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APPLICATION OF ADDITIONAL SECONDARY FACTORS TO LORAN-C POSITIONS FOR HYDROGRAPHIC OPERATIONS

by

Gerald E. Wheaton

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Application of Additional Secondary Factors to LORAN-C Positions for Hydrographic Operations

by

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The application of LORAN-C in the hyperbolic mode as a positioning system for hydrographic surveys was investigated. Observed LORAN-C time differences from a field test conducted in Monterey Bay, California were compared to calculated time differences determined from geographic positions based on a microwave positioning system. Four methods were used to determine the calculated time differences. The first three methods were (1) applying only the seawater Secondary Factor, (2) computing the time difference based on a Semi-Empirical TD Grid, and (3) applying ASF Correctors from the DMAHTC LORAN-C Correction Table. The final method applied multiple observed ASF Correctors at five minute latitude and longitude intervals. By applying multiple observed ASF Correctors, which was the most accurate method, a 38.3 meter 1 drms with a lane offset of 3 to 12 meters using the 9940 X-Y LORAN-C combination was obtained. Based upon the results presented, it may be possible to use LORAN-C for hydrographic surveys at scales of 1:80,000.

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I. INTRODUCTION

A. USE OF LORAN-C

In recent years there has been an increasing usage of a LORAN-C receiver and the LORAN-C network as the primary horizontal control for such scientific studies as deep ocean dumpsites, marine fisheries studies [Rulon, 1979], bathymetric surveys, and recently, a reconnaissance hydrographic survey. Examples of bathymetric surveys conducted by the National Oceanic and Atmospheric Administration (NOAA), which have used Loran-C for positioning are:

1) Su-100-1-79 Gulf of Alaska [NOAA H-9822, 1979],
2) SU-100-2-79 Gulf of Alaska [NOAA H-9823, 1979],
3) S-D902-WH-82 U.S. West Coast [NOAA Ship Surveyor, 1982].

Recently an attempt was made to use LORAN-C as the sounding position control for a reconnaissance hydrographic survey S-K902-WH-82 [NOAA, 1982]. This was a special survey conducted by the NOAA Ship Whiting in May 1982. Special surveys are field examinations of very limited extent or scope and frequently require unique survey or data collection procedures [Umbach, 1976]. The purpose of this project was to verify the existence and extent of reported shoaling in three safety fairways in the Gulf of Mexico [NOAA, 1982].

The use of Loran-C as a positioning system for basic hydrographic surveys has been very limited due to the absolute accuracy of the long range system. A basic hydrographic survey is defined as a survey which is so complete that it need not be supplemented by other surveys. "It must be adequate to supersede for charting purposes all prior

surveys" [Umbach, 1976]. Variables which affect the accuracy of LORAN-C are signal propagation variations, weather, and sky waves. The effects of weather and sky waves on LORAN-C propagation are best described by Samaddar [1980] and the American Practical Navigator, [DMA, 1977] respectively.

Signal propagation variations are due to the phase retardation of the signal as it passes over an all seawater path, over land paths, or partial seawater-land paths as compared to free space. Table I summarizes phase retardation changes [Mortimer, 1978]. Errors due to an all sea

TABLE I

Phase Retardation or Lag of Radio Waves

Propagation Path	Representation Propagation Velocity (km/sec)	Difference in Phase Lag at 500 km Compared with Wave in Line Above (m)
Vacuum	299792.5	-
Direct wave through earth's atmosphere	299691	170
Ground wave over sea water	299560	220
Ground wave over rugged mountains	298899	1,300

water path are known as the Secondary Factor (SF) and errors due to a land path or mixed path are known as the Additional Secondary Factor (ASF) [Speight, 1982].

ASF Corrections in the LORAN-C system can be as large as plus or minus four microseconds, which is 600 meters on the baseline. In other areas with the same LORAN-C coverage, these corrections may be much larger due to the expansion of the distance between adjacent hyperbolic lines of position. For example, at 32° N and 80° W, using lattice pair 9960-X, a four microsecond (μsec) error will offset the 9960-X line of position approximately 2438 meters [Speight, 1982].

B. APPLICATION OF ASF CORRECTORS FOR NAVIGATION

To compensate for the Loran-C positional errors caused by the ASF Correctors, the Secretary of Transportation tasked the Defense Mapping Agency Hydrographic/Topographic Center (DMAHTC), the National Oceanic and Atmospheric Administration (NOAA), and the United States Coast Guard (USCG) with the job of determining and applying the Additional Secondary Correctors for each Loran-C chain. This task was published in the Department of Transportation (DOT) National Plan for Navigation in the July 19, 1974 Federal Register. These corrections should provide 95% assurance that a vessel could fix its position to a predicted accuracy of 1/4 nautical mile (NM) within the U. S. Coastal Confluence Zone (CCZ) and the Great Lakes. The CCZ is defined as:

> "the seaward approaches to land, the inner boundary of which is the harbor entrance and the outer boundary of which is 50 nautical miles offshore or the edge of the Continental Shelf (100 fathom contour) whichever is greater."

The 1/4-NM accuracy requirement also affects the nautical chart. The National Ocean Survey (NOS), which publishes charts for the CCZ, engaged in a program with the USCG and DMAHTC to provide the coastal navigator with charts overprinted with lattices which meet 1/4-NM accuracy. The USCG, as operator of the LORAN-C radionavigation system,

conducts surveys to ensure that LORAN-C coverage exists within the CCZ and will be reponsible for the verification of 1/4-NM accuracy for all coastal LORAN-C service. In conjunction with NOS, it assists in surveys of coastal waters of the United States to allow production of LORAN-C charts based on observed field data to meet the standards set forth above [Speight, 1982].

DMAHTC, for LORAN-C civil need, prepares grid predictions from its data base. Based on analysis and verification of the predicted grid from a USCG and/or NOS survey, it produces revisions to the initial grid predictions [Speight, 1982]. At present, DMAHTC has provided NOS with ASF Corrected LORAN-C Lattices which are overprinted on the NOS Charts. Each chart with ASF Correctors applied contains one of the following notes:

"The LORAN-C lines of position overprinted on this chart have been prepared for use with groudwave signals and are presently compensated only for theoretical propagation delays, which have not yet been verified by observed data. Mariners are cautioned not to rely entirely on the lattices in inshore waters. Skywave corrections are not provided".

or

"The LORAN-C lines of position overprinted on this chart have been prepared for use with groundwave signals and are compensated with propagation delays computed from observed data. Mariners are cautioned not to rely entirely on the lattices in inshore waters. Skywave corrections are not provided" [Speight, 1982].

Presently, all of the NOS Charts of 1:80,000 to 1:120,000 scale covering the east coast, Gulf coast, and Great Lakes show LORAN-C lattices that have been compensated for Additional Secondary Factors. Most of the lattices on these charts have been constructed from DMAHTC data tapes that provide adjusted LORAN-C readings for each rate at every five minutes of latitude and longitude. A few lattices were constructed using a single ASF Correction for the entire chart area. Five minute data tapes were not

furnished by DMAHTC for constructing lines of position for LORAN-C rates on the West Coast Charts. On these charts a single average ASF Correction was used to adjust each lattice [NOAA, Marine Chart Division, 1982].

In addition to supplying corrected LORAN-C lattices for nautical charts, DMAHTC prepares, distributes, and periodically updates unclassified ASF LORAN-C Correction Tables [Speight, 1982]. The ASF Correction Tables are for precision navigation, utilizing digital computers to convert LORAN-C time differences to geographic coordinates [Speight, 1982]. Presently, the ASF correctors found in the LORAN-C Correction Tables were determined using theoretical propagation delays. ASF correctors listed in the tables are going to be updated with observed data and reprinted the first quarter of 1983 [Wallace, 1982].

C. APPLICATION OF ASF TO HYDROGRAPHIC POSITIONING

Schnebele [1979] investigated the possibility of using Loran-C as an electronic positioning system for hydrographic surveying. He concluded that in Monterey Bay, California a single Additional Secondary Factor (ASF) applied to offshore lines of position gave a root mean square error (drms) of 66 meters for the West Coast 9940 Y-W pair and a predicted 42 meter drms error for 9940 X-Y rates.

The 42 meter predicted drms is larger than Nelson's [General Electric Co., 1979] findings in San Francisco Bay. He demonstrated, in a dynamic mode, that the precision of LORAN-C was 60.8 meters 2 drms (30.4 meter 1 drms) with a worst case of 71.2 meters 2 drms (35.6 meter 1 drms). A mean difference or offset between the measured time difference and the calculated time difference was 34 nanoseconds for the 9940-X rate and one nanosecond for the 9940-Y rate.

He also obtained a precision of 38.0 meters 2 drms (19.0 meters 1 drms) in the static mode. Nelson also states, that the above precision is only achievable if the user has a LORAN-C receiver which has the performance capabilities of those used in the experiment. The LORAN-C receiver must have "comparable signal averaging time, extra notch filters, and attenuation of the signal" [General Electric Co., 1979].

D. OBJECTIVES

The National Ocean Survey requires that hyperbolic control systems used for hydrographic surveying exhibit a 1 drms of less than 0.5 millimeter at the scale of the survey [Umbach, 1976]. Although this requirement is generally for 2 mHz phase comparision systems, it can be inferred that it also applies to other hyperblic systems such as LORAN-C. The scale routinely used for coastal surveys is between 1:40,000 and 1:80,000 [Umbach, 1976] yielding an allowable error of 20 to 40 meters not including systematic errors. Schnebele [1979] concluded that hyperbolic LORAN-C, after applying a single ASF Corrector, is unsuitable for basic hydrographic surveying.

Whether or not applying multiple Additional Secondary Factors (ASF) to LORAN-C lines of position will reduce the drms sufficiently to meet the accuracy standards set by the National Ocean Survey Hydrographic Manual will be ascertained in this study. The term multiple ASF Correctors refers to the application of more than one corrector to LORAN-C lines of position over a given area. The variable ASF Correctors result from varying delays of the electromagnetic wave as it propagates over different land segments.

Three methods of applying multiple ASF Correctors were tested. The first method was the application of a

Semi-Empirical Time Difference Grid Calibration Model developed by The Analytic Science Corporation [1979]. The sponsoring agency was the United States Coast Guard. The Semi-Empirical Model applies Secondary Factors and Additional Secondary Factors for each geodetic position based on the distance over land, the distance over water, and the total distance using mean sea water and land conductivities.

The second method which was investigated applies ASF Correctors found in the DMAHTC LORAN-C Correction Tables [DMAHTC, 1981] to LORAN-C lines of positions. These correctors were derived from the ground conductivities which have been determined in the field by a Coast Guard calibration team [U.S. Naval Oceanographic Office, 1982].

Finally, a third method was pursued. ASF Correctors, which were determined by field observations, were applied to the LORAN-C lines of position. These were determined by computing the difference between the observed LORAN-C rates and the expected time difference which was calculated using four lines of position from a very accurate microwave positioning system. These ASF Correctors were determined at five minute latitude and longitude intervals.

II. NATURE OF THE PROBLEM

A. THE PRINCIPLES OF LORAN-C

To understand the problems associated with LORAN-C when used during hydrographic operations, one must first understand its principles of operation. LORAN-C is a low frequency, pulsed signal, hyperbolic, radio navigation system, employing time difference measurements of signals received by the navigator from at least three ground transmitting stations [Speight, 1982]. The stations are comprised of a master transmitting station, two or more secondary transmitting stations which are strategically spaced several hundred miles apart and, if necessary, a System Area Moniter (SAM) Station [U.S. Coast Guard, 1974].

System Area Monitor (SAM) stations associated with each LORAN-C chain apply differential-type corrections to the rates in real-time. SAM stations continuously monitor the signals from all transmitters in the chain. If the oberved time difference deviates by more than 0.05 μsec from the expected value, then the appropriate secondary adjusts its emission delay time in order to remove the error [Schnebele, 1979].

The master and at least two secondary stations are located such that the signals from the transmitting stations can be received throughout the desired coverage area. The master station is designated by the letter "M" and the secondary stations or slave stations are designatied W, X, Y, or Z [.U.S. Coast Guard, 1974].

All stations transmit on the common frequency of 100 kHz. Interference between transmitters is avoided through the use of time separation [Poppe, 1982]. After the master

station transmits a pulse, each secondary station delays its own transmission for a fixed time, called the secondary coding delay. This coding delay is synchronized through the use of cesium frequency standards at each station. The high stability and accuracy of these standards permit each station to derive its own time of transmission without reference to another station [DMA, 1977]. Secondary coding delays are predetermined by system propagation times and equipment characteristics [Laurila, 1976].

The pulse from the master transmitter is distinguished from those of the secondaries through phase coding of the pulses. Phase coding refers to the inversion of the negative and positive peaks of the sine wave comprising the 100 kHz carrier portion of the pulse. The purpose of the phase coding is twofold:

> "First, it permits automatic discrimination between the master and the various secondary stations, thereby permitting all stations to be identified by their relative timing with respect to the master"

> "Second, the phase coding provides protection against excessively long skywave delays which would cause the late arrival of the preceeding pulse to coincide with the leading edge or groundwave portion of a pulse being tracked" [Poppe, 1982].

The signals are received by a mobile receiver where the differences in time of arrival of the master signal and various secondary signals are measured and displayed on the indicator portion of the LORAN-C set. The accuracy of this time difference is increased by phase comparision "of the synchronized 100 kHz carrier within the master and secondary pulses" [Laurila, 1976]. This measured time difference (TD - in microseconds) represents a hyperbolic Line of Position (LOP) [U.S. Coast Guard, 1974]. The intersection of two or

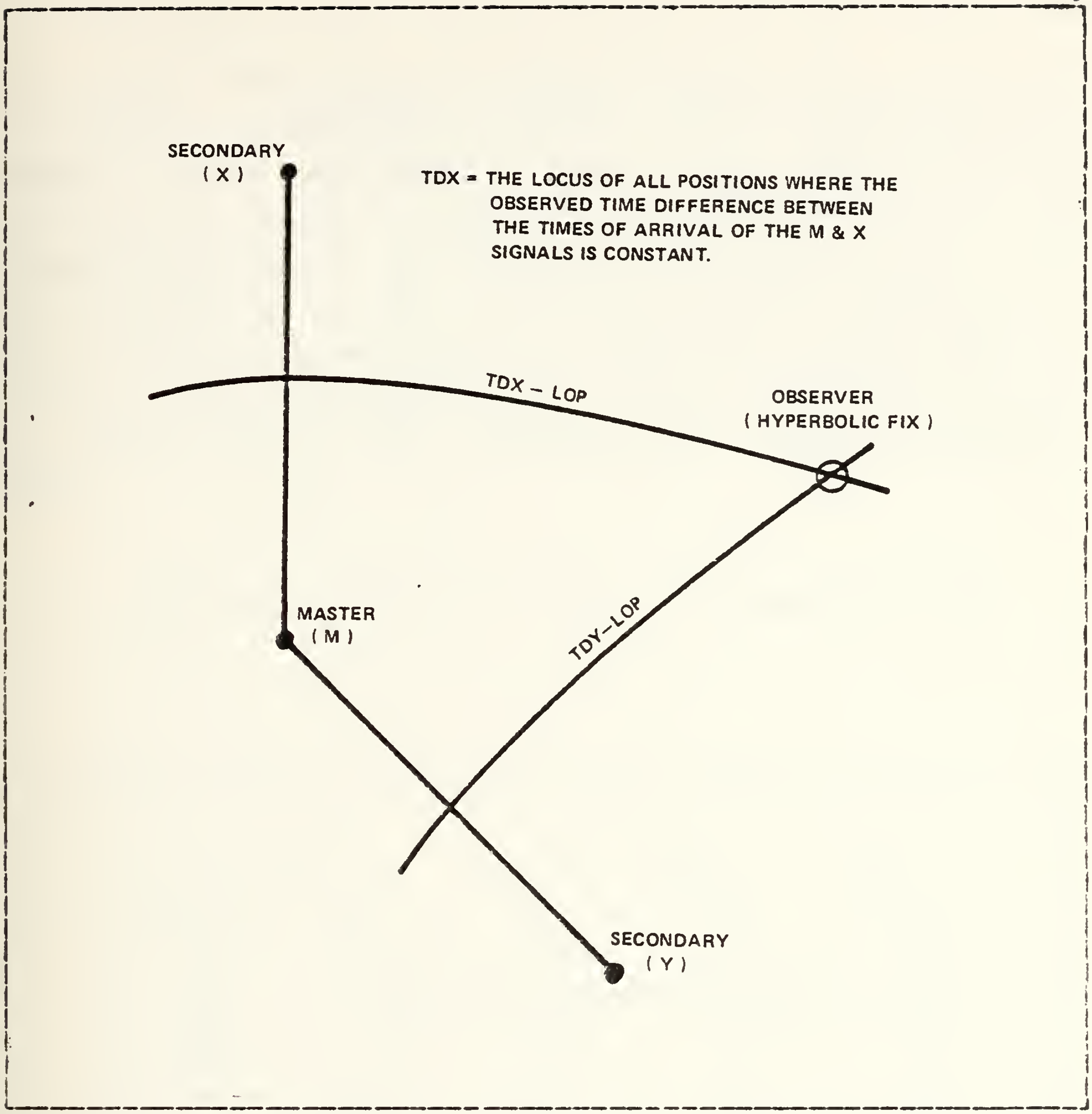

Figure 2.1 Hyperbolic Fix (From Coast Guard LORAN-C User Handbook, 1974)

more LORAN-C LOP's defines the position of the observer (Figure 2.1). When plotted on a chart, the intersection of the resultant hyperbolic lines defines a geographical position [Speight, 1982].

B. PHASE LAG

In a vacuum, the velocity of radiated energy from an antenna for LORAN-C is 299792.458 km/sec. Since radiated energy cannot be shown pictorially, the phase of the transmitted radiations is used. The lines of constant phase of the transmitted radiation are shown in Figure 2.2 by the curved lines labeled aa', bb', and other similar designations. They define the wave front as it proceeds outward from the antenna in all directions. The distance between each line of constant phase is one wavelength (λ) [Admiralty Manual, 1965].

$$\lambda \text{ (meters)} = 299792.458 \text{ km/sec} \div \text{frequency in kHz}$$

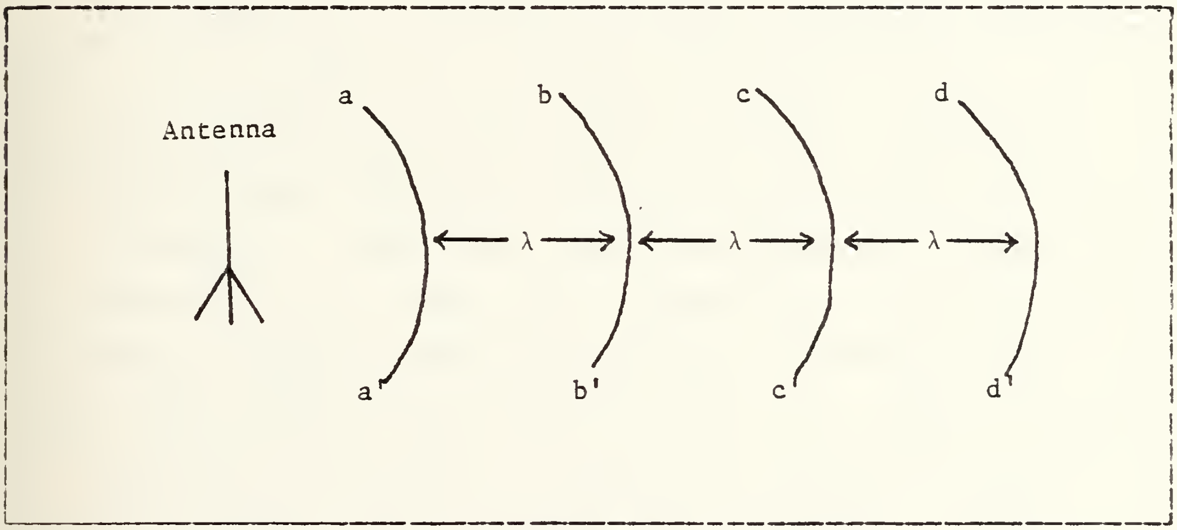

Figure 2.2 Transmitted Radiation

The velocity of the radiated energy in air depends on temperature, pressure, humidity, and the nature of the

surface over which the transmissions pass. The retardation of a transmitted wave is known as phase lag. When low frequencies are employed, such as LORAN-C at 100 kHz, the effects of change of temperature, pressure, and humidity are swamped by the effects caused by changes in the nature of the surface over which the transmissions are traveling [Admiralty Manual, 1965]. The General Electric Company, TEMPO division, conducted a LORAN-C Signal Analysis Experiment under the direction of the U.S. Coast Guard. This experiment was conducted along the U.S. West Coast. The General Electric Company recorded an overall change of 108 nsec and 116 nsec time of arrival from the master and X-secondary stations respectively after a storm [Samaddar, 1980]. If ASF Correctors are as large as two microseconds on the West Coast [DMAHTC, 1981] then the ASF Corrections are 20 times larger in magnitude than weather effects for the 9940 West Coast LORAN-C chain.

