International Hydrographic Review, Monaco, LIX (1), January 1982

LORAN-C COORDINATE CONVERTERS – PLAGUE OR PANACEA

by David H. GRAY (*) and Tony MORTIMER (**)

Paper presented at the 20th Canadian Hydrographic Conference, April 1981, Burlington, Ontario, Canada and reproduced with the kind permission of the Organizers.

ABSTRACT

The advent of Loran-C as the major radio navigation system for North America and the advancement of the electronic technology have resulted in economically viable conversion of hyperbolic readings to geographic coordinates. Although the user will appreciate such extras as : way points, course and speed made good, and track plotter, he should also be aware of the systematic errors that affect the coordinate conversion. The paper highlights these pro's and con's and the progress being made to set minimum performance standards for such converters.

INTRODUCTION

Latitude and longitude have been the universal method of quoting a position since the 1760s when John Harrison was able to demonstrate that his chronometer kept accurate time and hence a navigator could compute his astronomic position. It has only been in the last forty years with the use of such radio navigation systems as Decca, Loran, Consol and Omega that auxiliary coordinate systems have been developed and used to express positions. Electronic technology has certainly developed during the same period. The hot filament

(*) Canadian Hydrographic Service, 615 Booth Street, Ottawa, Ontario K1A OE6, Canada.
(**) Canadian Hydrographic Service, Pacific Region, Sidney, B.C., Canada.

vacuum tube was used extensively in the 1940s, the transistor came in the 1950s, the printed circuit board in the 1960s and the electronic chip in the 1970s. The third important constituent to having coordinate converters manufactured at all is the requirement that Loran-C, or equivalent, be used within the Coastal Confluence Zone of the United States of America by ships greater than 1600 gross registered tons. Thus the three necessary factors for the ability to market coordinate converters are present : the universal system in Loran-C, the legal necessity to have a Loran-C receiver on board, and the technology to develop the coordinate converter.

PERFORMANCE STANDARDS

Loran-C is a hyperbolic system and as such has varying lane widths and varying angles of intersection depending on the location with respect to the various transmitters. Loran-C also has other problems such as skywave interference and cycle slips at long ranges and signal delay called Additional Secondary Factor (ASF). Indeed, the United States recognizes that coordinate converters are a thing of the present and that minimum performance standards must be set. This is more than certification so that no one will get an electric shock when the equipment is plugged in but rather that such converters do work properly. One of the co-authors has had some input into the Special Committee 75 of the Radio Technical Commission for Marine Services that has been charged with setting up these minimum performance standards, where, on behalf of the Canadian Hydrographic Service, he has expressed some of the problems :

1) The computation algorithm used may be inaccurate, or in some cases, fail under certain conditions such as long range from the transmitters; high latitude; change of longitude at 0° or 180° meridian; poor fix geometry.

2) Accurate Loran-C calculations require that variation in the propagation velocity of the Loran-C signals be accurately modelled. The present convention is to base calculations on the vacuum velocity (299 792.5 km sec^{-1}) and to modify this by :

- i) The primary and secondary factors, which model propagation through the atmosphere and over sea water. These differ only slightly from the polar regions to the tropics, and are relatively predictable;
- ii) The Additional Secondary Factor (ASF) which accounts for the additional effect on the propagation velocity of transmission over land. The magnitude of the ASF depends on the type of land and is difficult to predict accurately. Failure to allow for ASF, or errors in predicting it, can cause position errors of several miles, and these errors may fluctuate quite rapidly (by 0.5 miles in ten miles' steaming at one point off Nova Scotia, for example);
- iii) With the usual geometry of Loran-C chains, and with ASF always being a delay in the signal travel time, it means that the position computed or plotted using lattices or algorithms not corrected for the ASF is farther off shore, and hence in safer waters, than the real

position. The amount of the discrepancy in position depends on the magnitude of the ASF's, the lane widths and the angles of intersection of the lines of positions.

3) The coordinate system, or datum, used by most coordinate converters is the World Geodetic System 1972 (WGS-72) whereas most charts published by National Ocean Survey and Canadian Hydrographic Service, for United States and Canadian waters respectively, are on the 1927 North American Datum (NAD-27). The discrepancy in position between the two coordinate systems varies from 0 to 125 metres for all but Alaskan waters where it differs by up to 180 metres (see fig. 1). Certain Canadian charts are not on NAD-27 but on a local system where the displacement in position is of the order of one mile ! For obvious reasons, CHS has declined to lattice such charts but that fact would not stop a mariner from plotting his position obtained from a coordinate converter on that chart and unknowingly being in a dangerous position.

