilt errors of the radar aerial on a rolling ship; siting of the directional gyro near the roll centre (±5 m); accurate bearing transmission systems from aerial and gyro (e.g. 4096 bit digital encoders); integration of at least 4 (preferably 16) bearing observations for each one used for prediction; and a computer programme which acquires target data not in a fixed time interval, but over a 10 per cent range reduction (e.g. 1 mile at 10 miles). The first two changes eliminate the long-term cyclic errors. The second two minimize the random errors. The last one ensures that the accuracy of the predicted C.P.A. is proportional to range (not range squared, as with a fixed plot time interval).

These modifications will produce a computer system in which the C.P.A. of a ship approaching at 27 kt. relative velocity, predicted at 8 miles range (6 in rough weather), is 90 per cent likely to be within $\pm\frac{1}{4}$ mile of the truth. A computer system using current equipment and practice will only score 30 per cent. The cost-effectiveness of such systems is the concern—the very deep concern—of shipowners today.

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