The change in transmission rates or phase lag are a result of the amount of energy transferred from the transmitted radiation. This energy transfer depends on the absorption qualities (inversely related to conductivity) of the surface over which they are passing and their wavelength (or frequency). The lower the conductivity and the longer the wavelength (or lower the frequency) the greater the transfer of energy, and vice versa. Seawater has a relatively high conductivity (5.0 mhos/meter). Land has a much lower conductivity, which varies from marsh (fairly high) to dry sand and rock (very low) [Admiralty Manual, 1965]. Two excellant papers that discuss the electrical properties of soil are those of Smith-Rose [1934] and Pressey, Ashwell, and Fowler [1956]. Smith-Rose [1934] found that the conductivities for soil ranged from 0.18 mhos/meter for a grey clay with salt to .00001 mhos/meter for granite.

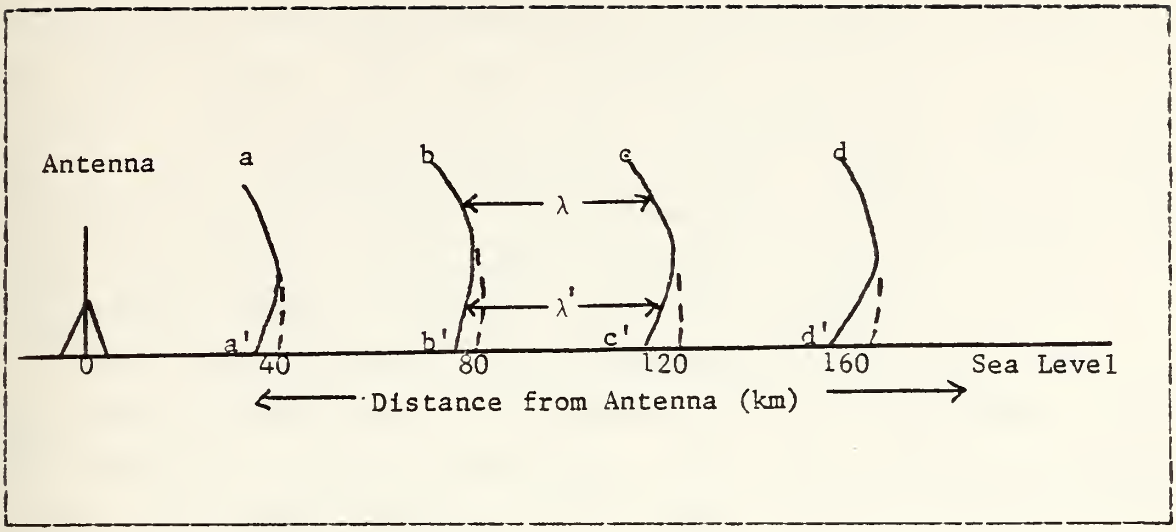

Figure 2.3 Phase Lag

Phase lag is illustrated in Figure 2.3. The lines of constant phase, aa', bb', and cc' become distorted as they progress along the sea surface. The dotted lines represent the position of the lines of constant phase in the absence of the sea surface. The wavelength (λ) in meters, measured at heights of several wavelengths above the sea, remains about the same as the direct wave through the earth's atmosphere at 299691 km/sec ÷ frequency in kHz. Near sea level the absorption of energy retards the progress of the wavefront, and makes the sea level wavelength (λ') less than λ. As the lines of constant phase progress away from the antenna the phase lag increases with distance. This is known as the Secondary Factor (SF) [Admiralty Manual, 1965].

The most intriguing feature of phase lag occurs at the coastal interface where there is an extreme change in the conductivites between land and sea. Visualizing the wave front in three dimensions, the lower part of the wave, slowed by the drag of the ground, lags further and further behind the upper part as the wave crosses the land. At the

coastline it suddenly encounters the much lower impedance of the sea, and in a very short distance the bottom of the wave tries to catch up with the top, as though the whole wave front were an elastic balloon. This is known as "phase recovery" [Eaton, 1979]. Phase recovery was verified during tests on Decca transmissions across the south coast of England by Pressey, Ashwell, and Fowler [1956].

The determination of the Secondary Factor for seawater is fairly direct since the conductivity of seawater (5.0 mhos/meter) is fairly constant. But for land the conductivity can vary depending on the type of soil and its water content [Smith-Rose, 1934].

Phase lag for radiated energy over land can be determined two ways:

1) Assign an average land conductivity to the ASF Model. For example, the average conductivity for the soil on the west coast is 0.003 mhos/meter. The average land conductivity will determine the average phase retardation of the path [The Analytic Science Corporation ,1979].

2) Determine every conductivity for each portion of a line segment from the transmitter to the receiver. The total of these conductivity segments constituting a land-water profile will determine the total phase retardation of the path [Speight, 1982].

C. TD MODEL

Positional fix accuracy using LORAN-C is primarily dependent on a chart makers ability to accurately compute the expected difference in time-of-arrival (TOA) of received groundwave signals from the transmitting stations. Time

differences (TD), are the differences between the TOAs of the secondary and master transmitters.

$$TD_i = TOA_i - TOA_m \tag{2.1}$$

i = Secondary Station
m = Master Station

TOA computations are dependent upon an accurate knowledge of the signal phase delay.

The phase delay of a groundwave signal is generally expressed as:

$$\Phi = T + SF \tag{2.2}$$

$$= \frac{nR}{C} + SF$$

where n is the surface refractive index, C is the speed of light in a vacuum, R is the range between the receiver position and the transmitting station. The primary phase delay, T, is the computed travel time of the LORAN-C pulse over a distance equal to the transmitter-to-receiver great circle path length, taking into account the velocity of electromagnetic waves and the index of refraction of the atmosphere. The secondary factor (SF) is a correction to the primary phase delay and accounts for the phase lag. The dominant term in (2.2) is the primary phase delay (T). The SF is usually an order of magnitude smaller [The Analytic Science Corporation, 1979].

Thus, time-of-arrivals can be expressed as:

$$TOA_i = T_i + SF_i + CD_i \tag{2.3}$$

$$TOA_m = T_m + SF_m \tag{2.4}$$

where CD is the true emission delay or coding delay for the LORAN-C chain [The Analytic Science Corporation, 1979]. The coding delay is equal to a time delay plus a computed one

way baseline time (Bc) which includes the secondary phase correction for an all seawater path. The oneway baseline time (Bc) is equal to the distance between the master and secondary transmitters in meters divided by the propagation velocity of LORAN-C through the earth's atmosphere (299.691 meters per microsecond [Navigation Department DMA, 1982]). See Table II for Coding Delay values for the 9940 chain

TABLE II

Coding Delay 9940 LORAN-C Chain

Pair 9940-W:	CD + Bc	=	11000	+ 2796.90	=	13796.90	µsec
9940-X:	CD + Bc	=	27000	+ 1094.49	=	28094.49	µsec
9940-Y:	CD + Bc	=	40000	+ 1967.27	=	41967,27	µsec

[Riordan, 1979]. Combining equations 2.1, 2.3, and 2.4, the true TD is given by equation 2.5 [The Analytic Science Corporation, 1979].

$$TD_i = (T_i - T_m) + (SF_i - SF_m) + CD_i \qquad (2.5)$$

D. SEMI-EMPIRICAL TD GRID CALIBRATION MODEL

The Semi-Empirical TD Model was developed by The Analytic Science Corporation [1979] in Reading, Massachusetts for the West Coast 9940 LORAN-C chain. Similar "time difference (TD) grid calibration techniques have been successfully employed to develop an accurate (approximately 100 nsec drms) calibrated grid for St. Marys River LORAN-C chain", [The Analytic Science Corporation, 1979].

1. Technical Approach

The Semi-Empirical Model is based on Millington's empirical approach for computing the secondary factor over a mixed (multiple-homogeneous segment) path which combines land and sea phase delays. The generalized semi-empirical polynomial functional form for the SF of the LORAN-C station is given by:

$$SF_j = SF(T_j, \beta_j) = \sum_{k=-K_1}^{K_2} A_k T_j^k + \sum_{l=1}^{L} (C_{jl} \sin l\beta_j + D_{jl} \cos l\beta_j) \quad (2.6)$$

where

j = secondary (W, X, or Y) or master (M) station,

$T_j = \frac{nR_j}{c}$ = jth station-to user primary phase delay,

R_j = jth station-to-user great-circle path length,

β_j = user path bearing angle at the jth station,

K_1, K_2 and L are positive integers,

C_{jl} and D_{jl} are the station-dependent coefficients of harmonic terms in the model,

A_k is the range-dependent coefficient of the model which may in general be station-dependent.

Data from 27 coastal sites distributed along the West Coast and 122 land-sea sites distributed in the Southern California CCZ (between Point Arguello and San Diego - see Figure 2.4) were used in a Kalman estimation algorithm to compute the uncertain coefficients of the land and sea models of the TD grid calibration algorithm. (An explanation of Kalman filtering for the layman is presented by Roger M. du Plessis [1967].) The calibrated algorithm

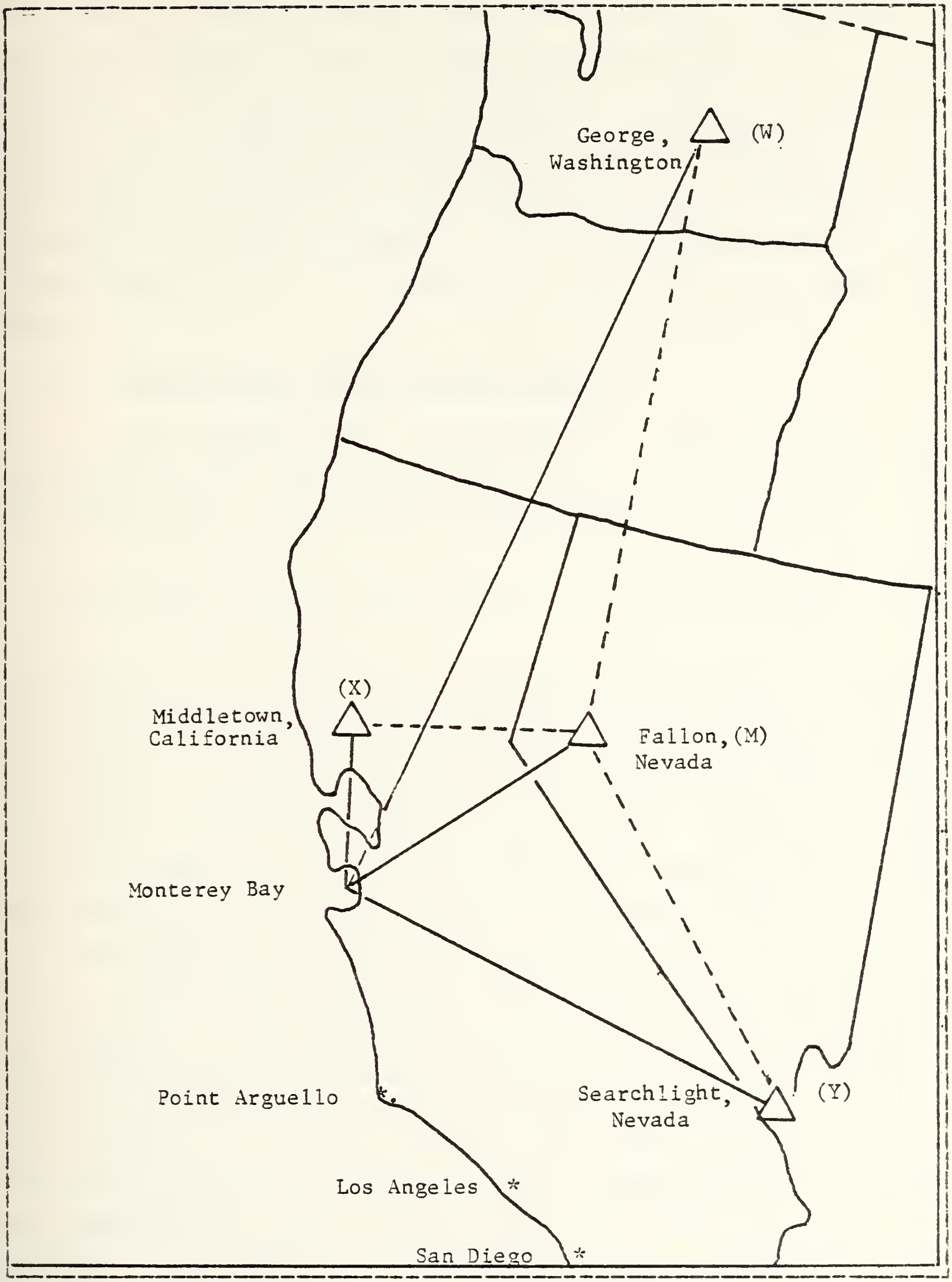

Figure 2.4 Location of West Coast LORAN-C Stations

was used to compute TDs at each data site and the TD residuals (difference between measured and calibrated TDs) were examined. Adjustments were then made to the TD model structure in an attempt to further reduce the residuals. This process of adjusting the model structure is repeated until the residuals agree with the expected theoretical covariance associated with the TD model. The model which exhibited the "best" performance was selected as the West Coast TD grid model.

2. Generalized Range/Bearing Model

The Generalized Range/Bearing (GRB) Model was selected as the "best" semi-empirical calibration model for the West Coast chain. The semi-empirical function is:

$$SF_j = A0 + A1T_j + \sum_{l=1}^{L} (C_{jl} \sin l\beta_j + D_{jl} \cos l\beta_j) \ \mu sec \qquad (2.7)$$

where A0, A1, C and D are the model coefficients, is the path bearing angle measured positive clockwise from north at the jth (W,X,Y or M) station and T is the path range to the jth station. The GRB model is relatively complex and is expected to exhibit superior performance. The extensive model is based on knowing the distance overland (TL), the distance over water (TS), the total distance (T), and the path bearing angle β (Figure 2.5).

It was noted that the calibrated model was expected to be accurate and applicable only over the extent of ranges and bearing angles embodied in the calibration data. Hence, outside the region covered by the calibration data the model may not be as accurate as within the data coverage region. Using the GRB model, a drms value of approximately 0.8 μsec was expected in areas where land data alone was used to calibrate the model. Inclusion of sea calibration data produced a drms value of 0.35 to 0.50 μsec.

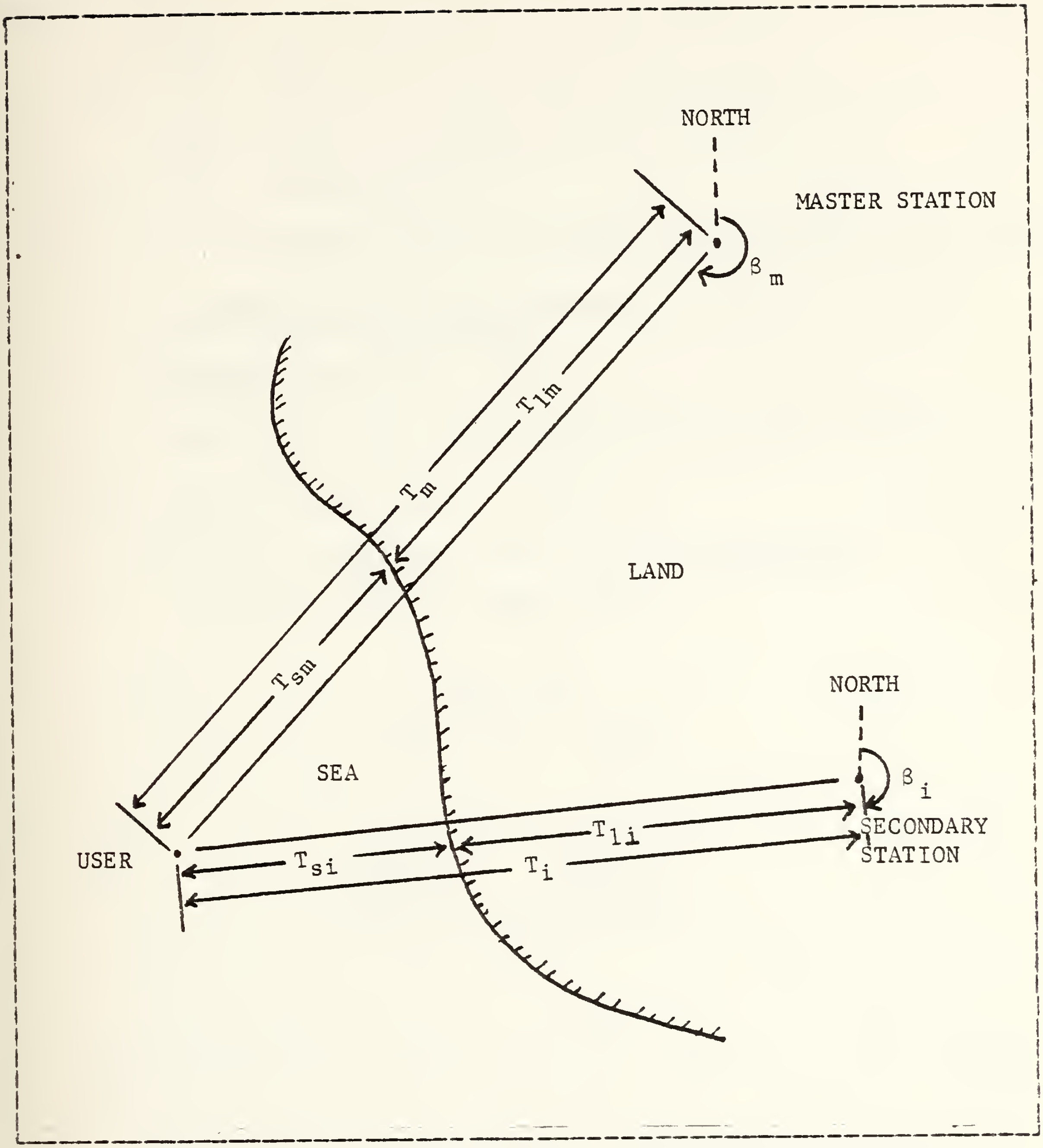

Figure 2.5 Mixed Path TD Geometry

The time difference (TD) is expressed by the following equation:

$$TD_i = (T_i - T_m) + (SF_i - SF_m) + CD_i + b_i \quad \mu sec \qquad (2.8)$$

where

$$T_i = \frac{n R_i}{c} \quad \mu sec,$$

$$T_m = \frac{n R_m}{c} \quad \mu sec,$$

R_i = ith secondary station-to-user great-circle path length,

c = the speed of an electromagnetic wave in a vacuum
= 2.99792458×10^8 m/sec,

n = surface refractive index
= 1.000338,

R_m = master station-to-user great-circle path length,

CD_i = coding delay found in Table II,

b_i = TD bias associated with the ith secondary station (µsec) (Table III).

TABLE III

TD Bias (b) - µsec

TDW	-0.854
TDX	-1.173
TDY	-0.353

$$SF_i = 0.5\ (-S1 + S2 + S3 - S4 + S5 + S6) \qquad (2.9)$$

The term S1 is the SF of a land path of length T_{sj} (µsec) from the jth station:

$$S1 = 0.795/T_{sj} + 0.439 + (0.00245)\ T_{sj} \quad \mu sec. \qquad (2.10)$$

The terms S2, S3, and S4 combine to make up the secondary factor for the seawater path lengths.

S2 is the SF for the total path. S3 is the SF using the seawater coefficients for the portion with seawater, and S4 is the SF using the seawater coefficients for the land path distance. The seawater coefficients are found in Table IV.

TABLE IV

Seawater Coefficients

a1	=	128.8
a2	=	0.187
a3	=	0.000652
b1	=	3.188
b2	=	-0.594
b3	=	0.000329

$$SF_s(T) = b1/T + b2 + (b3)\,T \quad \mu sec, \quad \text{if } 10 \le T \le 540 \quad \mu sec, \qquad (2.11a)$$

$$SF_s(T) = a1/T + a2 + (a3)\,T \quad \mu sec, \quad \text{if } T \ge 540\ \mu sec, \qquad (2.11b)$$

Term S5 and S6 are the SFs of land paths of length T_j and T_{lj}. SF5 is the Secondary Factor for the total length using the land coefficients whereas SF6 is the Secondary Factor for the distance over land using the land coefficients. The land coefficients are found in Table V.

$$S5 = SF_L(T_j, \beta_j),$$

$$S6 = SF_L(T_{Lj}, \beta_j),$$

where:

$$SF_L(T_j, \beta_j) = A0 + (A1)\,T_j + \sum_{l=1}^{2} (C_{jl} \sin l\beta_j + D_{jl} \cos l\beta_j) \qquad (2.12)$$

TABLE V

Land Coefficients

A0	=	1.428	D_{x2}	=	0.942
A1	=	0.00158	C_{y1}	=	0.0
C_{w1}	=	0.0	C_{y2}	=	0.588
C_{w2}	=	-0.711	D_{y1}	=	0.0
D_{w1}	=	0.323	D_{y2}	=	0.0
D_{w2}	=	0.0	C_{m1}	=	1.010
C_{x1}	=	0.0	C_{m2}	=	-0.196
C_{x2}	=	0.0	D_{m1}	=	-0.893
D_{x1}	=	0.0	D_{m2}	=	-0.355

E. DMAHTC MODEL

1. Sea SF Model

The equations for the Sea SF Model is:

$$SF = (B1/T) + B2 + (B3\ T)\ \text{usec, if } 10 \le T \le 537\ \mu\text{sec}, \quad (2.13a)$$

$$SF = (A1/T) + A2 + (A3\ T)\ \text{usec, if } T > 537\ \mu\text{sec}, \quad (2.13b)$$

where T is the primary phase delay (or range) in microseconds (usec); Ak and Bk (k = 1, 2, and 3) are the sea model coefficients used by DMAHTC in program TDGRID [Funakoshi, 1982]. The coefficients are found in Table VI.