4) A mariner plotting his position on a latticed chart will notice as soon as the fix accuracy degenerates due to a poor gradient or narrow angle of cut. A coordinate converter which merely displays latitude and longitude, without additional information on fix accuracy, gives no indication that all is not well, and can induce a very false sense of security.

5) If the groundwave from at least three secondaries can be received reliably, the coordinate converter can be made entirely self-starting. If only two secondaries are available, the converter must be given an initial position, and must be reinitialized, or confirmed, on crossing a baseline extension.

6) Loran-C is susceptible to $10\mu s$ errors when used at long distances from the transmitters. Because these errors usually occur as a gradual wander from the

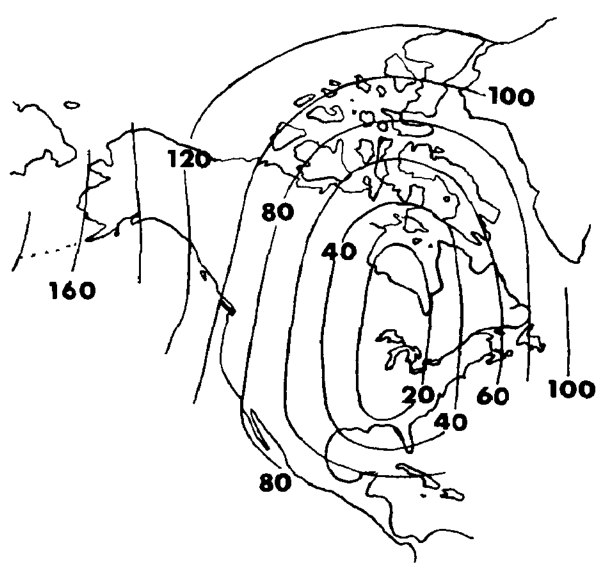

FIG. 1. – Approximate shift in position (in metres) between World Geodetic System 1972 (WGS-72) and 1927 North American Datum (NAD-27).

3rd to the 4th cycle, rather than as a sharp jump, they are difficult to detect at the time they occur. At long range, the fix geometry is usually weak, and consequently the position error resulting from a cycle error is generally several miles. When the mariner plots an independent fix (radar, satfix, etc.) on the latticed chart, the 10μs discrepancy in the Loran-C reading may show up quite clearly. However, a 10μs source of the error will not be at all obvious when comparing the independent fix against the Lat., Long. output of a coordinate converter.

Some suggestions that should be incorporated in the minimum performance standards were put forward :

1. To test the algorithm used in computation, and the modelling of the primary and secondary conversion factors, we suggest that a series of test positions be precisely calculated on an imaginary "benchmark" of an over-water Loran-C chain, and that coordinate converters be required to compute conversions between Loran-C and geographic positions to agree with the benchmark positions within an accuracy equivalent to $\pm 0.2\ \mu s$ in the Loran-C reading. We suggest this in preference to the undesirably restrictive alternative of specifying the algorithm to be used.

2. To avoid gross errors in ASF correction, the mariner should be able :

i) to interrogate the coordinate converter to find out what ASF it is applying;

ii) to override the ASF calculated by the converter when he has better information of his own.

ASF can be applied directly to the Time Differences (TDs) used in calculations, or by making the lat., long. output agree with a known lat., long. Because the latter type of adjustment becomes incorrect as soon as the pattern geometry (gradient, direction of position line) changes, we suggest that the direct method of applying ASF corrections to the TD is preferred.

3. Every coordinate converter must have a "weak fix" alarm. The level of fix error to trigger the alarm is a matter of discussion; it might be when the semi-major axis of the error diamond (or error ellipse) exceeds 0.5 N.M. for a Loran-C reading error of $\pm 0.2\ \mu s$. As a desirable option, we suggest an on-request output of the direction and magnitude of the semi-major axis of the error diamond (or error ellipse).

4. A convenient method is needed to initialize the converter when only two secondaries can be received reliably, and to warn the mariner that the ship has approached a baseline extension and the converter may need reinitializing. (The "weak fix" warning may serve this purpose).

5. In order to help the mariner detect cycle error, coordinate converters should be capable of performing the inverse calculation from Lat., Long. to TD so that the mariner can input his fix from an independent source (e.g. radar) and get a set of TDs to compare with those shown on the receiver.

6. The Loran-C receiver/coordinate converter must always be capable of displaying TDs as well as Lat., Long. (but not necessarily both at the same time).