2. Land SF Model

The solution used to resolve DMAHTC Tables ASF Corrections is called Millington's Method [DMAHTC, 1981].

TABLE VI

Sea SF Model Coefficients

A1	=	129.04323
A2	=	-0.40758
A3	=	0.00064576813
B1	=	2.741282
B2	=	-0.011402
B3	=	0.00032774815

This method is based on the premise that the phase distortion due to a composite land-sea path is the arithmetic average of the phase distortion found in the forward and reverse paths of the propagated signal [DMAHTC, 1981]. For example, in Figure 2.6 two azimuths have been drawn on the map and are labeled as 210° and 235°. Also placed on the map are the proper ground conductivities which have been determined in the field by the Coast Guard calibration team. A great circle drawn on the appropriate chart or charts from the LORAN-C Station coordinates to the area under consideration spans various lengths of land and seawater. Each length or segment will have a specific conductivity and distance. The total of these conductivity segments, constituting a land-water profile, will determine the total phase retardation along that path [U.S. Naval Oceanographic Office, 1982]. All azimuths and distances are computed based on the World Geodetic System (WGS) datum [DMAHTC, 1981]. The values of phase retardation for a given ground conductivity are tabulated in the National Bureau of Standards (NBS) Circular 573 [Speight, 1982].

The formula used to derive the ASF Correction for the time difference for a master-slave transmitting station pair is:

ASF Correction = (-Slave Error) - (-Master Error)

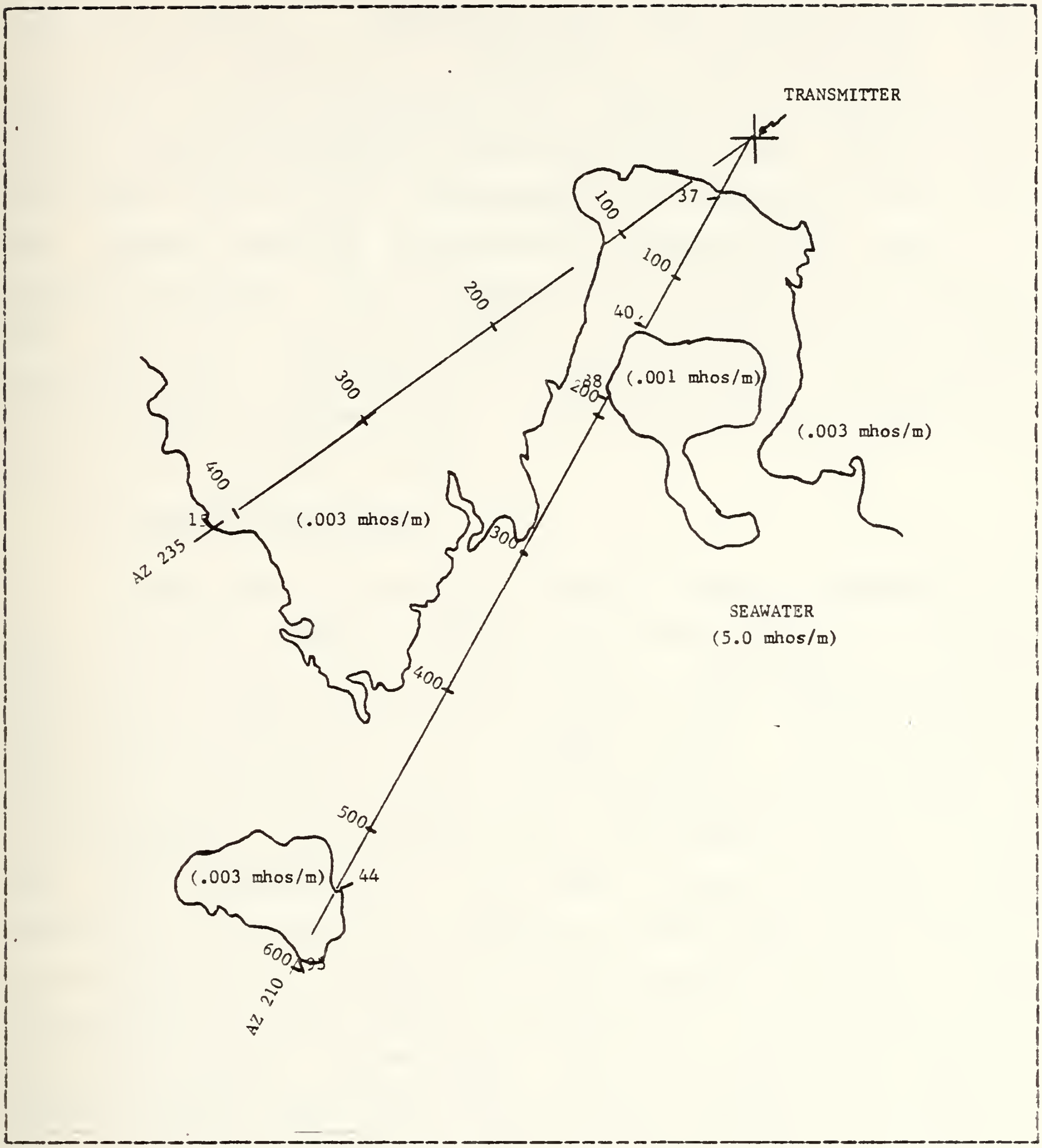

Figure 2.6 Composite Land-Sea Path

The mean values derived for one station from the forward and reverse solution of Millington's Method are subtracted from the Sea SF Model. The differences are

presented in an azimuth array. This array is a series of geodetic azimuths radiating from the transmitter with corrections computed at incremented distances along each azimuth. After the values are computed in the azimuthal array a computer program rearranges them into a matrix form. The matrix form is the arrangement of corrections into rows and columns covering a specified geographical area at a constant spacing. The purpose of the matrix is to enable the corrections from two LORAN-C transmitters to be added algebraically, combined into a single matrix, and arranged in the desired tabular form. This tabular form is the body of the table [DMAHTC, 1981].

3. <u>Table Description</u>

Each table contains a complete chain. Figures 2.5, 2.6, and 2.7 depict LORAN-C ASF Correctors for chains 9940-W, X, and Y for Monterey Bay, California. A table section is prepared for each station pair (master station and one slave station) in a LORAN-C chain. As a rule the limits of the table coverage are determined by the range of the groundwave transmissions for the LORAN-C chain. Each page of corrections in the table covers an area three degrees in latitude by one degree of longitude, with corrections printed in increments of five minutes of arc. Rate designation and page numbers are printed at the top of each correction page. Those pages where latitude and longitude limits contain both land and sea are included but corrections apply only for the area covered by the U.S. Coastal Confluence Zone (CCZ). Large land bodies and areas ouside the CCZ are represented by blank spaces on the page. ASF correction values can be either positive or negative (positive values are shown without sign). Areas requiring no correction show a zero value which in some cases in preceded

LATITUDE NORTH	LONGITUDE WEST												
	122° 0'	55	50	45	40	35	30	25	20	15	10	5	121° 0'
39° 0'													
55													
50													
45													
40													
35													
30													
25													
20													
15													
10													
5													
38° 0'													
55													
50													
45													
40													
35													
30													
25													
20													
15													
10													
5													
37° 0'													
55	-1.6	-1.6											
50	-1.6	-1.5	-1.4										
45	-1.5	-1.4	-1.6										
40	-1.4	-1.3	-1.5										
35	-1.3												
30	-1.4												
25	-1.4	-1.5											
20	-1.2	-1.1											
15	-1.4	-1.3	-1.6										
10	-1.3	-1.3	-1.7	-1.7									
5	-1.3	-1.4	-1.7	-1.7	-1.8								
36° 0'	-1.2	-1.6	-1.6	-1.7	-1.7	-1.7	-1.8						

Figure 2.7 9940-W ASF Correction Table

by a negative sign indicating that the zero results from the rounding off of a value slightly less than zero (indicates the trend of the correction).

LATITUDE NORTH	LONGITUDE WEST 122° 0'	55	50	45	40	35	30	25	20	15	10	5	121° 0'
39° 0'													
55													
50													
45													
40													
35													
30													
25													
20													
15													
10													
5													
38° 0'													
55													
50													
45													
40													
35													
30													
25													
20													
15													
10													
5													
37° 0'													
55	0.9	0.9											
50	0.9	0.9	0.8										
45	1.0	1.0	1.0										
40	1.0	1.2	1.1										
35	1.1												
30	1.0												
25	1.1	1.0											
20	1.3	1.4											
15	1.2	1.3	1.1										
10	1.3	1.3	1.0	1.0									
5	1.3	1.3	1.1	1.1	0.9								
36° 0'	1.3	1.3	1.2	1.2	1.0	1.0	0.7						

Figure 2.8 9940-X ASF Correction Table

The table can be entered directly by using the ship's position determined to the nearest five minutes of arc in latitude and longitude either by dead reckoning or

LATITUDE NORTH	LONGITUDE WEST 122° 0'	55	50	45	40	35	30	25	20	15	10	5	121° 0'
39° 0'													
55													
50													
45													
40													
35													
30													
25													
20													
15													
10													
5													
38° 0'													
55													
50													
45													
40													
35													
30													
25													
20													
15													
10													
5													
37° 0'													
55	-0.2	-0.2											
50	-0.3	-0.3	-0.3										
45	-0.3	-0.2	-0.4										
40	-0.4	-0.3	-0.6										
35	-0.5												
30	-0.7												
25	-0.6	-0.8											
20	-0.5	-0.6											
15	-0.4	-0.3	-0.3										
10	-0.2	-0.2	-0.2	-0.2									
5	-0.1	-0.1	-0.1	-0.1	-0.2								
36° 0'	0.0	0.0	0.0	0.1	-0.1	0.0	0.0						

Figure 2.9 9940-Y ASF Correction Table

some other means. To find the page with the appropriate correction, the Page Indexes of the table should be utilized. These indexes show the limits and page number of

all pages in the table. To locate the number of the page on which the desired correction is to be found the Page Index is entered with the ship's position. In some cases the ship's position will fall on the page limit in either latitude or longitude or both. These positions are repeated on both pages and either page may be used.

The ASF Correction is added algebraically to the time difference for the LORAN-C pair. Interpolation of this data will not necessarily improve the accuracy due to the method used to determine ASF Correctors [DMAHTC, 1981]. Since the correctors are computed in the azimuthal array and are based on the conductivity and distance over which the LORAN-C electromagnetic wave travels, the ASF Corrector between the published ASF Correctors in the tables may not be the linear interpolated values. For example, the ASF Corrector for a distance of 500 m with an azimuth of 180° is equal to 1.5 μsec. The ASF corrector for a distance of 500 m with an azimuth of 181° is equal to 1.6 μsec. The interpolated value between 1.5 and 1.6 is 1.55. The true ASF Corrector for the 180° 30' azimuth is 1.4 since the land distance for the same azimuth is less than the land distance for the 180° and 181° azimuth. The LORAN-C signal passed over a harbor [Dansford, 1982].

F. ATTEMPTED DETERMINATION OF ASF CORRECTORS BY HYDRO FIELD PARTIES

One of the major problems encountered by hydrographic survey operating units when using LORAN-C for position control is the determination of the ASF Correctors for the survey area. The four surveys mentioned in the Introduction all made attempts to determine the correctors by comparing the LORAN-C rates to a second source.

Bathymetric Surveys H-9822 [NOAA H-9822, 1979] and H-9823 [NOAA H-9823, 1979] Gulf of Alaska, compared the rates from an Internav LC-204 LORAN receiver to computed rates from a position obtained from a JMR-1 Satellite Navigation Receiver when available. Shore ties using radar ranges, visual bearings, and sextant angles in comparison to LORAN-C rates were also made prior to and after each survey. The calibrations of LORAN-C rates were based on the satellite positions only since the positional computation of LORAN-C and JMR Doppler Satellite were made on the WGS 1972 datum whereas the land ties were based on the NAD 1927 datum.

Bathymetric survey SU-40-7-82 which extended along the Washington, Oregon, and California Coasts used LORAN-C as navigational control. LORAN-C time differences were compared with SATNAV positions. The report did not indicate whether any correctors were applied [NOAA Ship Surveyor, 1982].

Finally, Hydrographic Survey S-K902-Wh-82, Reconnaissance Survey of Safety Fairways, Gulf of Mexico used LORAN-C as a positioning control system. The positioning unit was an LC-204 receiver. LORAN-C rates were input via the HYDROPLOT Controller, a special purpose input-output interface which is the nucleus of the computer system hardware [Umbach, 1976]. Positions were computed and plotted by Program RK121, LORAN-C Real-Time HYDROPLOT [Backus, 1980].

ASF Correctors for LORAN-C were achieved by visual calibration using three point sextant fixes using charted oil rigs as control in the vicinity of the survey area. A three-point sextant fix is a convenient and accurate method for determining the position of a hydrographic survey vessel. Sextants are used to measure two angles between

three objects of known geographic positon. The center object is common to both angles. The position of the observers taking the angles is fixed by the intersection of three circular lines of position [Umbach, 1976].

These sextant angles were recorded and later tranferred onto their respective charts using a plastic three-arm protractor. A plastic three-arm protractor is transparent and made up of one fixed arm and two movable arms which contain an etched line that is radial with the center of the protractor [Umbach, 1976]. Sextant angles observed in pairs for a resection fix with a common center mark may be plotted directly by this instrument. When the three arms are placed at the angles observed and fitted so as to pass through the plotted positions of the observed stations on the field sheet, the hole at the center of the three-arm protractor is the fixed positon of the vessel [Ingham, 1975].

Partial correctors for each area surveyed were defined by comparing the observed rates and the determined rates plotted on the nautical chart. The partial correctors were applied via the HYDROPLOT Controller. However, even after applying these correctors, the plotted position still disagreed with the ship's determined postion with respect to the oil rigs. Ship's personnel attributed the discrepancies to one or more of the following:

1) Accuracy of the charted rigs,
2) Weather effect on LORAN-C,
3) Time of day,
4) Propagation of signal over land path,
5) Three-arm protractor accuracy, and
6) Error in the conversion by the software of the LORAN-C rates to latitude and longitude [NOAA, 1982].

There is an apparent need for a LORAN-C calibration routine aboard NOAA ships which provides the ASF Correctors for program RK121, LORAN-C Real-Time HYDROPLOT. The routine should use the same geodetic distance computation found in RK121 and use the same datum as that of the nautical chart of the survey area.

The above mentioned discrepancies illustrate the deficiencies in applying a single ASF Corrector to LORAN-C data. The accuracies for hydrography cannot be met using single correctors because the errors are non-linear and systematic. They cannot be distributed like residuals in a traverse. Schnebele [1979] has already proven that single ASF area correctors to LORAN-C positions do not meet the accuracy standards of the NOS Hydrographic Manual.

Based on visual inspection of the DMAHTC LORAN-C Correction Tables, ASF Correctors should be updated every five minutes of Latitude or Longitude change. In Monterey Bay, California, there is approximately 0.1 to 0.2 μsec difference for every five minutes of change, a potential error of 55 to 110 meters.

III. EXPERIMENTAL PROCEDURE

A. FIELD PROCEDURES

In order to compare the use of differential LORAN-C with ASF multiple correctors, typical survey operations were planned for the southern portion of Monterey Bay, California. This survey was conducted in conjunction with a comparative evaluation of multiple lines of positon for selective positioning methods [Anderson, 1982]. Four microwave ranging systems were set on known geographic positions

TABLE VII

Geographic Names and Positions

Microwave System Stations	Geographic Position (NAD 1927)	Dates used.
Seaside 4 (1964)	36° 36' 23.44596" 121° 51' 38.83281"	June 3-5,1982
Use Mon Ecc.	36° 36' 04.73031" 121° 52' 35.98040"	June 3-5,1982
Geoceiver Ecc.	36° 36' 32.49281" 121° 53' 25.21162"	June 3-5,1982
Mussel Ecc.	36° 36' 18.25484" 121° 54' 11.49661"	June 3-5,1982
Park (1931)	36° 53' 13.30600" 121° 49' 46.74300"	June 6-7,1982
Mulligan RM1	36° 44' 56.49531" 121° 47' 52.31090"	June 6-7,1982
Range 7 (1972)	36° 39' 02.47787" 121° 49' 08.58202"	June 6-7,1982
Mussel (1932)	36° 37' 18.15100" 121° 54' 11.49661"	June 6-7,1982

listed in Table VII. A series of tracklines were run in two separate areas as shown on Figure 3.1. To ensure that the microwave postioning system was working properly, the equipment was calibrated over known baselines of 1497.47 meters and 7877.31 meters at the beginning and end of the project. Trackline observations were only made during the daytime in fair weather conditions so as to eliminate sky waves and weather changes that influence LORAN-C signal propagation characteristics [Samaddar, 1982]. The vessel used was the 126 foot R/V Acania which is operated by the Naval Postgraduate School.

The positioning equipment consisted of a Micrologic ML-1000 LORAN-C receiver (0.01 usec resolution) and a Trisponder Microwave System provided by Racal-DECCA Survey, Inc. The Trisponder Microwave System consisted of four DNT1 Model 217C transponders, four DNT1 Model 21017 HP sector antennas with 87° by 5° beam widths, one DNT1 DDMU (Digital Distance Measuring Unit), two Omni DVTI Model 21019 HP antennas, a Houston Instruments Model DP3-M2D/RC3 plotter, and a Texas Instruments 743 terminal (Table VIII). The manufacturer's published accuracy for the positioning equipment is ± 1 m for a single range [Racal-DECCA Survey, 1981]. Anderson [1982] discusses the accuracy of four lines of position. The four Decca Trisponder distances were recorded via a Texas Instruments 743 data terminal while the LORAN-C rates were manually logged. The data was acquired at one minute intervals while the ship maintained constant course and speed. The recorded LORAN-C rates were 9940-W, X, and Y of the West Coast chain.

To test the potential for calibrating the LORAN-C System using the Semi-Empirical Model, the correction tables, and multiple observed field correctors, the positions derived from the microwave system measurements were used to compute

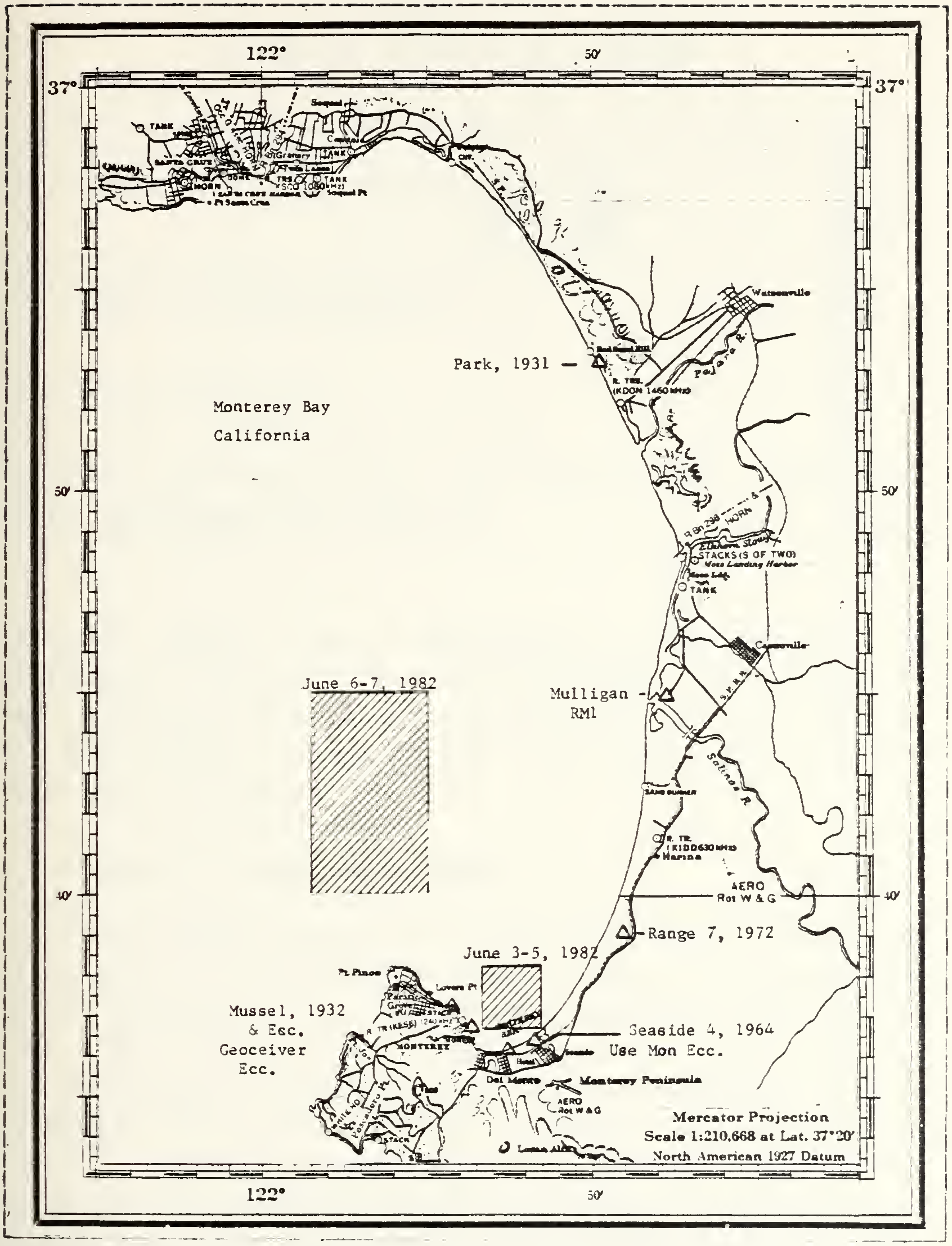

Figure 3.1 Location of Test Areas in Monterey Bay

TABLE VIII

Microwave Positioning Equipment

Equipment		S/N
DNT1 Model 217C Transponders	(Code 72R)	3323
	(Code 74R)	3320
	(Code 76R)	3321
	(Code 78R)	3322
DNT1 Model 2107 HP Sector Antenna (87° by 5° Beam Widths)		185
		186
		187
		191
DNT1 DDMV Model 540		426
Omni, DNT1 Antenna Model 21019 HP		194
		200
Houston Instruments Plotter Model DP3-M2D/RC3		10722-10
Texas Instruments 743 Terminal		34418

expected LORAN-C time differences at each point. The difference or offset between these expected time differences and the observed values were computed for the three methods. The mean offset, standard error, and drms values were also computed and compared.

B. MICROWAVE SYSTEM POSITIONING

The geographic position of the ship based on four lines of position was determined using a computer program called GPBYLQ (Geographic Position by Least Squares) written by the author (See Appendix A). GPBYLQ contains subroutine LSQR (Least Squares), which is a least squares adjustment written by Paul R. Wolf, Ph.D. [1974] and revised by LCDR D. Leath [1981]. Geographic postions were converted to X,Y (meters) which in turn were converted to geographic position via subroutines GPTOXY and XYTOGP, respectively [Wallace, 1974].

Subroutine GPTOXY and XYTOGP are based on the Modified Transverse Mercator Grid which was centered in the survey area.

The Modified Transverse Mercator (MTM) projection is used by the National Ocean Survey and is similar to the projection used in the Universal Transverse Mercator (UTM) system. The main difference is that in the MTM a Central Meridian is picked that is near the survey area instead of being fixed at a particular meridian [Wallace, 1971]. Central Meridian (CMER), False Easting (FEST), and Controlling Latitude (CLAT) are the three parameters which define the MTM projection. CMER is the mean longitude computed using the maximum and minimum longitudes of the survey limits, FEST is the X-Coordinate that is assigned to the Central Meridian, and CLAT is the distance in meters from the equator to some reference latitude [Wallace, 1971]. The Central Meridian, False Easting, and Controlling Latitude used for Monterey Bay, California referenced to NOS Chart 18685 are:

CMER = 121° 56' 00.0",

FEST = 20000.0,

CLAT = 4050000.0,

To be consistent with the National Ocean Survey charts of the area, all computations were done relative to North American Datum (NAD) 1927 geographic positions. All programs were executed on an IBM 3033 computer located at W.R. Church Computer Center, Naval Postgraduate School, Monterey, California.

C. LORAN-C COMPUTATIONS

The differences or offset between the observed and computed LORAN-C rates using the Semi-Empirical TD Model, ASF LORAN-C Correction Tables, or the Multiple Observed

TABLE IX

LORAN-C 9940 Chain Data

Station	Geographic Position (NAD 1927)
Master - Fallon, Nevada	39° 33' 07.03"N 118° 49' 52.23"W
Slave - George, Washington 9940-W	47° 03' 48.82"N 119° 44' 34.78"W
Slave - Middletown, California 9940-X	38° 46' 57.49"N 122° 29' 40.04"W
Slave - Searchlight, Nevada 9940-Y	35° 19' 18.32"N 114° 48' 13.95'W

Correctors were compared to the offsets between the observed TD rates and the computed rates for which only the seawater Secondary Factors (SF) were applied. The comparison of the offsets between the four methods illustrates the improvement in positional accuracy after applying ASF Correctors.

1. Seawater Secondary Factors (SF)

Time differences using only the seawater Secondary Factors for each of the geographic positions were computed using program LORAN written by the author (Appendix C). Seawater Secondary Factors (SF) were computed using formula 2.13 and the coeffecients found in Table VI. All TOA distances in meters were determined using subroutine INVER1. INVER1 is a geodetic inverse routine using T. Vincenty's modified Rainsford's method with Helmert's elliptical terms, programed by LCDR L. Pfeifer, NOAA [1975]. Subroutine INVER1 is accurate to 0.0001 m halfway around the world [Pfeifer, 1982]. All distances were converted to microseconds using 299.792458 m/μsec. Time differences (TD) were

computed from equation 2.5. North American Datum 1927 geographic positions were used for all computations. See Table IX for the positions of LORAN-C 9940 transmitters [Riordan, 1979].

To ensure that subroutine INVER1 was functioning properly the distances between the master and secondary stations were compared to the NOS published baseline distance [Riordan, 1979]. The published distances and the results from routine INVER1 are listed below.

	Published Baseline Distance (m)	Computed Baseline Distance - INVER1 (m)
9940-W	837,777.0929	837,777.115
9940-X	327,886.3720	327,886.316
9940-Y	589,298.5712	589,298.589

The difference between the published and computed baselines ranged from 0.02 to 0.06 m.

Differences or offsets (x_i) were obtained by subtracting the observed LORAN-C rates from the computed values from the various methods. The mean difference or offset ($\bar{x}$) and standard deviation (s) in microseconds for each rate were determined using equations 3.1 and 3.2 [Wonnacott, 1935]:

Mean offset (μsec): $$\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i \qquad (3.1)$$

where: x_i = original observation in usec,

n = number of observations;

Standard error: (μsec) $$s = \frac{1}{n-1} \sum_{i=1}^{n} (x_i - \bar{x})^2. \qquad (3.2)$$

The mean offset in microseconds can be converted to meters using equation 3.3 [Heinzen, 1977]:

$$\text{Mean offset (meters):} \qquad l = \frac{\bar{x}\ w}{\sin \alpha} \tag{3.3}$$

where w = distance corresponding to one microsecond on the baseline = 149.896229 meters [Bigelow, 1963].

α = one-half the angle between the radius vectors from the position to the master and secondary stations.

Equation 3.4 was used to compute drms values in meters [Heinzen, 1977]:

$$\text{drms} = \frac{1}{\sin({}_1 + {}_2)} \sqrt{\frac{(s_1 w)^2}{\sin^2 \alpha_1} + \frac{(s_2 w)^2}{\sin^2 \alpha_2} + \frac{2\rho\cos(\alpha_1 + \alpha_2)\ s_1 w\ s_2 w}{(\sin\alpha_1)\ (\sin\alpha_2)}} \tag{3.4}$$

where: ρ = correlation coefficient = 0.33,

s and α are as above with the subscript denoting the appropriate secondary station.

The correlation coefficient (ρ) is a result of the secondary station having a common line of position with the master station. Although often ignored, various authors assign values ranging from 0.33 to 0.40. Bigelow [1963] chooses ρ = 0.33.

2. Semi-Empirical TD Grid

To determine if the Semi-Empirical TD Grid would reduce either the drms value or the offset between the observed and expected TD rates, program LOPLC (Line of Position - LORAN-C) was written by the author (Appendix B). Program LOPLC computes the distance over land, distance over water, the total distance, and the azimuth from north for the transmitting station using Subroutine INVER1. The

land-sea distances were computed by selecting a point which was located along the coast of Monterey Bay. Subroutine SHORPT (Shore Point) interpolated a geodetic position from 23 geodetic points which outlined Monterey Bay, California. The land/sea Secondary Factor was determined in Subroutine SECFAC which is found in program LOPLC using equations 2.8 through 2.12. All computations were based on NAD 1927 geodetic datum.

Tests were made on program LOPLC using data found in the Semi-Empirical TD Grid article [The Analytic Science Corporation, 1979] using the WGS 1972 datum. Station TASC 55 located at latitude 34° 34' 18.3" N and longitude 120° 39' 40.3" W, was selected from The Analytic Science Corporation article. It was one of the stations used to calibrate the coefficients for the Semi-Empirical TD equations discussed earlier. The only distances listed for TASC 55 were the individual distances over land and over water. The total distance between the transmitters and TASC 55 was computed by adding the land and sea distances. The following station-to-site path segment lengths are listed for TASC 55:

Station	Land Distance (km)	Sea Distance (km)	TASC 55 Total Distance (km)	INVER1 Total Distance (km)
Master	540.730	35.548	576.278	576.083
X-Secondary	369.248	126.096	495.344	495.178
Y-Secondary	525.659	15.832	541.491	541.308

Using the land distances, sea distance, and total distances to TASC 55, and the computed azimth from subroutine INVER1, program LOPLC produced offsets of 0.86 μsec and 1.13 μsec for 9940-X and 9940-Y respectively when compared to the expected time differences at TASC 55.

An attempt was made to determine if this discrepency was due to program LOPLC. A comparison of the total distances in the report between the transmitters and TASC 55 were compared to the total distances computed by INVER1. The difference in distance between Subroutine INVER1 and the total distances from the Semi-Empirical TD Grid acticle ranged from 160 - 200 m corresponding to 0.5 to 0.65 usec. This results in time difference errors of 0.04 usec for the 9940-X rate and a 0.10 μsec for the 9940-Y rate, implying that the offsets, 0.86 μsec and 1.13 μsec, are caused in part by the method in which the azimuth from north is determined. Unfortunately, azimuth data from TASC 55 was not presented in the article. The Analytic Science Corporation has been contacted on numerous occasions in an attempt to ascertain their method of determining distance and azimuth. As of this date there has been no response.

Nevertheless, the data from Monterey Bay was utilized in Program LOPLC to obtain results that could be compared to that obtained by the other methods. If this method is accurate enough, ASF Correctors could be determined via computer for each individual position without using tables or field determined correctors. The mean offset ($\bar{x}$) and standard error (s) in microseconds between the observed and calculated rates were computed using equations 3.1 and 3.2, respectively. The mean offset (l) and drms in meters were computed using equation 3.3 and 3.4, respectively.

3. Calculated Table ASF Correctors

The offset between the observed LORAN-C rates and the expected values with applied ASF Correctors from the LORAN-C Correction Tables and the seawater Secondary Factor (equation 2.13) were determined using program LORTAB which

was written by the author (Appendix D). The ASF Corrector for each position was selected using subroutine TABLE. Subroutine TABLE, which is found in program LORTAB determines an ASF Corrector for each data point based on its geodetic position. The ASF Correctors used in subroutine TABLE (see Figures 2.5, 2.6, and 2.7) are located between latitude 36° 35' N and 36° 55'N and longitude 121° 50' W and 122° 00' W. The difference in sign between the ASF Correctors in subroutine TABLE and those found in the LORAN-C Correction Table is due to the difference in their application. ASF Correctors from the tables are applied to observed rates while ASF Correctors from Subroutine TABLE are applied to the calculated LORAN-C rates. Negative ASF Correctors from the LORAN-C Correction Table were applied to the calculated time differences to be consistent with the application of Secondary Factors to the computed primary phase delay.

As before equations 3.1 through 3.4 were used to compute the the mean offset, standard error, and drms. If this application of LORAN-C Correction Tables is accurate enough, it precludes the need to determine ASF Correctors in the field.

4. Observed ASF Correctors

Observed ASF Correctors were determined using Program ASFSEL (ASF Selection) which was written by the author (Appendix E), Schnebele's prior data [1979], and the June 1982 data. Program ASFSEL (ASF Selection) was written by the author. This program computes the ASF Correctors by subtracting the observed LORAN-C rates from the expected values. Only the seawater Secondary Factors from equation 2.13 have been applied to the calculated time differences.

The mean ASF Correctors for the LORAN-C rates were determined at every minute of latitude and longitude between 36° 50' N and 36° 35' N and 122° 04'W and 122° 49' W. See Appendix E for mean ASF Correctors at one minute intervals. The ASF Correctors were then selected and assigned to subroutine TABLE in Program LORTAB at five minute latitude and longitude intervals. All values were entered to the nearest hundredth of a microsecond. Equations 3.1 through 3.4 were used as before for computations. This determination of ASF Correctors in the field, if accurate enough, may allow the use of LORAN-C as a positioning system for hydrographic surveying in the future.

IV. RESULTS

A total of 620 time differences (TD) and geographic positions based on four lines of position were recorded in the southern portion of Montery Bay in order to compare the use of differential LORAN-C with ASF Multiple Correctors. The data was divided into four sets. The first data set is Schnebele's [1979] prior data consisting of a total of 130 data points collected on two separate days, June 12 and July 25, 1979 between latitude 36° 38' N and 36° 47' N and longitude 121° 49' W and 122° 02' W. The recorded LORAN-C time difference rates were 9940-Y and 9940-W.

The second data set consists of 193 time differences collected on June 7, 1982. The recorded LORAN-C rates were also 9940-Y and 9940-W. Data set Number 2 is located between latitude 36° 40' N and 36° 45' N and longitude 121° 54' W and 122° 00'W. See Figure 3.1 for the location of test areas in Monterey Bay, California.

Data set Number 3 is located in the same area as data set Number 2, between latitude 36° 40' N and 36° 45' N and longitude 121° W 54' and 122° 00' W. This set, consisting of 128 points with recorded rates 9940-X and 9940-Y, was recorded on June 6, 1982.

The final set, data set Number 4 was recorded between June 3 and June 5, 1982. It contains 169 points located between latitude 36° 36 N and 36° 39' N and longitude 121° 53' W and 121° 58' W. The recorded rates were 9940 -X and 9940-Y which are the same as data set three. The data for rates 9940-X and 9940-Y was kept separate so as to determine if there was a significant difference between the offshore (data set three) and inshore (data set four) drms values due to phase recovery (see Chapter Two).

TABLE X

Data Set Parameter

Set Number	Collection Date	TD Rates	Number of Data Points	Area Limits Lat	Lon
1	June 12, 1979 July 25, 1979	9940-Y 9940-W	130	36/38 36/47	121/49 122/02
2	June 7, 1982	9940-Y 9940-W	193	36/40 36/45	121/54 122/00
3	June 6, 1982	9940-X 9940-Y	128	36/40 36/45	121/54 122/00
4	June 5, 1982	9940-X 9940-Y	169	36/36 36/39	121/53 121/58

Table X provides a convenient breakdown of the parameters for each of the data sets. The table consists of the data set number, the date the data was collected, the LORAN-C time difference rates, the number of data points, and the area limits in latitude and longitude. It defines the parameters for the four data sets of Tables XI (Seawater Secondary Factor Errors), XII (Semi-Empirical TD Grid Correction Errors), XIII (Multiple LORAN-C Correction Table Errors), and XIV (Multiple Observed Correction Errors). All basic data and computations are kept on file with the NOAA hydrography instructor at the Naval Postgraduate School, Monterey, California. (Individuals seeking this information should contact the Oceanography Department.)

A. SEAWATER SECONDARY FACTORS

LORAN-C rates were computed using only the seawater Secondary Factor (equation 2.13). The LORAN-C computed time differences are basically uncorrected rates since no Additional Secondary Factors were applied. Offsets between

TABLE XI

Seawater Secondary Factor Errors

Rates	Mean Offset (x-µsec)	Mean Offset (l-m)	Standard Error (s-µsec)	drms (m)
a) Set 1 (Schnebele's data, 130 data points)				
Y	-0.508	-148.636	0.088	110.4
W	-1.241	-683.693	0.134	
b) Set 2 (June 7, 1982, 193 data points)				
Y	-0.526	-154.295	0.077	101.3
W	-1.283	-701.947	0.124	
c) Set 3 (June 6, 1982, 128 data points)				
X	1.565	535.449	0.059	38.6
Y	-0.550	-161.404	0.083	
d) Set 4 (June 3-5, 1982, 169 data points)				
X	1.582	550.089	0.055	68.1
Y	-0.817	-237.109	0.187	

the observed and calculated rates using only the seawater Secondary Factor were computed to illustrate the improvement in position after applying the Semi-Empirical TD Model, ASF Loran-C Correction Tables, or the Multiple Observed ASF Correctors. The mean offset in microseconds and meters, standard error, and the drms are found in Table XI. Examples of offsets for several data points are listed in Appendix B after program LORAN.

It was stated earlier in Chapter One that Schnebele obtained a 66 m 1 drms using Y and W rates. The drms of 66 m was obtained using 48 data points which were located 10 km or more offshore. The 110.4 m 1 drms for the Y and W rates in Table XI is a result of combining the 130 inshore and offshore positions. The increase from 66.0 m 1 drms for the offshore positions to 110.4 m for combined offshore and inshore positions indicates that the application of a single

ASF Corrector is dependant on the size of the area. The 48 data points were located between latitude 36° 41' N and 36° 46' N and longitude 121° 55' W and 122° 02' W.

Schnebele also obtained the 66 m 1 drms by adjusting the LORAN-C observed time differences which were skewed due to the ship's motion and the five second averaging interval of the LORAN-C receiver. These caused the observed TDs to be several seconds old in comparison to the microwave system measurements [Schnebele, 1979]. Due to the large amounts of data from the June 1982 survey operations, no deskewing was done.

The offset, standard error, and drms for data set Number 2 (June 7, 1982) compares well to data set Number 1 (Schnebele's data - all). Also, the 38.6 m 1 drms for the X-Y rates is between Schnebele's 42.0 m 1 drms prediction [Schnebele, 1979] and Nelson's findings of 30 m 1 drms in San Francisco Bay [General Electric Co., 1979]. The large drms of 68.1 m for data set Number 4 (X-Y rates) is probably due to the phase recovery of the electromagnetic wave from the 9940-Y transmitter located in Searchlight, Nevada. Finally, if ASF Correctors are not applied, drms values ranged from 38.6 m for 9940 X-Y to 101.4 m for 9940 Y-W for data sets 2 and 3. The large offsets for all data sets indicate a systematic error, ranging from 150 m to 700 m, which precludes the use of this method for hydrographic surveying.

B. SEMI-EMPIRICAL TD GRID

To determine if the Semi-Empirical TD Grid would reduce the offset and drms for hydrographic surveying, program LOPLC (Appendix C) was applied to data sets 1 through 4. The Semi-Empirical TD Grid applies a Secondary Factor and an Additional Secondary Factor to the primary phase delay based

on the distance overland, the distance over water, and the total distance using mean land and water conductivities. The mean offset in meters and microseconds, standard error, and drms are listed in Table XII. Examples of offsets for several data points can be found in Appendix C after program

TABLE XII

Semi-Empirical TD Grid Correction Errors

Rates	Mean Offset (x-µsec)	Mean Offset (l-m)	Standard Error (s-µsec)	drms (m)
a) Set 1 (Schnebele's data, 130 data points)				
Y	1.131	330.672	0.086	113.5
W	1.145	630.278	0.139	
b) Set 2 (June 7, 1982 data, 193 data points)				
Y	1.108	324.975	0.077	112.7
W	1.105	603.926	0.126	
c) Set 3 (June 6, 1982 data, 128 data points)				
X	1.131	386.940	0.061	39.4
Y	0.589	172.923	0.084	
d) Set 4 (June 3-5, 1982 data, 169 data points)				
X	1.050	365.113	0.052	68.2
Y	0.341	99.084	0.189	

LOPLC. Earlier, Program LOPLC had been tested with data found in the article by The Analytic Science Corporation [1979]. Program LOPLC produced offsets of 0.86 µsec and 1.13 µsec for the time differences from rates 9940-X and 9940-Y, respectively. As previously stated, the large offsets may be due to the method by which the distance and azimuth were computed. The drms, for the data from Monterey Bay, obtained with the Semi-Empirical TD Grid was similar to the drms errors for seawater Secondary Factor Model. This might be an indication that Program LOPLC is correct but the

bias needs to be adjusted to reduce the large offset between the observed and calculated TD rates. The mean offset ranged from 99 to 630 m. Bias reduction could be achieved by applying land-sea data for the entire West Coast to the Semi-Empirical model. Again, the existence of large offset values precludes the use of this method for hydrographic surveying.

C. TABLE ASF CORRECTORS

To determine if the multiple ASF corrections from the LORAN-C Correction Table would reduce the offset and drms to meet the NOS accuracy standards, program LORTAB (Appendix D) was applied to data sets 1 through 4. ASF Correctors from

TABLE XIII

Multiple LORAN-C Correction Table Errors

Rates	Mean Offset (x-µsec)	Mean Offset (l-m)	Standard Error (s-µsec)	drms (m)
a) Set 1 (Schnebele's data, 130 data points)				
Y	-0.229	-67.068	0.104	123.6
W	0.169	92.540	0.160	
b) Set 2 (June 7, 1982 data, 192 data points)				
Y	-0.309	-90.614	0.085	116.9
W	0.123	67.189	0.144	
c) Set 3 (June 6, 1982 data, 128 data points)				
X	0.559	191.134	0.073	47.3
Y	-0.319	-93.486	0.101	
d) Set 4 (June 3-5, 1982 data, 169 data points) No ASF Corrections listed in Table for the south-east end of Monterey Bay next to the shore line.				

the LORAN-C Correction Tables are determined from field observation of land conductivities by the U.S. Coast Guard

Calibration Team [Marine Science Department, 1982]. The results are listed in Table XIII.

When compared to the Seawater Secondary Factor Error in Table XI, the drms values using LORAN-C Correction Tables were increased slightly while the offsets were reduced substantially. The offsets ranged from 65 - 200 m. Since the drms ranged from 47.3 to 116.9 m for rates 9940 X-Y and 9940 Y-W respectively, the application of ASF Corrector from the tables does not meet the NOS accuracy standard. Again, large offsets and the increase in drms precludes the use of this method for hydrographic surveying.