The standards for coordinate converters as being prepared by the committee include :

1) The coordinate converter reproduces, within certain specified tolerances, the latitude and longitude of given Time Differences (TD's) at any geographic point in which the TD's are determined from Defense Mapping Agency's publication 225. These are lattice tables based on the World Geodetic System 1972 and all sea water paths between transmitters and receivers.

2) The coordinate converter allows for the manual or automatic insertion of ASF corrections to the TD's to reproduce geographic positions that would be obtainable if charts on the same datum were available. Defense Mapping Agency is in the process of publishing the ASF corrections at five minute intervals of latitude and longitude for the Coastal Confluence Zone of the United States for each of the applicable Loran-C chains.

3) The coordinate converter indicates when the geometry of the position fix is poor.

How are these coordinate converters going to affect the officers on watch of a merchant ship in American waters? Assume a diligent officer decides to take a position fix. He leaves the bridge for the chart room and first checks the approximate position on the coordinate converter, looks up the Radio Aids book or Sailing Directions to check that the receiver is using the best pair of TD's. Next he has to find the ASF corrections for each pair. He consults the 100-page book on the first TD, looks up the approximate position, finds the associated ASF, dials that in to the converter, and checks the value. Then he has to repeat the process with the other TD. Now his coordinate converter should have the correct position, so he plots the position using the latitude and longitude, makes a value judgement on the new course, navigational hazards, etc. Now the officer can go back to the bridge; however fifteen minutes have elapsed and the ship could be on a collision course with another ship. After a few instances such as that, he will throw the coordinate converter overboard and plot his position using Time Differences.

The whole concept of coordinate converters is to make life easier for the mariner. Therefore, the automatic input of ASF corrections is obligatory for easing the work. The elimination from the solution or cautioning the result of the solution from such problems as: blink, very weak signals, poor geometry, and skywave is required. The truly smart automatic selection of TD's for the best geometry is desirable. The possibility of a multiple TD solution and the automatic selection of GRI are also desirable for a fully automatic coordinate converter. These things are not just pipe dreams of the authors; automatic ASF corrections, and cautioning due to blink, skywave (actually stronger than predicted groundwave) are a reality.

CONVERTERS TESTED

The authors have on several occasions used the latest commercial receivers. The most recent occasion was Nov./Dec. 1980 during the calibration cruise of the newest secondary to the Canadian West Coast Chain (5990) on CSS *Parizeau*. There were three receiver/coordinate converters loaned by distributers or manufacturers. A CLX-85 was the simplest; it was tuned for only the 5990 chain, received all three secondaries and computed a position, had no capability to force a signal onto a different cycle other than by restarting the cycle search, and did not compensate for ASF. The second receiver was a Furuno with a coordinate converter and video screen track plotter attachments. This receiver, although it tracked all three TD's, could only compute positions from the X and Y TD's (this was because the information on the third secondary was not available at the time of manufacture), and required the entering of an approximate position into the coordinate converter to initialize the iterative solution. The track plotter displayed the positions at a selected scale, at a selected update rate and in relation to displayed event markers. The plotter showed how noisy the Loran-C was if it was set to a large scale and fast update rate, signalled any cycle slips by a severe straight line across the screen, displayed tracking skywave by the resulting track being distinctly wavy and reproduced a good facsimile of the positional error ellipse when the ship was tied up at a wharf. The third receiver was a Trimble 10A which has automatic notch filters, receives and tracks up to four TD's concurrently, assesses signal strengths versus predicted strengths (exceptionally stronger signals are diagnosed as skywave and are rejected), automatically selects TD's for the solution, automatically applies ASF corrections and computes the position.

POSITION COMPARISONS

During this same cruise, positions were determined by doppler satellite (SATNAV) with velocity input from log and gyrocompass corrected to TAO Loran-C through a real time navigation system called BIONAV. The accuracy of this reference system is about 150 metres or, for convenience, 0.1 nautical miles. The data set was analyzed by fitting polynomial surfaces for the ASF's of each of the four transmitters of the chain. Data that did not fit to two or more of the surfaces were considered outliers and were removed. Generally, the standard deviation of the fit of a second or third order polynomial was 0.5 microsec. or 150 metres. During the cruise positions from the coordinate converters were recorded at many of the satellite fixes. Indeed, there were over 160 comparisons of positions between coordinate converters and accepted satellite fixes for two of the converters. The Furuno was loaned to the bridge for part of the cruise so there are only 107 fix comparisons. Table 1 shows the magnitude of the coordinate comparisons.