D. MULTIPLE OBSERVED CORRECTORS

To determine if multiple observed correctors would diminish the offset and drms values, mean ASF Correctors were selected at one minute latitude and longitude intervals using Program ASFSEL. One minute ASF Correctors are shown at the end of Program ASFSEL in Appendix E. From the one minute grid, mean ASF Correctors were selected and entered into Subroutine TABLE at five minute latitude and longitude intervals in Program LORTAB. The following is an example of the 9940-X ASF Correctors at five minute latitude and longitude intervals for the program:

	122/00/00.0	121/55/00.0	121/50/00.0
36/50/00.0	-1.52	-1.63	
36/45/00.0	-1.52	-1.56	-1.61
36/40/00.0		-1.58	-1.60

This is the same format used in the LORAN-C Correction Tables. Program LORTAB was applied to the four data sets. The error results are listed in Table XIV.

The drms value obtained with multiple observed correctors were all reduced when compared to the drms for the

TABLE XIV

Multiple Observed Correction Errors

Rates	Mean Offset (X-μsec)	Mean Offset (l-m)	Standard Error (s-μsec)	drms (m)
a) Set 1 (Schnebele's data, 130 data points)				
Y	0.033	9.585	0.076	87.6
W	0.052	28.604	0.113	
b) Set 2 (June 7, 1982, 193 data points)				
Y	0.028	8.318	0.073	89.3
W	-0.016	-8.944	0.116	
c) Set 3 (June 6, 1982, 128 data points)				
X	-0.034	-11.490	0.055	38.3
Y	0.010	2.913	0.086	
d) Set 4 (June 3.5, 1982, 169 data points)				
X	0.001	0.383	0.052	67.5
Y	-0.008	-2.225	0.187	

seawater Secondary Corrector. The most impressive reduction in drms was within Schnebele's data which covered an area of seven minutes of latitude and 12 minutes of longitude. The drms for seawater Secondary Correctors was 110.4 m whereas the drms for the same data using multiple observed correctors was 87.6 m. This is a smaller drms than that of the June 7, 1982 data (data set Number 2) which was obtained three years later. It appears that 87.6 m 1 drms is nearly the minimum error that can be obtained for the 9940 Y-W rates in Monterey Bay after applying multiple observed ASF Correctors at five minute latitude and longitude intervals. For the LORAN-C rates 9940 X-Y, a 38.3 m 1 drms was obtained for same five minute area covered by data set Number 2 (June 7, 1982). LORAN-C rates 9940 X-Y were not obtained for the same size area covered by data set Number 1 (seven minutes of latitude and twelve minutes of longitude - 9940 Y-W) due

to the restriction of ship time and the length of time the Racal-DECCA Trisponder electronic equipment had been loaned.

The drms for the June 3-5, 1982 inshore data was only reduced to 67.5 m from 68.1 m for seawater Secondary Correctors. The small change in error at the coast is probably a result of the erratic behavior of phase recovery discussed earlier in Chapter Two. The drms value could presumably be reduced if the correctors were applied at one minute intervals. This would be a very costly method of calibrating Loran-C for hydrographic surveying.

V. CONCLUSIONS

It was noted in Chapter One that the smallest scale routinely used for coastal surveys is 1;80,000. This yields an allowable error of 40 m 1 drms with no systematic errors. This paper determined whether or not applying multiple Additional Secondary Factors (ASF) Correctors to LORAN-C lines of position would reduce the drms sufficiently to meet the accuracy standards set by the National Ocean Survey.

Three methods of applying multiple ASF Correctors were tested. The first approach computes the time difference based on a Semi-Empirical TD Grid. The Semi-Empirical Model produced large offsets in the 9940-W, 9940-X, and 9940-Y time differences. The offsets ranged from 99 to 630 m. The drms for 9940 X-Y combination was 39.4 m and the drms for 9940 W-Y combination was 102.7 m.

The second method applies ASF Correctors found in the DMAHTC LORAN-C Correction Tables to LORAN-C lines of position. The application of the tables reduced the offset in the LORAN-C time differences. The offsets were between 67 and 191 m. The drms was increased to 47.3 m for the 9940 X-Y combination and 116.9 m for the 9940 W-Y pair.

The final and most accurate method applies multiple observed ASF Correctors at five minute latitude and longitude intervals to LORAN-C lines of position. This method again reduced the offset in the time difference. This offset was between 3 and 12 m for the 9940 X-Y combination. Part of the offset may have been a result of the microwave positioning system. Reference is made to Anderson's [1982] paper (in preparation) on the evaluation of multiple lines of position.

The drms values were also reduced to 38.3 m for the 9940 X-Y rates and 89.3 m for the 9940 W-Y combination. The 38.3 m 1 drms can be decreased by improving the sampling time for LORAN-C receivers. Nelson obtained 30 m 1 drms for the 9940 X-Y rates with special LORAN-C equipment used in San Francisco Bay, California [General Electric Co., 1979]. Improving the sampling time for LORAN-C receivers used as positioning equipment for hydrographic surveys should be investigated.

With drms values of 38.3 m with the possibility of obtaining 30.0 m 1 drms and offsets ranging from 3 to 12 m, it may be possible to use LORAN-C for hydrographic surveys at scales of 1:80,000 or less using multiple observed ASF Correctors. The use of DMAHTC LORAN-C Correction Tables should not be ignored. After updating these ASF Correctors with observed data, the LORAN-C Correction Tables may allow LORAN-C to be used as a positioning system for hydrographic surveys.

APPENDIX A

PROGRAM GPBYLQ

```
C     PROGRAM GPBYLQ
C
C     GENERAL PROGRAM FOR DETERMINING GP FROM KNOWN STATION
C     POSITIONS AND THE DISTANCES FROM THEM USING LEAST
C     SQUARES.  GP TO XY AND XY TO GP ARE DETERMINED BY
C     SUBROUTINES GPTOXY AND XYTOGP WHICH ARE BASED ON THE
C     MODIFIED TRANSVERSE MERCATOR PROJECTION (MTM).
C
C     PROGRAMMED BY GERALD E. WHEATON, LT. NOAA
C
C     LEAST SQUARES ADJUSTMENT BY PAUL R. WOLF, PH.D. AND
C     REVISED BY D. LEATH, LCDR
C
C     PROGRAM INPUT VARIABLE NAMES
C     TITLE = ANY JOB IDENTIFICATION NAMES OR NUMBERS
C     M AND N = THE NUMBER OF EQUATIONS (M) AND UNKNOWNS (N)
C     XO AND YO = BEST QUESTIMATE OF THE POSTION
C     STA(I,1) = X COORDINATE OF KNOW STATION
C     STA(I,2) = Y COORDINATE OF KNOW STATION
C     STA(I,3) = DISTANCE FROM KNOW STATION
C     A(I,J) = THE COEFFICIENT MATRIX
C     EL(I,J) = THE CONSTANT MATRIX
C     QLL(I,J) = THE WEIGHT MATRIX (WEIGHTS ARE ENTERED AS
C     1'S IF THE SOLUTION IS EQUALLY WEIGHTED)
C
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION XCORD(30),YCORD(30),WT(30),ISNO(30)
      COMMON /ISTAT/ STA(30,3),FXY(30)
      COMMON /LSQX/ A(30,30),EL(30,1),QLL(30,30),AT(30,30),
```

```
     1AQ(30,30), QXX(30,30), AQL(30,10), X(30,1), V(30,1),
     2VAR(30), TITLE(80)
C
C     READ AND WRITE OUTPUT TITLE
C
      WRITE(6,509)
      READ(5,710)TITLE
      WRITE(6,710)TITLE
C
C     DEFINE NUMBER OF SIGNALS (NOT GREATER THAN 30) AND
C     NUMBER OF DATA SETS.
C
      READ(5,502) NSIG,NDATA
502   FORMAT(I5,I10)
C
C     DEFINE THE CENTRAL MERIDIAN (CMER), FALSE EASTING
C     (FEST), AND CENTRAL LATITUDE (CLAT).
C     CMER IS EXPRESSED IN DEGREES, MINUTES, AND SECONDS.
C     FEST IS THE X-COORDINATE THAT IS ASSIGNED TO THE
C     CENTRAL MERIDIAN AND IS EXPRESSED IN METERS.
C     CLAT IS DEFINED AS THE CONTROLLING LATITUDE.
C     IT IS USED TO REFERENCE THE Y-COORDINATES AND
C     IS EXPRESSED IN METERS.
C
      READ(5,503) ILONC,ILMINC,RLSECC,FEST,CLAT
503   FORMAT(1X,I3,1X,I2,1X,F8.5,1X,F7.1,F10.1)
      CMER = ((IABS(ILONC) * 60 + ILMINC) * 60) + RLSECC
C
C     DEFINE VARIABLE FOR:
C         NUMBER OF EQUATIONS (M)
C         NUMBER OF UNKNOWNS (N)
C         IPAGE = NUMBER OF LINES PER PAGE.
C
      IPAGE = 1
```

```
      M = 4
      N = 2
C
C     NULL WEIGHTS
C
      DO 3  IM=1,30,1
      DO 3  JM=1,30,1
3     QLL(IM,JM) = 0.0
C
C     READ STATION NUMBERS ,POSITION, AND WEIGHTS.
C     CONVERT POSITIONS (GP) TO SECONDS AND THEN TO XY.
C
      DO 12  J=1,NSIG,1
      READ(5,800)ISNO(J),ILAT,IMIN,RSEC,JLON,JMIN,SSEC,WT(J)
800   FORMAT(1X,I3,I4,I3,F9.5,I5,I3,F9.5,F5.1)
C
      RMAST = ((IABS(ILAT) * 60 + IMIN) * 60) + RSEC
      RMASTL = ((IABS(JLON) * 60 + JMIN) * 60) + SSEC
C
      CALL GPTOXY(RMAST,RMASTL,XMETER,YMETER,FEST,CLAT,CMER)
      XCORD(J) = XMETER
12    YCORD(J) = YMETER
C
C     READ DATA  (STATION NUMBERS AND THE DISTANCES)
C
15    DO 40  JCOUNT=1,NDATA,1
      READ(5,805) IF,IS,IT,I4,NREC
805   FORMAT(5I5)
      DO 16  ICOUNT=1,NSIG,1
      IF(ISNO(ICOUNT) .EQ. IF) IF=ICOUNT
      IF(ISNO(ICOUNT) .EQ. IS) IS=ICOUNT
      IF(ISNO(ICOUNT) .EQ. IT) IT=ICOUNT
16    IF(ISNO(ICOUNT) .EQ. I4) I4=ICOUNT
C
```

```
      STA(1,1) = XCORD(IF)
      STA(1,2) = YCORD(IF)
      QLL(1,1) = WT(IF)
C
      STA(2,1) = XCORD(IS)
      STA(2,2) = YCORD(IS)
      QLL(2,2) = WT(IS)
C
      STA(3,1) = XCORD(IT)
      STA(3,2) = YCORD(IT)
      QLL(3,3) = WT(IT)
C
      STA(4,1) = XCORD(I4)
      STA(4,2) = YCORD(I4)
      QLL(4,4) = WT(I4)
C
C     READ THE DISTANCE RECORD AND LORAN RATE.
C
      DO 38 KCOUNT=1,NREC,1
      READ(5,507) STA(1,3),STA(2,3),STA(3,3),STA(4,3),
     1 RATE1,RATE2
507   FORMAT(6F10.1)
C
C     DETERMINE BEST GUESS COORDINATES XO AND YO
C     WITH SUBROUTINE GUESS.
C
19    CALL GUESS(XO,YO)
C
      IJUMP = 0
C
C     COMPUTE FXY, A AND L MATRIX
C
20    DO 25 I=1,M
      FXY(I) = DSQRT(DABS((XO-STA(I,1))**2
```

```
     1 (YO-STA(I,2))**2))
      A(I,1) = (XO-STA(I,1)) / (FXY(I))
      A(I,2) = (YO-STA(I,2)) / (FXY(I))
25    EL(I,1) = STA(I,3) - FXY(I)
C
C     CALL SUBROUTINE LSQR
C
      CALL LSQR(M,N)
C
C     COMPUTE THE NEW QUESSTIMATE FOR XO AND YO
C
      XO = XO + X(1,1)
      YO = YO + X(2,1)
C
C     EXIT IF STANDARD ARE MET USING IJUMP OR
C     XO AND YO CUT OFF
C
      IF(DABS(X(1,1)).LE.1.00 .AND. DABS(X(2,1)).LE.1.00)
     1 GO TO 35
      IF(IJUMP .EQ. 10) GO TO 35
30    GO TO 20
C
C     COMPUTE ERROR ELLIPSE
C
35    CONTINUE
      CALL ELIPSE(SU,SV)
C
C     CONVERT XY TO GP
C
      CALL XYTOGP(XO,YO,SECLAT,SECLON,FEST,CLAT,CMER)
      CALL TODMS(SECLAT,IDEGP,IMINP,RSECP)
      CALL TODMS(SECLON,JDEGP,JMINP,SSECP)
C
C     PAGE AND CONTINUE WITH NEXT SET OF OBSERVATIONS
```

```
C
      WRITE(6,505) IDEGP,IMINP,RSECP,JDEGP,JMINP,SSECP,
     1 RATE1,RATE2
C     WRITE(6,505) IDEGP,IMINP,RSECP,JDEGP,JMINP,SSECP,
     1 SU,SV
505   FORMAT(I4,I3,F6.2,I5,I3,F6.2,2F9.2)
C     IF(IPAGE .EQ. 50) WRITE(6,509)
      IF(IPAGE .EQ. 50) IPAGE = 0
38    IPAGE = IPAGE + 1
C
C     FORMAT STATEMENTS
C
710   FORMAT(80A1)
509   FORMAT(1H1)
40    CONTINUE
      STOP
      END
C=====================================================================
      SUBROUTINE LSQR(M,N)
C---------------------------------------------------------------------
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON /LSQX/ A(30,30),EL(30,1),QLL(30,30),AT(30,30),
     1AQ(30,30), QXX(30,30), AQL(30,10), X(30,1), V(30,1),
     2VAR(30), TITLE(80)
C
C     COMPUTE A TRANSPOSE BY TRANSPOSING THE A MATRIX (AT)
C
      DO 61 I=1,M
      DO 61 J=1,N
   61 AT(J,I)=A(I,J)
C
C     USING STEPS (1), (2), AND (3) COMPUTE THE INVERSE
C     OF THE TRANSPOSE (AT) * WEIGHTED MATRIC (QLL) *
C     MATRIX A = QXX.
```

```
C
C      (1)  COMPUTE AQ = AT * QLL
C
      DO 71 I=1,N
      DO 71 J=1,M
      AQ(I,J)=0.
      DO 71 K=1,M
   71 AQ(I,J)=AQ(I,J)+(AT(I,K)*QLL(K,J))
C
C      (2)  COMPUTE QXX = AQ * A
C
      DO 81 I=1,N
      DO 81 J=1,N
      QXX(I,J)=0.
      DO 81 K=1,M
   81 QXX(I,J)=QXX(I,J)+AQ(I,K)*A(K,J)
C
C      (3)  INVERT QXX MATRIX
C
      DO 307 K=1,N
      DO 302 J=1,N
      IF(J-K) 304,302,304
  304 QXX(K,J)=QXX(K,J)/QXX(K,K)
  302 CONTINUE
      QXX(K,K)=1./QXX(K,K)
      DO 307 I=1,N
      IF(I-K) 305,307,305
  305 DO 303 J=1,N
      IF(J-K) 306,303,306
  306 QXX(I,J)=QXX(I,J)-QXX(I,K)*QXX(K,J)
  303 CONTINUE
      QXX(I,K)=-QXX(I,K)*QXX(K,K)
  307 CONTINUE
C
```

```
C     USING STEPS (4) AND (5), COMPUTE THE UNKNOWNS X
C     BY MULT THE INVERSE QXX AND AQL.
C
C      (4)  COMPUTE AQL = AQ * EL
C
      DO 101 I=1,N
      AQL(I,1)=0.
      DO 101 K=1,M
  101 AQL(I,1)=AQL(I, 1)+AQ(I,K)*EL(K, 1)
C
C      (5)  COMPUTE X = QXX * AQL
      DO 201 I=1,N
C
      X(I, 1)=0.
      DO 201 K=1,N
  201 X(I, 1)=X(I, 1)+QXX(I,K)*AQL(K, 1)
C
C      (6)  COMPUTE THE RESIDUAL  (V = A * X -EL)
C
      DO 301 I=1,M
      V(I, 1)=0.
      DO 301 K=1,N
  301 V(I, 1)=V(I, 1)+A(I,K)*X(K, 1)
      DO 1 I=1,M
    1 V(I, 1)=V(I, 1)-EL(I,1)
C
C     COMPUTE THE STANDARD DEVIATION OF UNIT WEIGHT SIGMA
C        DM - NUMBER OF OBSERVATIONS
C        DN - NUMBER OF KNKNOWNS
C
      SIGMA=0.
      DM=M
      DN=N
      DO 382 I=1,M
```

```
  382 SIGMA=SIGMA+V(I,1)**2*QLL(I,I)
      SIGMA=DSQRT (SIGMA/(DM-DN))
C
C     COMPUTE THE STANDARD DEVIATION OF THE ADJUSTED UNKNOWNS
C     QXX - ARE THE ELEMENTS OF THE COVARIANCE MATRIX.
C
      DO 446 I=1,N
  446 VAR(I)=DSQRT(QXX(I,I)*SIGMA**2)
C
  510 CONTINUE
      RETURN
      END
C=================================================================
      SUBROUTINE ELIPSE(SU,SV)
C-----------------------------------------------------------------
C
C     SOLVE FOR THE SEMI MAJOR AND SEMI MINOR AXIS OF
C     THE ERROR ELLIPSE
C
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON /LSQX/ A(30,30),EL(30,1),QLL(30,30),AT(30,30),
     1AQ(30,30), QXX(30,30), AQL(30,10), X(30,1), V(30,1),
     2VAR(30), TITLE(80)
C
      SUS = .5*(QXX(1,1) + QXX(2,2) + DSQRT(DABS(QXX(1,1)-
     1 QXX(2,2)+4.0*QXX(1,2)*QXX(2,1))))
      SVS = .5*(QXX(1,1) + QXX(2,2) - DSQRT(DABS(QXX(1,1)-
     1 QXX(2,2)+4.0*QXX(1,2)*QXX(2,1))))
C
      SU =  DSQRT(SUS)
      SV =  DSQRT(SVS)
C
      RETURN
      END
```

```
C=============================================================
      SUBROUTINE GUESS(XO,YO)
C-------------------------------------------------------------
C
C     SUBROUTINE GUESS DETERMINES THE BEST GUESS COORDINATES
C     TO BE USED IN SUBROUTINE LSQR.  USE RIGHT SIDE RULE FOR
C     STATION ORDER.
C
      IMPLICIT REAL*8 (A-H,O-Z)
      CCMMON /ISTAT/ STA(30,3),FXY(30)
C
C     DETERMINE DISTANCE BETWEEN STATION 1 AND STATION 2
C
      D=DSQRT((STA(2,1)-STA(1,1))**2+(STA(2,2)-STA(1,2))**2)
C
C     DETERMINE ANGLE ALPHA BETWEEN XO,YO/STA2/STA1
C
      ALPHA=DARCOS((STA(2,3)**2-STA(1,3)**2+D**2)/
     1 (2.0*STA(2,3)*D))
C
C     DETERMINE ANGLE BROVO BETWEEN X-AXIS AND STA2-STA1
C
      BROVO=DARSIN((STA(1,2)-STA(2,2))/D)
C
C     DETERMINE X AND Y LENGTH
C
      X=STA(2,3)*DCOS(ALPHA+BROVO)
      Y=STA(2,3)*DSIN(ALPHA+BROVO)
C
C     DETERMINE XO AND YO
C
      XO = STA(2,1)+X
      YO = STA(2,2)+Y
C
```

```
      RETURN
      END
C===============================================================
      SUBROUTINE GPTOXY(SECLAT,SECLON,XCO,YCO,FEST,CLAT,CMER)
C---------------------------------------------------------------
C
      IMPLICIT REAL*8 (A-H,O-Z)
      DATA E2,RKO,A /.006768658D0,.99998D0,6378206.4D0/
      DATA RKGEO,W1,W2 /0.04848136 8D0,0.11422D0,21.73607D0/
      DATA W3,W4/5104.57338D0,6367399.689D0/
      DATA RADSEC /.000004848136811D0/
C
C
      RADLAT = SECLAT * RADSEC
      SINLAT = DSIN(RADLAT)
      SIN2LA = SINLAT * SINLAT
      COSLAT = DCOS(RADLAT)
      COS2LA = COSLAT * COSLAT
      P = (CMER - SECLON) / 10000.0D0
      V = A / DSQRT(1.0D0 - E2*SIN2LA)
      TANCON = 1.0D0 - SIN2LA/COS2LA
      S = W4 * (RADLAT - SINLAT*COSLAT/10.0D0**6 *
     *     (W3 -COS2LA*(W2-W1*COS2LA)))
      T1 = S * RKO - CLAT
      T2 = RKGEO * COSLAT * RKO * V
      T3 = T2 * RKGEO / 2.0D0
      T4 = T3 * SINLAT
      T5 = T3 * RKGEO * COS2LA / 3.0D0
      T6 = T5 * TANCON
      T7 = (4.0D0 + TANCON) *T5 *RKGEO * SINLAT / 4.0D0
      XCO = (T2 + (T6 *P**2) ) *P + FEST
      YCO = (T7*P**4) + (T4 *P**2) + T1
      RETURN
      END
```

```
C==============================================================
      SUBROUTINE XYTOGP(XCO,YCO,SECLAT,SECLON,FEST,CLAT,CMER)
C--------------------------------------------------------------
C
      IMPLICIT REAL*8 (A-H,O-Z)
C
      DATA E2,A,SR /0.006768658D0,6378206.4D0,
     1 0.000004848136 8D0/
      DATA W1,W2,W3 /0.24682D0,30.02335D0,5078.64977D0/
C
      D = CLAT + YCO
      WO = 0.157049981D0/10.0D0**6 * D
      SINWO = DSIN(WO)
      COSWO = DCOS(WO)
      COS2WO = COSWO * COSWO
      PHI1 = WO + SINWO*COSWO/10.0D0**6 *
     *      (W3+COS2WO*(W2+W1*COS2WO))
      PHI2 = PHI1 / 0.99998D0
      PHI3 = PHI2 / SR
      Q = (XCO - FEST) / 10.0D0**6
      V = A / DSQRT(1.0D0 - E2*DSIN(PHI2)**2)
      T = DCOS(PHI2) * SR
      C = V * 0.99998D0
      T1 = 10.0D0**6 / (T*C)
      T2 = (T1*10.0D0**6) / (2.0D0*C)
      T3 = (T2*10.0D0**6) / (3.0D0*C)
      T4 = (T3*10.0D0**6) / (4.0D0*C)
      DELLON = (T1-Q**2*T3*(2.0D0*DTAN(PHI2)**2+1.0D0))*Q
      SECLAT = (((3.0D0*DTAN(PHI2)**2+5.0D0)*T4)*Q**2-T2)
     1   *Q**2*DSIN(PHI2) + PHI3
      SECLON = CMER - DELLON
      RETURN
      END
$ENTRY
```

DATA SET EXAMPLE - PROGRAM GPBYLQ.