It must be remembered that the Furuno had the capability of computing positions from only the X and Y TD's whereas the other two could use any two of the three available TD's. Essentially the three converters appear to have very similar distribution of errors. It is interesting to note that the 95 % confidence bound of the three converters extends beyond the oft-talked-about quarter mile accuracy of the system and certainly beyond the 200 metre, or less, repeatability of the system in the area surveyed. The authors then looked at three areas important because they are where landfalls are made most frequently; namely, off Cape Beale, between Vancouver Island and Queen Charlotte Islands, and

Table 1
Percentage distribution of coordinate comparisons between Loran-C coordinate converters and doppler satellite positions

Nautical Miles	CLX-85	Furuno	Trimble
0.00 to 0.09	6 %	6 %	6 %
0.10 to 0.19	15	21	18
0.20 to 0.29	20	27	24
0.30 to 0.39	13	9	23
0.40 to 0.49	13	5	15
0.50 to 0.59	7	5	6
0.60 to 0.69	6	4	3
0.70 to 0.79	3		
0.80 to 0.89	2	4	
0.90 to 0.99	4	3	1
1.00 to 1.99	7		2
2.00 to 2.99	3	1	2
greater than 3.00...	1	5	

Dixon Entrance. Figure 2 shows the error ellipse of the distribution of the comparisons between SATNAV and Loran-C fixes for each of the three converters in each of the three areas. The statistical analysis proved two facts :

1) All receivers performed better in the central and south areas than they did in Dixon Entrance.
2) The Trimble converter performed better than the other two in Dixon Entrance.

Otherwise, there is no difference between the converters at the 95 % confidence level.

The other available features that are usually associated with Loran-C coordinate converters, such as speed and course made good and distance to way points, were not investigated in this cruise. One of the co-authors has previously reported on the speed made good in an article in *Lighthouse* (MORTIMER, 1979).

More and more manufacturers are making coordinate converters and there is no doubt that converters will become a greater percentage of the Loran-C market. A few years ago there were several pamphlets on what the buyer should know and/or ask about Loran-C receivers. The same should be done for converters and here are a few starters :

1) Does the converter work on all Loran-C chains or only one ? On all secondaries ? North and south of the equator, east and west of Greenwich ?
2) Does the mariner select which secondaries are used in the computation or does the converter, in which case does he know which ones, and can he override the selection ? Are only two TD's used at any one time or more than two ?