SHIP'S POSITION LATITUDE (D-M-S)	SHIP'S POSITION LONGITUDE (D-M-S)	OBSERVED LORAN RATES 9940-X (μsec)	OBSERVED LORAN RATES 9940-Y (μsec)
36 36 40.20	121 52 48.62	27508.79	42742.71
36 36 42.41	121 52 48.16	27508.81	42742.93
36 36 44.56	121 52 47.52	27508.83	42743.15
36 36 46.84	121 52 46.98	27508.76	42743.26
36 36 49.09	121 52 46.59	27508.76	42743.48

APPENDIX B

PROGRAM LORAN

```
C     PROGRAM LORAN
C
C     PROGRAM COMPUTES LINE OF POSITIONS FOR LORAN-C USING
C     THE SECONDARY FACTOR (SF) BASED ON SEAWATER EM MODEL.
C
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION AXIS(13),RF(13)
      DIMENSION XSLAV1(1000),XSLAV2(1000)
      DATA RHOSEC,PI,UNCOV,RN/2.062648062471D05,
     1 3.14159265358980D0,299.792458D0,1.000338D0/
      DATA XMEAN1,XMEAN2,VAR1,VAR2/0.00D0,0.00D0,
     1 0.00D0,00.0D0/
      DATA XMEAN3,XMEAN4/0.00D0,0.00D0/
C
CCCCCC*********************************
      DATA AXIS/6.3782064D06,6.378388   D06,6.377397155D06,
     1 6.37816 D06,6.37816D06,6.378249145D06,6.378165D06,
     2 6.378166D06,6.378165 D06,6.378145D06,6.3775634D06,
     3 6.378245D06,6.3781350D06/
      DATA RF/6.3565838   D06,2.97   D02,2.9915281285D02,
     1 2.9825D02,2.98247167427D02,2.93465D02,2.9825D02,
     2 2.983 D02,2.983D02,2.9825 D02,6.3562569D06,
     3 2.983 D02,2.9826D02/
C*****ELLIPSOID OPTION NUMBER
C     1. CLARKE 1866                 8. MERCURY
C     2. INTERNATIONAL (HAYFORD)     9. MARSHALL ISLAND
C     3. BESSEL 1841                10. NAVY 8D
C     4. AND (AUSTRALIAN)           11. AIRY
C     5. 1967 REFERENCE             12. KRASSOWSKI 1940
```

```
C     6. CLARKE 1880 MOD          13. WGS 1972
C     7. SAO
C
CCCCCC***********************************
C     CC1-2 = ELLIPSOID NUMBER (K)
C     CC3-5 = NUMBER OF POINTS ALONG COAST (IREC)
C
      READ(5,100) K,IREC
100   FORMAT(1X,I2,I4)
      TWOPI=2.*PI
      A=AXIS(K)
      F=1./RF(K)
      IF(F.LT.3.D-3) F=(A-1./F)/A
C
C     READ MASTER AND SLAVE STATIONS POSITIONS
C     THE FIRST RECORD IS THE NUMBER OF MASTER AND SLAVE
C     STATIONS FOR THE PARTICULAR CHAIN.
C
      WRITE(6,202)
202   FORMAT(1H1)
      WRITE(6,201)
201   FORMAT(1H )
      READ(5,105) ILATM,IMINM,RSECM,ILONM,ILMINM,RLSECM
      WRITE(6,105) ILATM,IMINM,RSECM,ILONM,ILMINM,RLSECM
105   FORMAT(1X,I3,1X,I2,1X,F5.2,1X,I4,1X,I2,1X,F5.2)
      RMAST = ((IABS(ILATM) * 60 + IMINM) * 60 + RSECM) /
     1 RHOSEC
      IF(ILATM .LT. 0) RMAST = -RMAST
      RMASTL = ((IABS(ILONM) * 60 + ILMINM) *60 +RLSECM) /
     1 RHOSEC
      IF(ILONM .GT. 0) RMASTL = TWOPI - RMASTL
C
C     READ THE FIRST SLAVE STATION AND CHANGE THE LATITUDE
C     AND LONGITUDE INTO RADIANS.
```

```
C
      READ(5,101) ILATS,IMINS,RSECS,ILONS,ILMINS,RLSECS,
     1 DELAY1
      WRITE(6,101) ILATS,IMINS,RSECS,ILONS,ILMINS,RLSECS,
     1 DELAY1
101   FORMAT(1X,I3,1X,I2,1X,F5.2,1X,I4,1X,I2,1X,F5.2,F9.2)
      RSLAV1 = ((IABS(ILATS) * 60 + IMINS) * 60 + RSECS) /
     1 RHOSEC
      IF(ILATS .LT. 0) RSLAV1 = -RSLAV1
      RSLAL1 = ((IABS(ILONS) * 60 + ILMINS) * 60 + RLSECS) /
     1 RHOSEC
      IF(ILONS .GT. 0) RSLAL1 = TWOPI - RSLAL1
C
C     READ THE SECOND SLAVE STATION AND CHANGE THE LATITUDE
C     AND  LONGITUDE INTO RADIANS.
C
      READ(5,101) ILATS,IMINS,RSECS,ILONS,ILMINS,RLSECS,
     1 DELAY2
      WRITE(6,101) ILATS,IMINS,RSECS,ILONS,ILMINS,RLSECS,
     1 DELAY2
      RSLAV2 = ((IABS(ILATS) * 60 + IMINS) * 60 + RSECS) /
     1 RHOSEC
      IF(ILATS .LT. 0) RSLAV2 = -RSLAV2
      RSLAL2 = ((IABS(ILONS) * 60 + ILMINS) * 60 + RLSECS) /
     1 RHOSEC
      IF(ILONS .GT. 0) RSLAL2 = TWOPI - RSLAL2
      WRITE(6,201)
C
C     READ THE RECORDS POSITIONS AND OBSERVED RATES, THEN
C     COMPUTE THE TOTAL DISTANCE.
C
      DO 550 I=1,IREC,1
      READ(5,104) ILAT,IMIN,RSEC,ILON,ILMIN,RLSEC,
     1 RATE1,RATE2
```

```
104   FORMAT(1X,I3,I3,F6.3,I5,I3,F6.3,3X,2F10.2)
C
C     CONVERT LAT AND LONG TO RADIANS.
C
      RPOST = ((IABS(ILAT) * 60 + IMIN) * 60 + RSEC) /
     1 RHOSEC
      IF(ILAT .LT. 0) RPOST = -RPOST
      RPOSTL = ((IABS(ILON) * 60 + ILMIN) * 60 + RLSEC) /
     1 RHOSEC
      IF(ILON .GT. 0) RPOSTL = TWOPI - RPOSTL
C
C     COMPUTE DISTANCES AND AZIMUTHS FROM THE OBSERVED POINT
C
C             MASTER
C
      CALL INVER1(A,F,RPOST,RPOSTL,RMAST,RMASTL,FAZM,BAZM,
     1 DISTM)
      UDISTM = (RN * DISTM) / UNCOV
      CALL SECFAC(UDISTM,SFM)
C
C             SLAVE1
C
      CALL INVER1(A,F,RPOST,RPOSTL,RSLAV1,RSLAL1,FAZ1,BAZ1,
     1 DIST1)
      UDIST1 = (RN * DIST1) / UNCOV
      CALL SECFAC(UDIST1,SF1)
C
C             SLAVE2
C
      CALL INVER1(A,F,RPOST,RPOSTL,RSLAV2,RSLAL2,FAZ2,BAZ2,
     1 DIST2)
      UDIST2 = (RN * DIST2) / UNCOV
      CALL SECFAC(UDIST2,SF2)
C
```

```
C     COMPUTE THE RATES AND COMPARE TO THE OBSERVED RATES
C
      TDM1 = UDIST1 - UDISTM + SF1 - SFM + DELAY1
      DIFF1 = TDM1 - RATE1
C
      TDM2 = UDIST2 - UDISTM + SF2 - SFM + DELAY2
      DIFF2 = TDM2 - RATE2
C
C     COMPUTE THE LANE WIDTH IN METERS BASED ON EQUATION
C     4.20 IN ELECTRONIC SURVEYING AND NAVIGATION -
C     LAURILA, PAGE 94.
C
      BR1 = DABS(FAZ1 - FAZM)
      BR2 = DABS(FAZ2 - FAZM)
      WIDTH1 = (DIFF1 * UNCOV * 0.5) / DSIN(BR1 * 0.5)
      WIDTH2 = (DIFF2 * UNCOV * 0.5) / DSIN(BR2 * 0.5)
C
C     WRITE THE POSITION OF VESSEL, COMPUTED RATE, OBSERVED
C     RATE, AND THE DIFF BETWEEN THEM.
C
      WRITE(6,200) ILAT,IMIN,RSEC,ILON,ILMIN,RLSEC,RATE1,
      DIFF1,RATE2,DIFF2
200   FORMAT(1X,I3,I3,1X,F6.3,I5,I3,1X,F6.3,F12.2,F8.2,
     1 F12.2,F8.2)
      WRITE(6,201)
C
C     XMEAN1 AND XMEAN2 ARE THE MEAN DIFFS BETWEEN THE
C     COMPUTED RATE AND THE OBERSERVED. XSLAV1 AND XSLAV2
C     ARE THE STORED DIFFS.
C
      XMEAN1 = XMEAN1 + DIFF1
      XMEAN2 = XMEAN2 + DIFF2
      XMEAN3 = XMEAN3 + WIDTH1
      XMEAN4 = XMEAN4 + WIDTH2
```

```
      XSLAV1(I)  = DIFF1
      XSLAV2(I)  = DIFF2
550   CONTINUE
C
C     COMPUTE THE MEAN AND STANDARD DEVIATION
C
      XMEAN1 = XMEAN1 / IREC
      XMEAN2 = XMEAN2 / IREC
      XMEAN3 = XMEAN3 / IREC
      XMEAN4 = XMEAN4 / IREC
C
      DO 600 I = 1,IREC,1
      VAR1 = VAR1 + ((XSLAV1(I)  - XMEAN1)**2)
600   VAR2 = VAR2 + ((XSLAV2(I)  - XMEAN2)**2)
C
      VAR1 = VAR1 / (IREC - 1.0)
      VAR2 = VAR2 / (IREC - 1.0)
C
      SD1 = DSQRT(VAR1)
      SD2 = DSQRT(VAR2)
C
      WRITE(6,201)
      WRITE(6,210) XMEAN1,SD1,XMEAN3
      WRITE(6,201)
      WRITE(6,211) XMEAN2,SD2,XMEAN4
      WRITE(6,202)
210   FORMAT(1X,' SLAVE #1, MEAN = ',F10.3,
     1 ' STANDARD DEVIATION = ',
     2 F10.3,' DISTANCE IN METERS = ',F10.3)
211   FORMAT(1X,' SLAVE #2, MEAN = ',F10.3,
     1 ' STANDARD DEVIATION = ',
     2 F10.3,' DISTANCE IN METERS = ',F10.3)
      STOP
      END
```

```
C=====================================================================
      SUBROUTINE SECFAC(UTDIST,SF)
C---------------------------------------------------------------------
C
C     THIS ROUTINE WILL COMPUTE THE SEA SECONDARY FACTOR
C        UTDIST = TOTAL DISTANCE
C        SF = SECONDARY FACTOR
C
      IMPLICIT REAL*8 (A-H,O-Z)
C
C
C     COEFFICIENTS
C
      A0 =  129.04323
      A1 = -0.40758
      A2 =  0.00064576813
C
      B0 =  2.741282
      B1 = -0.011402
      B2 = .00032774815
C
      IF(UTDIST .GT. 537) GO TO 10
      SF = ( B0 / UTDIST) + B1 + ( B2 * UTDIST)
      GO TO 20
10    SF = ( A0 / UTDIST) + A1 + ( A2 * UTDIST)
C
20    CONTINUE
      RETURN
      END
C=====================================================================
      SUBROUTINE INVER1(A,FINV,GLAT1,GLON1,GLAT2,GLON2,FAZ,
     1 BAZ,S)
C---------------------------------------------------------------------
C
```

```
C *** SOLUTION OF THE GEODETIC INVERSE PROBLEM AFTER
C *** T.VINCENTY MODIFIED RAINSFORD'S METHOD WITH HELMERT'S
C *** ELLIPTICAL TERMS.  EFFECTIVE IN ANY AZIMUTH AND AT
C *** ANY DISTANCE SHORT OF ANTIPODAL STANDPOINT/FOREPOINT
C *** MUST NOT BE THE GEOGRAPHIC POLE
C
C *** A IS THE SEMI-MAJOR AXIS OF THE REFERENCE ELLIPSOID
C *** FINV IS THE FLATTENING (NOT RECIPROCAL) OF THE
C *** REFERNECE ELLIPSOID LATITUDES AND LONGITUDES IN
C *** RADIANS POSITIVE NORTH AND EAST FORWARD AZIMUTHS AT
C *** BOTH POINTS RETURNED IN RADIANS FROM NORTH GEODESIC
C *** DISTANCE S RETURNED IN UNITS OF SEMI-MAJOR AXIS A
C
C *** PROGRAMMED FOR CDC-6600 BY LCDR L.PFEIFER NGS
C *** ROCKVILLE MD 18FEB75.  MODIFIED FOR IBM SYSTEM 360
C *** BY JOHN G GERGEN NGS ROCKVILLE MD 7507.
C
      IMPLICIT REAL*8 (A-H,O-Z)
      DATA EPS/0.5D-13/,PI/3.141592653589 8D0/
      TWOPI=2.*PI
      R=1.-FINV
      TU1=R*DSIN(GLAT1)/DCOS(GLAT1)
      TU2=R*DSIN(GLAT2)/DCOS(GLAT2)
      CU1=1./DSQRT(TU1*TU1+1.)
      SU1=CU1*TU1
      CU2=1./DSQRT(TU2*TU2+1.)
      S=CU1*CU2
      BAZ=S*TU2
      FAZ=BAZ*TU1
      X=GLON2-GLON1
  100 SX=DSIN(X)
      CX=DCOS(X)
      TU1=CU2*SX
      TU2=BAZ-SU1*CU2*CX
```

```
      SY=DSQRT(TU1*TU1+TU2*TU2)
      CY=S*CX+FAZ
      Y=DATAN2(SY,CY)
      SA=S*SX/SY
      C2A=-SA*SA+1.
      CZ=FAZ+FAZ
      IF(C2A.GT.0.)CZ=-CZ/C2A+CY
      E=CZ*CZ*2.-1.
      C=((-3.*C2A+4.)*FINV+4.)*C2A*FINV/16.
      D=X
      X=((E*CY*C+CZ)*SY*C+Y)*SA
      X=(1.-C)*X*FINV+GLON2-GLON1
      IF(DABS(D-X).GT.EPS) GO TO 100
      FAZ=DATAN2(TU1,TU2)
      IF(FAZ.GE.TWOPI) FAZ=FAZ-TWOPI
      IF(FAZ.LT.0.D0) FAZ=FAZ+TWOPI
      BAZ=DATAN2(CU1*SX,BAZ*CX-SU1*CU2)+PI
      IF(BAZ.GE.TWOPI) BAZ=BAZ-TWOPI
      IF(BAZ.LT.0.D0) BAZ=BAZ+TWOPI
      X=DSQRT((1./R/R-1.)*C2A+1.)+1.
      X=(X-2.)/X
      C=1.-X
      C=(X*X/4.+1.)/C
      D=(0.375*X*X-1.)*X
      X=E*CY
      S=1.-E-E
      S=((((SY*SY*4.-3.)*S*CZ*D/6.-X)*D/4.+CZ)*SY*D+Y)*C*A*R
      RETURN
      END
$ENTRY
```

DATA SET EXAMPLE - PROGRAM LORAN

SHIP'S POSITION LATITUDE (D-M-S)			SHIP'S POSITION LONGITUDE (D-M-S)			OBSERVED LORAN RATES & ERRORS (E) 9940-Y (μsec)	EY (μsec)	9940-W (μsec)	EW (μsec)
36	43	45.800	121	55	27.160	42789.34	-0.49	16294.04	-1.06
36	44	3.400	121	55	32.340	42791.13	-0.38	16293.46	-1.10
36	44	21.180	121	55	37.390	42793.04	-0.38	16292.73	-0.99
36	44	37.490	121	55	46.950	42795.13	-0.58	16292.03	-1.06
36	44	53.260	121	55	57.710	42796.93	-0.51	16291.43	-1.27

APPENDIX C

PROGRAM LOPLC

```
C     PROGRAM LOPLC
C
C     PROGRAM COMPUTES LINE OF POSITIONS FOR LORAN-C USING
C     THE SECONDARY FACTOR (SF) AND ADDITIONAL SECONDARY
C     FACTOR (ASF) THE SF AND ASF ARE BASED ON
C     SEMI-EMPIRICAL TD GRID.
C
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION PHI(100),ELON(100),DISTM(100),DIST1(100),
     1 DIST2(100),AXIS(13),RF(13),AZ1(100),AZ2(100),AZM(100)
      DATA RHOSEC,PI,UNCOV/2.062648062471D05,
     1 3.14159265358980D0,299.693D0/
C
CCCCCC*************************************
      DATA AXIS/6.3782064D06,6.378388   D06,6.377397155D06,
     1 6.37816 D06,6.37816D06,6.378249145D06,6.378165D06,
     2 6.378166D06,6.378165 D06,6.378145D06,6.3775634D06,
     3 6.378245D06,6.378135 0D06/
      DATA RF/6.3565838    D06,2.97   D02,2.9915281285D02,
     1 2.9825D02,2.98247167427D02,2.93465D02,2.9825D02,
     2 2.983 D02,2.983D02,2.9825 D02,6.3562569D06,
     3 2.983 D02,2.9826D02/
C*****ELLIPSOID OPTION NUMBER
C     1. CLARKE 1866                8. MERCURY
C     2. INTERNATIONAL (HAYFORD)    9. MARSHALL ISLAND
C     3. BESSEL 1841               10. NAVY 8D
C     4. AND (AUSTRALIAN)          11. AIRY
C     5. 1967 REFERENCE            12. KRASSOWSKI 1940
C     6. CLARKE 1880 MOD           13. WGS 1972
```

```
C      7. SAO
C
CCCCCC*************************************
C      CC1-2 = ELLIPSOID NUMBER (K)
C      CC3-5 = NUMBER OF POINTS ALONG COAST (IREC)
C
       READ(5,100) K,IREC,ISTA1,ISTA2
100    FORMAT(1X,I2,I4,2I3)
       TWOPI=2.*PI
       A=AXIS(K)
       F=1./RF(K)
       IF(F.LT.3.D-3) F=(A-1./F)/A
C
C      READ MASTER STATION POSITIONS.
C
       READ(5,105) ILATM,IMINM,RSECM,ILONM,ILMINM,RLSECM
105    FORMAT(1X,I3,1X,I2,1X,F5.2,1X,I4,1X,I2,1X,F5.2)
       RMAST = ((IABS(ILATM) * 60 + IMINM) * 60 + RSECM) /
      1 RHOSEC
       IF(ILATM .LT. 0) RMAST = -RMAST
       RMASTL = ((IABS(ILONM) * 60 + ILMINM) *60 +RLSECM) /
      1 RHOSEC
       IF(ILONM .GT. 0) RMASTL = TWOPI - RMASTL
C
C      READ THE FIRST SLAVE STATION AND CHANGE THE LATITUDE
C      AND LONGITUDE INTO RADIANS.DELAY IS THE CODING DELAY
C      AND BIAS IS THE OFFSET IN MICROSECONDS.
C
       READ(5,101) ILATS,IMINS,RSECS,ILONS,ILMINS,RLSECS,
      1 DELAY1,BIAS1
101    FORMAT(1X,I3,1X,I2,1X,F5.2,1X,I4,1X,I2,1X,F5.2,
      1 F9.2,F7.3)
       RSLAV1 = ((IABS(ILATS) * 60 + IMINS) * 60 + RSECS) /
      1 RHOSEC
```

```
      IF(ILATS .LT. 0) RSLAV1 = -RSLAV1
      RSLAL1 = ((IABS(ILONS) * 60 + ILMINS) * 60 + RLSECS) /
     1 RHOSEC
      IF(ILONS .GT. 0) RSLAL1 = TWOPI - RSLAL1
C
C     READ THE SECOND SLAVE STATION AND CHANGE THE LATITUDE
C     AND LONGITUDE INTO RADIANS.
C
      READ(5,101) ILATS,IMINS,RSECS,ILONS,ILMINS,RLSECS,
     1 DELAY2,BIAS2
      RSLAV2 = ((IABS(ILATS) * 60 + IMINS) * 60 + RSECS) /
     1 RHOSEC
      IF(ILATS .LT. 0) RSLAV2 = -RSLAV2
      RSLAL2 = ((IABS(ILONS) * 60 + ILMINS) * 60 + RLSECS) /
     1 RHOSEC
      IF(ILONS .GT. 0) RSLAL2 = TWOPI - RSLAL2
C
C     READ COAST POINT LAT AND LONG AND CONVERT TO RADIANS.
C     STORE LAT IN PHI AND LONG IN ELON.
C
      DO 500 I=1,IREC,1
      READ (5,102) INUM,ILAT,IMIN,RSEC,ILON,ILMIN,RLSEC
102   FORMAT(1X,I4,I4,I3,F7.3,I5,I3,F7.3)
      PHI(I) = ((IABS(ILAT) * 60 + IMIN) * 60 + RSEC) /
     1 RHOSEC
      IF(ILAT .LT. 0) PHI(I) = -PHI(I)
      ELON(I) = ((IABS(ILON) * 60 + ILMIN) * 60 + RLSEC) /
     1 RHOSEC
      IF(ILON .GT. 0) ELON(I) = TWOPI - ELON(I)
C
C     COMPUTE DISTANCE FROM COAST POINT TO MASTER AND
C     SLAVE STATIONS. SET UP COMPUTATION AND CALL INVER1
C
      P1 = PHI(I)
```

```
      E1 = ELON(I)
      CALL INVER1(A,F,P1,E1,RMAST,RMASTL,AZF,AZB,S)
      DISTM(I) = S
      AZM(I) = AZF
      CALL INVER1(A,F,P1,E1,RSLAV1,RSLAL1,AZF,AZB,S)
      DIST1(I) = S
      AZ1(I) = AZF
      CALL INVER1(A,F,P1,E1,RSLAV2,RSLAL2,AZF,AZB,S)
      DIST2(I) = S
      AZ2(I) = AZF
      WRITE(6,210) I,INUM,ILAT,IMIN,RSEC,ILON,ILMIN,RLSEC,
     1 AZM(I),AZ1(I),AZ2(I)
210   FORMAT(1X,I4,I4,I4,I3,F7.3,I5,I3,F7.3,3F10.3)
500   CONTINUE
C
C     READ THE NUMBER OF RECORDS AND THEIR POSITIONS.
C     COMPUTE THE TOTAL DISTANCE OVER LAND AND SEA.
C      TDISTM = TOTAL DISTANCE FROM MASTER TO DATA POINT.
C      TDISTS = TOTAL DISTANCE FROM SLAVE TO DATA POINT.
C
C     COMPUTE THE FORWARD AND BACK AZIMUTHS
C       FAZM AND FAZS = FORWARD AZIMUTH TO THE MASTER AND
C       SLAVE STATION.
C       BAZM AND BAZS = BACK AZIMUTH TO THE MASTER AND
C       SLAVE STATION.
C
      READ(5,103) JREC
103   FORMAT(1X,I4)
C
      DO 550 I=1,JREC,1
      READ(5,104)ILAT,IMIN,RSEC,ILON,ILMIN,RLSEC,RATE1,RATE2
104   FORMAT(1X,I3,I3,F6.3,I5,I3,F6.3,F9.3,F9.3)
C
C     CONVERT LAT AND LONG TO RADIANS.
```

```
C
      RPOST = ((IABS(ILAT) * 60 + IMIN) * 60 + RSEC) /
     1 RHOSEC
      IF(ILAT .LT. 0) RPOST = -RPOST
      RPOSTL = ((IABS(ILON) * 60 + ILMIN) * 60 + RLSEC) /
     1 RHOSEC
      IF(ILON .GT. 0) RPOSTL = TWOPI - RPOSTL
C
C     COMPUTE DISTANCES AND AZIMUTHS FROM THE OBSERVED
C     POINT TO THE INTERPOLATED SHORE POINT AND WRITE.
C
      ISTA = 1
      CALL SHORPT(IREC,RPOST,RPOSTL,RMAST,RMASTL,UTDISM,
     1 USDIST,ULDIST,FAZM,BAZM)
      CALL SECFAC(UTDISM,USDIST,ULDIST,BAZM,ISTA,SFM)
C
      CALL SHORPT(IREC,RPOST,RPOSTL,RSLAV1,RSLAL1,UTDIS1,
     1 USDIST,ULDIST,FAZ1,BAZ1)
      CALL SECFAC(UTDIS1,USDIST,ULDIST,BAZ1,ISTA1,SF1)
C
      CALL SHORPT(IREC,RPOST,RPOSTL,RSLAV2,RSLAL2,UTDIS2,
     1 USDIST,ULDIST,FAZ2,BAZ2)
      CALL SECFAC(UTDIS2,USDIST,ULDIST,BAZ2,ISTA2,SF2)
C
C     COMPUTE THE RATES AND COMPARE TO THE OBSERVED RATES
C
      TDM1 = UTDIS1 - UTDISM + SF1 - SFM + DELAY1 + BIAS1
      DIFF1 = TDM1 - RATE1
C
      TDM2 = UTDIS2 - UTDISM + SF2 - SFM + DELAY2 + BIAS2
      DIFF2 = TDM2 - RATE2
C
C     COMPUTE THE LANE WIDTH IN METERS BASED ON EQUATION
C     4.20 IN ELECTRONIC SURVEYING AND NAVIGATION - LAURILA,
```

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C     PAGE 94.
C
      BR1 = DABS(FAZ1 - FAZM)
      IF(BR1 .GT. PI) BR1 = TWOPI - BR1
      BR2 = DABS(FAZ2 - FAZM)
      IF(BR2 .GT. PI) BR2 = TWOPI - BR2
      WIDTH1 = (DIFF1 * UNCOV * 0.5) / DSIN(BR1 * 0.5)
      WIDTH2 = (DIFF2 * UNCOV * 0.5) / DSIN(BR2 * 0.5)
C
C     WRITE THE POSITION OF VESSEL,  OBSERVED RATES,
C     AND THE DIFFERENCES BETWEEN THEM.
C
      WRITE(6,200) ILAT,IMIN,RSEC,ILON,ILMIN,RLSEC,RATE1,
     1 DIFF1,RATE2,DIFF2
200   FORMAT(1X,I2,I3,F7.3,I4,I3,F7.3,F10.2,F6.2,F10.2,F6.2)
C
C     XMEAN1 AND XMEAN2 ARE THE MEAN DIFFS BETWEEN THE
C     COMPUTED RATE AND THE OBERSERVED. XSLAV1 AND XSLAV2
C     ARE THE STORED DIFFS.
C
      XMEAN1 = XMEAN1 + DIFF1
      XMEAN2 = XMEAN2 + DIFF2
      XMEAN3 = XMEAN3 + WIDTH1
      XMEAN4 = XMEAN4 + WIDTH2
      XSLAV1(I) = DIFF1
      XSLAV2(I) = DIFF2
550   CONTINUE
C
C     COMPUTE THE MEAN AND STANDARD DEVIATION
C
      XMEAN1 = XMEAN1 / JREC
      XMEAN2 = XMEAN2 / JREC
      XMEAN3 = XMEAN3 / JREC
      XMEAN4 = XMEAN4 / JREC
```

```
C
      DO 600 I = 1,JREC,1
      VAR1 = VAR1 + ((XSLAV1(I) - XMEAN1)**2)
600   VAR2 = VAR2 + ((XSLAV2(I) - XMEAN2)**2)
C
      VAR1 = VAR1 / (JREC - 1.0)
      VAR2 = VAR2 / (JREC - 1.0)
C
      SD1 = DSQRT(VAR1)
      SD2 = DSQRT(VAR2)
C
      WRITE(6,201)
      WRITE(6,210) XMEAN1,SD1,XMEAN3
      WRITE(6,201)
      WRITE(6,211) XMEAN2,SD2,XMEAN4
      WRITE(6,202)
210   FORMAT(1X,' SLAVE #1, MEAN = ',F10.3,
     1 ' STANDARD DEVIATION = ',
     2 F10.3,' DISTANCE IN METERS = ',F10.3)
211   FORMAT(1X,' SLAVE #2, MEAN = ',F10.3,
     1 ' STANDARD DEVIATION = ',
     2 F10.3,' DISTANCE IN METERS = ',F10.3)
      WRITE(6,201)
201   FORMAT(1H )
202   FORMAT(1H1)
      STOP
      END
C==============================================================
      SUBROUTINE SHORPT(IREC,RPOST,RPOSTL,RCONT,RCONTL,UDIST,
     1 USD,ULD,FA,BA)
C--------------------------------------------------------------
C
C     SUBROUTINE SHORPT WILL SELECT A POINT ALONG THE SHORE
C     WHICH IS OUTLINED FROM NORTH BY SELECTED POINTS WITH
```

```
C     KNOWN LATITUDES AND LONGITUDES.  THE SHORE POINT IS
C     INTERPOLATED BETWEEN TWO KNOWN POINTS USING THE TOTAL
C     DISTANCE BETWEEN THE POSITION AND THE CONTROL STATION
C     AND THE AZIMUTH BETWEEN THE SHORE POINTS AND THE
C     RECEIVERS POSITION.
C
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION FAZM(100)
      COMMON/SHORE/PHI(100),ELON(100),UNCOV,RN,A,F
      DATA PI/3.14159265358980/
C
      TWOPI = 2.0 * PI
C
      CALL INVER1(A,F,RPOST,RPOSTL,RCONT,RCONTL,FA,BA,RDISTT)
      UDIST = (RN * RDISTT) / UNCOV
C
      RCOMP = 99999.99
C
      DO 10 J=1,IREC,1
      P1 = PHI(J)
      E1 = ELON(J)
      CALL INVER1(A,F,P1,E1,RCONT,RCONTL,AZF,AZB,RDISTL)
      CALL INVER1(A,F,RPOST,RPOSTL,P1,E1,FAZ,BAZ,RDISTS)
      USD = (RN * RDISTS) / UNCOV
      ULD = (RN * RDISTL) / UNCOV
      FAZM(J) = AZF
C
C     COMPUTE THE DIFFERENCE BETWEEN THE TOTAL DISTANCE
C     (UDIST) AND THE SUMMATION OF THE DISTANCE OVER THE WATER
C     (USD) AND THE DISTANCE OVER THE LAND (ULD).  IT THE
C     DISTANCE IS LESS THAN RCOMP, UPDAT RCOMP AND JSTA.
C     JSTA IS THE CLOSEST POINT ALONG THE SHORELINE WHICH IS
C     NEAR THE EM PROPAGATION PATH.
C
```

```
      FDIFF = DABS(UDIST -  (USD + ULD))
      IF(FDIFF .GT. RCOMP)  GO TO 10
      RCOMP = FDIFF
      JSTA = J
10    CONTINUE
C
C     NOW DETERMINE THE INTERPOLATED LATITUDE AND LONGITUDE
C     SHORE POINT USING AZIMUTH PERCENTAGE.
C
      IUPPER = JSTA - 1
      ILOWER = JSTA + 1
      AZMU  = FAZM(IUPPER)
      AZML  = FAZM(ILOWER)
      IF(AZMU .GT. FA .AND. FA .GE. FAZM(JSTA)) ICH = IUPPER
      IF(FAZM(JSTA) .GE. FA .AND. FA .GT. AZML) ICH = ILOWER
C
      RADJ  = 1.00 - DABS((FAZM(ICH) - FA) / (FAZM(ICH) -
     1 FAZM(JSTA)))
C
      RNWPHI = PHI(JSTA) + ((PHI(ICH) - PHI(JSTA)) * RADJ)
      IF(ELON(JSTA) .LE. ELON(ICH)) RADJ = 1.0 - RADJ
      RNWELN = ELON(JSTA) + ((ELON(ICH) - ELON(JSTA)) * RADJ)
C
      CALL TODMS(RNWPHI,IDG,MIN,SEC)
      RHOLD = TWOPI - RNWELN
      CALL TODMS(RHOLD,IDGL,MINL,SECL)
C
      CALL INVER1(A,F,RNWPHI,RNWELN,RCONT,RCONTL,AZ,BZ,RDISTL)
      CALL INVER1(A,F,RPOST,RPOSTL,RNWPHI,RNWELN,AZ,BZ,RDISTS)
      USD = (RN * RDISTS) / UNCOV
      ULD = (RN * RDISTL) / UNCOV
      RETURN
      END
C=====================================================================
```

```
      SUBROUTINE SECFAC(UTDIST,USDIST,ULDIST,AZI,ISTA,SF)
C--------------------------------------------------------------
C
C     THIS ROUTINE WILL COMPUTE THE LAND/SEA SECONDARY FACTOR
C        UTDIST = TOTAL DISTANCE
C        USDIST = DISTANCE OVER THE SEA WATER PATH
C        ULDIST = DISTANCE OVER THE LAND PATH
C        AZI = AZIMUTH FROM NORTH.
C
C        MASTER = 1 (ISTA)
C        W      = 2
C        X      = 3
C        Y      = 4
C
      IMPLICIT REAL*8 (A-H,O-Z)
      S1 = (.795 / USDIST) + 0.439 + (.00245 * USDIST)
C
      IF(UTDIST .GT. 540) GO TO 10
      S2 = (3.188 / UTDIST) - 0.594 + (.000329 * UTDIST)
      GO TO 20
10    S2 = (128.8 / UTDIST) + 0.187 + (.000652 * UTDIST)
C
20    IF(USDIST .GT. 540) GO TO 30
      S3 = (3.188 / USDIST) - 0.594 + (.000329 * USDIST)
      GO TO 40
30    S3 = (128.8 / USDIST) + 0.187 + (.000652 * USDIST)
C
40    IF(ULDIST .GT. 540) GO TO 50
      S4 = (3.188 / ULDIST) - 0.594 + (.000329 * ULDIST)
      GO TO 60
50    S4 = (128.8 / ULDIST) + 0.187 + (.000652 * ULDIST)
C
60    S5 = 1.428 + (.00158 * UTDIST)
      S6 = 1.428 + (.00158 * ULDIST)
```

```
      TAZI = 2.0 * AZI
      GO TO (70,80,90,100),ISTA
70    RHOLD =    (1.010*DSIN(AZI)) - (.196*DCOS(AZI))
     1         - (.893*DSIN(TAZI)) - (.355*DCOS(TAZI))
      GO TO 200
80    RHOLD =    (.323*DCOS(AZI)) - (.711*DSIN(TAZI))
      GO TO 200
90    RHOLD =    (.942*DCOS(TAZI))
      GO TO 200
100   RHOLD =    (.588*DSIN(TAZI))
C
200   S5 = S5 + RHOLD
      S6 = S6 + RHOLD
      SF = 0.5 * (S5 + S6 - S1 + S2 + S3 - S4)
      WRITE(6,500) S1,S2,S3,S4,S4,S5,S6,SF
500   FORMAT(1X,7F15.5)
      RETURN
      END
C================================================================
      SUBROUTINE INVER1(A,FINV,GLAT1,GLON1,GLAT2,GLON2,FAZ,
     1 BAZ,S)
C----------------------------------------------------------------
      See Appendix B for subroutine INVER1.
```

Short points around Monterey Bay, California. The point are used to interpolate geodetic point for computation of the distance over land and the distance over sea.

NO.	LATITUDE	LONGITUDE
1	36 57 18.606	122 05 37.525
2	36 56 59.264	122 03 01.817
3	36 57 05.076	122 01 31.701
4	36 57 49.538	122 01 07.857
5	36 57 17.949	121 58 19.830
6	36 58 08.589	121 57 07.288
7	36 58 32.140	121 55 10.083
8	36 58 01.498	121 53 57.390
9	36 56 46.115	121 52 22.313
10	36 55 38.140	121 51 24.399
11	36 53 13.806	121 49 46.743
12	36 49 38.384	121 47 48.895
13	36 47 39.241	121 47 10.818
14	36 46 27.554	121 47 39.637
15	36 44 56.717	121 47 52.416
16	36 41 14.439	121 48 32.642
17	36 39 17.211	121 49 28.533
18	36 37 31.128	121 50 31.728
19	36 36 23.446	121 51 34.833
20	36 36 03.628	121 52 50.879
21	36 36 24.782	121 53 48.453
22	36 37 18.151	121 54 11.628
23	36 38 00.300	121 55 57.538

DATA SET EXAMPLE - PROGRAM LOPLC

SHIP'S POSITION LATITUDE (D-M-S)			SHIP'S POSITION LONGITUDE (D-M-S)			OBSERVED LORAN RATES & ERRORS (E) 9940-Y (µsec)	EY (µsec)	9940-W (µsec)	EW (µsec)
36	43	45.800	121	55	27.160	42789.34	1.14	16294.04	1.32
36	44	3.400	121	55	32.340	42791.13	1.25	16293.46	1.29
36	44	21.180	121	55	37.390	42793.04	1.25	16292.73	1.40
36	44	37.490	121	55	46.950	42795.13	1.05	16292.03	1.33
36	44	53.260	121	55	57.710	42796.93	1.12	16291.43	1.11

APPENDIX D

PROGRAM LORTAB

```
C     PROGRAM LORTAB
C
C     PROGRAM COMPUTES LINE OF POSITION FOR LORAN-C USING
C     SF SALT WATER CORRECTION FACTOR AND DMAHTC CALCULATED
C     OR FIELD OBSERVED ASF CORRECTIONS.
C
C
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION AXIS(13),RF(13)
      DIMENSION XSLAV1(1000),XSLAV2(1000)
      DATA RHOSEC,PI,UNCOV,RN/2.062648062471D05,
     1 3.14159265358 98D0,299.792458D0,1.000338D0/
      DATA XMEAN1,XMEAN2,VAR1,VAR2/0.00D0,0.00D0,
     1 0.00D0,00.0D0/
      DATA XMEAN3,XMEAN4/0.00D0,0.00D0/
C
CCCCCC**********************************
      DATA AXIS/6.3782064D06,6.378388   D06,6.377397155D06,
     1 6.37816 D06,6.37816D06,6.378249145D06,6.378165D06,
     2 6.378166D06,6.378165 D06,6.378145D06,6.3775634D06,
     3 6.378245D06,6.3781350D06/
      DATA RF/6.3565838   D06,2.97   D02,2.9915281285D02,
     1 2.9825D02,2.982471674 27D02,2.93465D02,2.9825D02,
     2 2.983 D02,2.983D02,2.9825 D02,6.3562569D06,
     3 2.983 D02,2.9826D02/
C*****ELLIPSOID OPTION NUMBER
C     1. CLARKE 1866                 8. MERCURY
C     2. INTERNATIONAL (HAYFORD)     9. MARSHALL ISLAND
C     3. BESSEL 1841                10. NAVY 8D
```

```
C      4. AND (AUSTRALIAN)             11. AIRY
C      5. 1967 REFERENCE               12. KRASSOWSKI 1940
C      6. CLARKE 1880 MOD              13. WGS 1972
C      7. SAO
C
CCCCCC*********************************
C      CC1-2 = ELLIPSOID NUMBER (K)
C      CC3-5 = NUMBER OF POINTS ALONG COAST (IREC)
C
       READ(5,100) K,IREC,ID1,ID2
100    FORMAT(1X,I2,I4,2I3)
       TWOPI=2.*PI
       A=AXIS(K)
       F=1./RF(K)
       IF(F.LT.3.D-3) F=(A-1./F)/A
C
C      READ MASTER AND SLAVE STATIONS POSITIONS
C      THE FIRST RECORD IS THE NUMBER OF MASTER AND SLAVE
C      STATIONS FOR THE PARTICULAR CHAIN.
C
       WRITE(6,202)
202    FORMAT(1H1)
       WRITE(6,201).
201    FORMAT(1H )
       READ(5,105) ILATM,IMINM,RSECM,ILONM,ILMINM,RLSECM
       WRITE(6,105) ILATM,IMINM,RSECM,ILONM,ILMINM,RLSECM
105    FORMAT(1X,I3,1X,I2,1X,F5.2,1X,I4,1X,I2,1X,F5.2)
       RMAST = ((IABS(ILATM) * 60 + IMINM) * 60 + RSECM) /
      1 RHOSEC
       IF(ILATM .LT. 0) RMAST = -RMAST
       RMASTL = ((IABS(ILONM) * 60 + ILMINM) *60 +RLSECM) /
      1 RHOSEC
       IF(ILONM .GT. 0) RMASTL = TWOPI - RMASTL
C
```