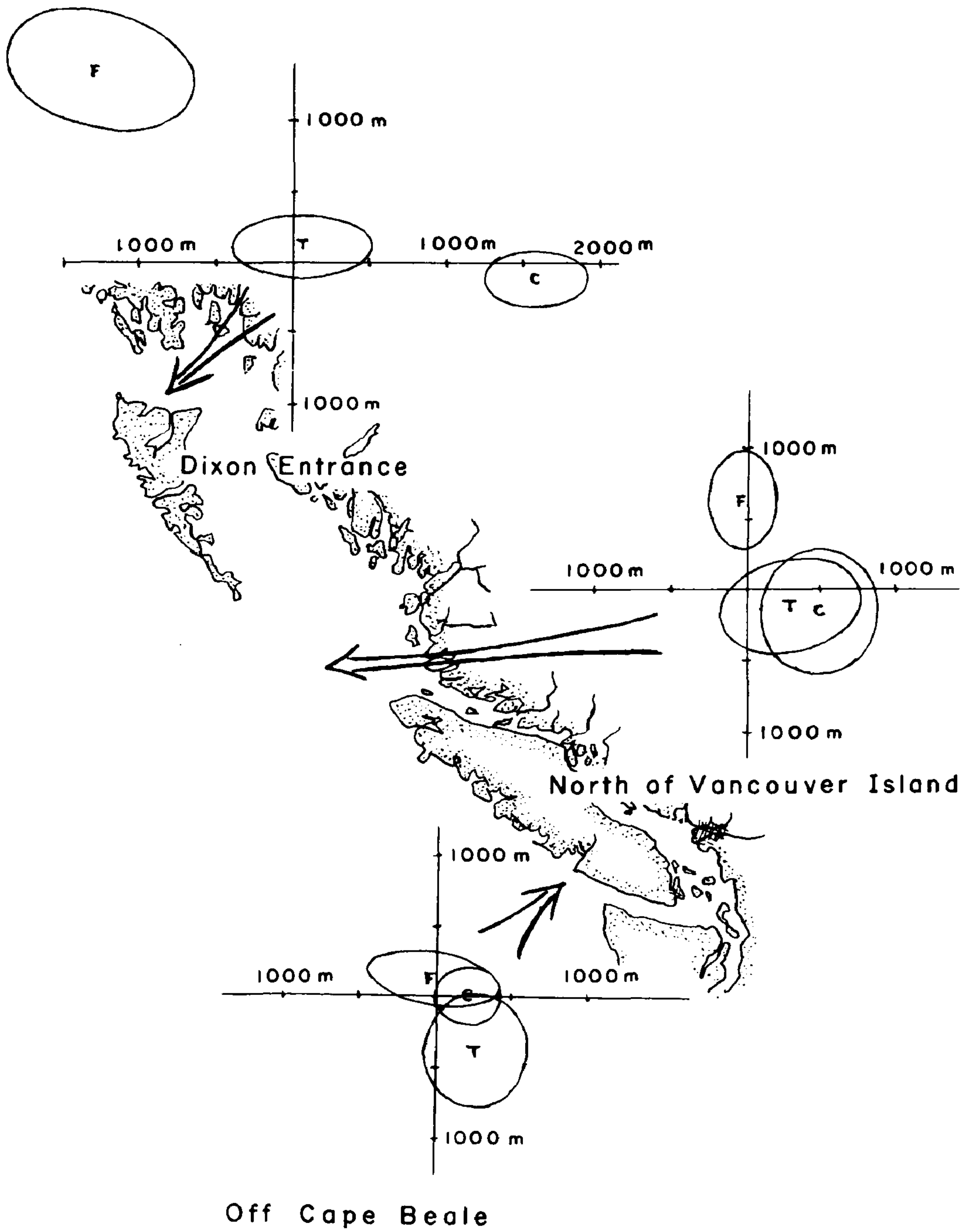

FIG. 2. – Differences in position between SATNAV and LORAN C coordinate converters.
F = Furuno; C = CLX-85; T = Trimble.

3) What coordinate system is used ? WGS-72, NAD-27 ?
4) Can back-lobe and side-lobe positions be computed as well as front-lobe ?
5) Is there any provision to enter ASF corrections ? Manual or automatic ? If automatic can it be overridden ?
6) Is there any indicator of a weak position fix geometry ? Blink ? Sky-wave ? Cycle error ? Signal to Noise Ratio ?
7) Can TD's as well as Lat/Long be displayed ?

The coordinate converter market is much like the auto market : a Rolls Royce with every imaginable option and faultless engineering or a second hand Volkswagen 'Beetle' with only the barest of necessities – not even a gas gauge.

CONCLUSIONS

Prior to full, automatic, use of coordinate converters, CHS charts and positions from coordinate converters will have to be brought to the same datum. The charts that could be latticed and are grossly in error need immediate grid conversion.

ASF corrections will have to be applied to TD's before accurate positions can be obtained from a coordinate converter. The use of automatic ASF corrections will simplify the mariner's duties to the point where he will accept the use of coordinate converters for accurate positioning for navigation. The authors consider that users with only manual insertion of ASF corrections will eventually refuse to enter them or enter them incorrectly and thus degrade the position accuracy, perhaps to a dangerous level.

The mariner must be aware of the accuracy of the position fix through the knowledge of the lane expansion and angle of cut. Preferably the coordinate converter should automatically switch to the most favourable pair and indicate which pair is being used; or alternatively, the selection should be operator controlled. An alarm should indicate when the fix geometry degrades below a specified level.

Canada needs to publish ASF correction data. The authors recommend chartlets published in Radio Aids to Marine Navigation (RAMN) as being the best presentation format and location since CHS has the ASF data and previously supplied the Decca Fixed Errors that are published in RAMN. RAMN is also a legally required publication just as the charts are when in Canadian waters.

A pamphlet on coordinate converter information, uses, and dangers could be published.

SUMMARY

The initial question was whether Loran-C coordinate converters were either a plague or panacea. In a way, both answers are correct. Poor equipment in competent hands and good equipment in inexperienced hands can lead to dangerous situations. Good equipment in competent hands being used with proper procedures is the only safe permutation. CHS will be forced to continue to publish latticed charts so long as receivers that produce only TD's are marketed. Canada will also have to publish ASF data and other information for manufacturers and users of coordinate converters. On the other side of the balance are such advantages as the universal method to quote position, great circle sailing, way points, course and speed made good, and track plotter capabilities.

REFERENCES

MORTIMER, A.R. (1979): Comments on the Internav Loran-C Coordinate Converter Unit (CC-2), *Lighthouse*, Ed. 20, November.

WELLS, D. (1980): A new integrated navigation system : BIONAV. Hydrographic Society Symposium on Position Fixing at Sea, Southampton, England, April.