```
C     READ THE FIRST SLAVE STATION AND CHANGE THE LATITUDE
C     AND LONGITUDE INTO RADIANS.
C
      READ(5,101) ILATS,IMINS,RSECS,ILONS,ILMINS,RLSECS,
     1 DELAY1
      WRITE(6,101) ILATS,IMINS,RSECS,ILONS,ILMINS,RLSECS,
     1 DELAY1
101   FORMAT(1X,I3,1X,I2,1X,F5.2,1X,I4,1X,I2,1X,F5.2,F9.2)
      RSLAV1 = ((IABS(ILATS) * 60 + IMINS) * 60 + RSECS) /
     1 RHOSEC
      IF(ILATS .LT. 0) RSLAV1 = -RSLAV1
      RSLAL1 = ((IABS(ILONS) * 60 + ILMINS) * 60 + RLSECS) /
     1 RHOSEC
      IF(ILONS .GT. 0) RSLAL1 = TWOPI - RSLAL1
C
C     READ THE SECOND SLAVE STATION AND CHANGE THE LATITUDE
C     AND  LONGITUDE INTO RADIANS.
C
      READ(5,101) ILATS,IMINS,RSECS,ILONS,ILMINS,RLSECS,
     1 DELAY2
      WRITE(6,101) ILATS,IMINS,RSECS,ILONS,ILMINS,RLSECS,
     1 DELAY2
      RSLAV2 = ((IABS(ILATS) * 60 + IMINS) * 60 + RSECS) /
     1 RHOSEC
      IF(ILATS .LT. 0) RSLAV2 = -RSLAV2
      RSLAL2 = ((IABS(ILONS) * 60 + ILMINS) * 60 + RLSECS) /
     1 RHOSEC
      IF(ILONS .GT. 0) RSLAL2 = TWOPI - RSLAL2
      WRITE(6,201)
C
C     READ THE RECORDS POSITIONS AND OBSERVED RATES, THEN
C     COMPUTE THE TOTAL DISTANCE.
C
      DO 550 I=1,IREC,1
```

```
      READ(5,104) ILAT,IMIN,RSEC,ILON,ILMIN,RLSEC,
     1 RATE1,RATE2
104   FORMAT(1X,I3,I3,F6.3,I5,I3,F6.3,3X,2F10.2)
C
C     CONVERT LAT AND LONG TO RADIANS.
C
      RPOST = ((IABS(ILAT) * 60 + IMIN) * 60 + RSEC) /
     1 RHOSEC
      IF(ILAT .LT. 0) RPOST = -RPOST
      RPOSTL = ((IABS(ILON) * 60 + ILMIN) * 60 + RLSEC) /
     1 RHOSEC
      IF(ILON .GT. 0) RPOSTL = TWOPI - RPOSTL
C
C     COMPUTE DISTANCES AND AZIMUTHS FROM THE OBSERVED POINT
C
C            MASTER
C
      CALL INVER1(A,F,RPOST,RPOSTL,RMAST,RMASTL,FAZM,BAZM,
     1 DISTM)
      UDISTM = (RN * DISTM) / UNCOV
      CALL SECFAC(UDISTM,SFM)
C
C            SLAVE1
C
      CALL INVER1(A,F,RPOST,RPOSTL,RSLAV1,RSLAL1,FAZ1,BAZ1,
     1 DIST1)
      UDIST1 = (RN * DIST1) / UNCOV
      CALL SECFAC(UDIST1,SF1)
C
C            SLAVE2
C
      CALL INVER1(A,F,RPOST,RPOSTL,RSLAV2,RSLAL2,FAZ2,BAZ2,
     1 DIST2)
      UDIST2 = (RN * DIST2) / UNCOV
```

```
      CALL SECFAC(UDIST2,SF2)
C
C     DETERMINE THE ADDITIONAL SECONDARY CORRECTORS FROM THE
C     LORAN-C CORRECTION TABLE FOR THE WEST COAST CHAIN 9940
C
      CALL TABLE(RPOST,RPOSTL,ID1,ASF1)
      CALL TABLE(RPOST,RPOSTL,ID2,ASF2)
C
C     COMPUTE THE RATES AND COMPARE TO THE OBSERVED RATES
C
      TDM1 = UDIST1 - UDISTM + SF1 - SFM + ASF1 + DELAY1
      DIFF1 = TDM1 - RATE1
C
      TDM2 = UDIST2 - UDISTM + SF2 - SFM + ASF2 + DELAY2
      DIFF2 = TDM2 - RATE2
C
C
C     COMPUTE THE LANE WIDTH IN METERS BASED ON EQUATION
C     4.20 IN ELECTRONIC SURVEYING AND NAVIGATION -
C     LAURILA, PAGE 94.
C
      BR1 = DABS(FAZ1 - FAZM)
      BR2 = DABS(FAZ2 - FAZM)
      WIDTH1 = (DIFF1 * UNCOV * 0.5) / DSIN(BR1 * 0.5)
      WIDTH2 = (DIFF2 * UNCOV * 0.5) / DSIN(BR2 * 0.5)
C
C     WRITE THE POSITION OF VESSEL, COMPUTED RATE, OBSERVED
C     RATE, AND THE DIFF BETWEEN THEM.
C
      WRITE(6,200) ILAT,IMIN,RSEC,ILON,ILMIN,RLSEC,RATE1,
      DIFF1,RATE2,DIFF2
200   FORMAT(1X,I3,I3,1X,F6.3,I5,I3,1X,F6.3,F12.2,F8.2,
     1 F12.2,F8.2)
      WRITE(6,201)
```

```
C
C     XMEAN1 AND XMEAN2 ARE THE MEAN DIFFS BETWEEN THE
C     COMPUTED RATE AND THE OBERSERVED. XSLAV1 AND XSLAV2
C     ARE THE STORED DIFFS.
C
      XMEAN1 = XMEAN1 + DIFF1
      XMEAN2 = XMEAN2 + DIFF2
      XMEAN3 = XMEAN3 + WIDTH1
      XMEAN4 = XMEAN4 + WIDTH2
      XSLAV1(I) = DIFF1
      XSLAV2(I) = DIFF2
550   CONTINUE
C
C     COMPUTE THE MEAN AND STANDARD DEVIATION
C
      XMEAN1 = XMEAN1 / IREC
      XMEAN2 = XMEAN2 / IREC
      XMEAN3 = XMEAN3 / IREC
      XMEAN4 = XMEAN4 / IREC
C
      DO 600 I = 1,IREC,1
      VAR1 = VAR1 + ((XSLAV1(I) - XMEAN1)**2)
600   VAR2 = VAR2 + ((XSLAV2(I) - XMEAN2)**2)
C
      VAR1 = VAR1 / (IREC - 1.0)
      VAR2 = VAR2 / (IREC - 1.0)
C
      SD1 = DSQRT(VAR1)
      SD2 = DSQRT(VAR2)
C
      WRITE(6,201)
      WRITE(6,210) XMEAN1,SD1,XMEAN3
      WRITE(6,201)
      WRITE(6,211) XMEAN2,SD2,XMEAN4
```

```
      WRITE(6,202)
210   FORMAT(1X,' SLAVE #1, MEAN = ',F10.3,
     1 ' STANDARD DEVIATION = ',
     2 F10.3,' DISTANCE IN METERS = ',F10.3)
211   FORMAT(1X,' SLAVE #2, MEAN = ',F10.3,
     1 ' STANDARD DEVIATION = ',
     2 F10.3,' DISTANCE IN METERS = ',F10.3)
      STOP
C=====================================================================
      SUBROUTINE SECFAC(UTDIST,SF)
C---------------------------------------------------------------------
C
C     THIS ROUTINE WILL COMPUTE THE SEA SECONDARY FACTOR
C        UTDIST = TOTAL DISTANCE
C        SF = SECONDARY FACTOR
C
      IMPLICIT REAL*8 (A-H,O-Z)
C
C
C     COEFFICIENTS
C
      A0 =  129.04323
      A1 = -0.40758
      A2 =  0.00064576813
C
      B0 =  2.741282
      B1 = -0.011402
      B2 = .00032774815
C
      IF(UTDIST .GT. 537) GO TO 10
      SF = ( B0 / UTDIST) + B1 + ( B2 * UTDIST)
      GO TO 20
10    SF = ( A0 / UTDIST) + A1 + ( A2 * UTDIST)
C
```

```
20    CONTINUE
      RETURN
      END
C=====================================================================
      SUBROUTINE TABLE(RLAT,RLON,ID,ASF)
C---------------------------------------------------------------------
C
C     SUBROUTINE TABLE SELECTS THE PROPER ASF CORRECTOR FROM
C     THE LORAN-C CORRECTION TABLE PUBLISHED BY THE DEFENSE
C     MAPPING AGENCY.
C        RLAT = POSITION LATITUDE IN SECONDS
C        RLON = POSITION LONGITUDE IN SECONDS
C        ID   = LORAN-C CHAIN IDENTIFIER
C             W = 1
C             X = 2
C             Y = 3
C        ASF = ADDITIONAL SECONDARY FACTORS
C
C     THE FOLLOWING TABLES OF ASF CORRECTORS ARE FOR
C     MONTEREY BAY, CALIFORNIA - 9940 -W, -X, -Y.
C
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION TABLEW(3,5),TABLEX(3,5),TABLEY(3,5)
C
      DATA TABLEW/ 1.6D0,1.6D0,0.0D0,
     1             1.6D0,1.5D0,1.4D0,
     2             1.5D0,1.4D0,1.6D0,
     3             1.4D0,1.3D0,1.5D0,
     4             1.3D0,0.0D0,0.0D0/
C
      DATA TABLEX/ -0.9D0,-0.9D0, 0.0D0,
     1             -0.9D0,-0.9D0,-0.8D0,
     2             -1.0D0,-1.0D0,-1.0D0,
     3             -1.0D0,-1.2D0,-1.1D0,
```

```
     4              -1.1D0, 0.0D0, 0.0D0/
C
      DATA TABLEY/ 0.2D0,0.2D0,0.0D0,
     1             0.3D0,0.3D0,0.3D0,
     2             0.3D0,0.2D0,0.4D0,
     3             0.4D0,0.3D0,0.6D0,
     4             0.5D0,0.0D0,0.0D0/
      DATA RHOSEC,PI/2.062648062471D05,3.14159265358980D0/
C
      TWOPI = PI * 2.0
C
C     CONVER RLAT AND RLON TO SECONDS
C
      HLAT = RLAT * RHOSEC
      HLON = TWOPI - RLON
      HLON = HLON * RHOSEC
C
C     STARTING LAT AND LONG FOR SEARCH
C        LAT = 37/00/00.0    LONG = 122/05/00.0
C
C
C     DETERMINE THE ASF CORRECTOR FOR THE LORAN-C COMBINATION
C
C     LATITUDE
C
      SLAT = 133200.0
      SLON = 439500.0
      RMID = 300.0
      RDIFF = 150.0
C
      DO 10 J=1,5,1
      SLAT = SLAT - RMID
      ULAT = SLAT + RDIFF
      VLAT = SLAT - RDIFF
```

```
10    IF(hLAT .LT. ULAT .AND. hLAT .GE. VLAT) GO TO 15
15    CONTINUE
C
C     LONGITUDE
C
      DO 30 I=1,3,1
      SLON = SLON - RMID
      ULON = SLON + RDIFF
      VLON = SLON - RDIFF
30    IF(hLON .LT. ULON .AND. hLON .GT. VLON) GO TO 35
35    CONTINUE
C
C     DETERMINE ASF CORRECTOR
C
      ASF = 0.0
      IF(ID .EQ. 1) ASF = TABLEW(I,J)
      IF(ID .EQ. 2) ASF = TABLEX(I,J)
      IF(ID .EQ. 3) ASF = TABLEY(I,J)
      RETURN
      END
C=================================================================
      SUBROUTINE INVER1(A,FINV,GLAT1,GLON1,GLAT2,GLON2,FAZ,
     1 BAZ,S)
C-----------------------------------------------------------------
```

See Appendix B for subroutine INVER1.

DATA SET EXAMPLE - PROGRAM LORTAB

SHIP'S POSITION LATITUDE (D-M-S)	SHIP'S POSITION LONGITUDE (D-M-S)	OBSERVED LORAN RATES & ERRORS (E) 9940-Y (μsec)	EY (μsec)	9940-W (μsec)	EW (μsec)
36 43 45.800	121 55 27.160	42789.34	-0.29	16294.04	0.34
36 44 3.400	121 55 32.340	42791.13	-0.18	16293.46	0.30
36 44 21.180	121 55 37.390	42793.04	-0.18	16292.73	0.41
36 44 37.490	121 55 46.950	42795.13	-0.38	16292.03	0.34
36 44 53.260	121 55 57.710	42796.93	-0.31	16291.43	0.13

APPENDIX E

PROGRAM ASFSEL

```
C     PROGRAM ASFSEL
C
C     PROGRAM DETERMINES OBSERVED ASF CORRECTORS BY SCANNING
C     DATA AT 1 DEGREE LATITUDE AND LONGITUDE INTERVALS. THE
C     ASF CORRECTORS ARE DETERMINED BY SUBTRACTING THE
C     CALCULATED TD USING THE SEAWATER SECONDARY FACTOR FROM
C     THE OBSERVED TD RATES.
C
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION AXIS(13),RF(13)
      DIMENSION ASFCR1(16,26),ASFCR2(16,26),
     1 INO1(16,26),INO2(16,26)
      DATA RHOSEC,PI,UNCOV,RN/2.062648062471D05,
     1 3.14159265358 98D0,299.792458D0,1.000338D0/
      DATA XMEAN1,XMEAN2,VAR1,VAR2/0.00D0,0.00D0,
     1 0.00D0,00.0D0/
      DATA XMEAN3,XMEAN4/0.00D0,0.00D0/
C
CCCCCC************************************
      DATA AXIS/6.3782064D06,6.378388   D06,6.377397155D06,
     1 6.37816 D06,6.37816D06,6.378249145D06,6.378165D06,
     2 6.378166D06,6.378165 D06,6.378145D06,6.3775634D06,
     3 6.378245D06,6.3781350D06/
      DATA RF/6.3565838    D06,2.97   D02,2.99152812 85D02,
     1 2.9825D02,2.98247167427D02,2.93465D02,2.9825D02,
     2 2.983 D02,2.983D02,2.9825 D02,6.3562569D06,
     3 2.983 D02,2.9826D02/
C*****ELLIPSOID OPTION NUMBER
C     1. CLARKE 1866                    8. MERCURY
```

```
C      2. INTERNATIONAL (HAYFORD)    9. MARSHALL ISLAND
C      3. BESSEL 1841               10. NAVY 8D
C      4. AND (AUSTRALIAN)          11. AIRY
C      5. 1967 REFERENCE            12. KRASSOWSKI 1940
C      6. CLARKE 1880 MOD           13. WGS 1972
C      7. SAO
C
CCCCCC***********************************
C      CC1-2 = ELLIPSOID NUMBER (K)
C      CC3-5 = NUMBER OF POINTS ALONG COAST (IREC)
C
       READ(5,100) K,IREC,ID1,ID2
100    FORMAT(1X,I2,I4,2I3)
       TWOPI=2.*PI
       A=AXIS(K)
       F=1./RF(K)
       IF(F.LT.3.D-3) F=(A-1./F)/A
C
C      READ MASTER AND SLAVE STATIONS POSITIONS
C      THE FIRST RECORD IS THE NUMBER OF MASTER AND SLAVE
C      STATIONS FOR THE PARTICULAR CHAIN.
C
       WRITE(6,202)
202    FORMAT(1H1)
       WRITE(6,201)
201    FORMAT(1H )
       READ(5,105) ILATM,IMINM,RSECM,ILONM,ILMINM,RLSECM
       WRITE(6,105) ILATM,IMINM,RSECM,ILONM,ILMINM,RLSECM
105    FORMAT(1X,I3,1X,I2,1X,F5.2,1X,I4,1X,I2,1X,F5.2)
       RMAST = ((IABS(ILATM) * 60 + IMINM) * 60 + RSECM) /
      1 RHOSEC
       IF(ILATM .LT. 0) RMAST = -RMAST
       RMASTL = ((IABS(ILONM) * 60 + ILMINM) *60 +RLSECM) /
      1 RHOSEC
```

```
      IF(ILONM .GT. 0) RMASTL = TWOPI - RMASTL
C
C     READ THE FIRST SLAVE STATION AND CHANGE THE LATITUDE
C     AND LONGITUDE INTO RADIANS.
C
      READ(5,101) ILATS,IMINS,RSECS,ILONS,ILMINS,RLSECS,
     1 DELAY1
      WRITE(6,101) ILATS,IMINS,RSECS,ILONS,ILMINS,RLSECS,
     1 DELAY1
101   FORMAT(1X,I3,1X,I2,1X,F5.2,1X,I4,1X,I2,1X,F5.2,F9.2)
      RSLAV1 = ((IABS(ILATS) * 60 + IMINS) * 60 + RSECS) /
     1 RHOSEC
      IF(ILATS .LT. 0) RSLAV1 = -RSLAV1
      RSLAL1 = ((IABS(ILONS) * 60 + ILMINS) * 60 + RLSECS) /
     1 RHOSEC
      IF(ILONS .GT. 0) RSLAL1 = TWOPI - RSLAL1
C
C     READ THE SECOND SLAVE STATION AND CHANGE THE LATITUDE
C     AND  LONGITUDE INTO RADIANS.
C
      READ(5,101) ILATS,IMINS,RSECS,ILONS,ILMINS,RLSECS,
     1 DELAY2
      WRITE(6,101) ILATS,IMINS,RSECS,ILONS,ILMINS,RLSECS,
     1 DELAY2
      RSLAV2 = ((IABS(ILATS) * 60 + IMINS) * 60 + RSECS) /
     1 RHOSEC
      IF(ILATS .LT. 0) RSLAV2 = -RSLAV2
      RSLAL2 = ((IABS(ILONS) * 60 + ILMINS) * 60 + RLSECS) /
     1 RHOSEC
      IF(ILONS .GT. 0) RSLAL2 = TWOPI - RSLAL2
      WRITE(6,201)
C
C     READ THE RECORDS POSITIONS AND OBSERVED RATES, THEN
C     COMPUTE THE TOTAL DISTANCE.
```

```
C
      DO 550 I=1,IREC,1
      READ(5,104) ILAT,IMIN,RSEC,ILON,ILMIN,RLSEC,
     1 RATE1,RATE2
104   FORMAT(1X,I3,I3,F6.3,I5,I3,F6.3,3X,2F10.2)
C
C     CONVERT LAT AND LONG TO RADIANS.
C
      RPOST = ((IABS(ILAT) * 60 + IMIN) * 60 + RSEC) /
     1 RHOSEC
      IF(ILAT .LT. 0) RPOST = -RPOST
      RPOSTL = ((IABS(ILON) * 60 + ILMIN) * 60 + RLSEC) /
     1 RHOSEC
      IF(ILON .GT. 0) RPOSTL = TWOPI - RPOSTL
C
C     COMPUTE DISTANCES AND AZIMUTHS FROM THE OBSERVED POINT
C     -
C             MASTER
C
      CALL INVER1(A,F,RPOST,RPOSTL,RMAST,RMASTL,FAZM,BAZM,
     1 DISTM)
      UDISTM = (RN * DISTM) / UNCOV
      CALL SECFAC(UDISTM,SFM)
C
C             SLAVE1
C
      CALL INVER1(A,F,RPOST,RPOSTL,RSLAV1,RSLAL1,FAZ1,BAZ1,
     1 DIST1)
      UDIST1 = (RN * DIST1) / UNCOV
      CALL SECFAC(UDIST1,SF1)
C
C             SLAVE2
C
      CALL INVER1(A,F,RPOST,RPOSTL,RSLAV2,RSLAL2,FAZ2,BAZ2,
```

```
     1 DIST2)
      UDIST2 = (RN * DIST2) / UNCOV
      CALL SECFAC(UDIST2,SF2)
C
C     DETERMINE WHICH LAT AND LONG THE ASF CORRECTOR
C     IS ASSIGNED TO.
C
      CALL ASSIGN(RPOST,RPOSTL,JN1,JN2)
C
C     COMPUTE THE RATES AND COMPARE TO THE OBSERVED RATES
C
      TDM1 = UDIST1 - UDISTM + SF1 - SFM + DELAY1
      DIFF1 = TDM1 - RATE1
C
      TDM2 = UDIST2 - UDISTM + SF2 - SFM + DELAY2
      DIFF2 = TDM2 - RATE2
C
C     SUM THE DIFFERENCES TO THE MATRIX AND COUNT THE NUMBER
C     OF ASF CORRECTORS FOR EACH BLOCK TO LATTER DETERMINE
C     THE MEAN.
C
      ASFCR1(JN1,JN2) = ASFCR1(JN1,JN2) + DIFF1
      ASFCR2(JN1,JN2) = ASFCR2(JN1,JN2) + DIFF2
      INO1(JN1,JN2) = INO1(JN1,JN2) + 1
550   INO2(JN1,JN2) = INO2(JN1,JN2) + 1
C
C     DETERMINE THE MEAN ASF CORRECTOR FOR EACH LAT AND LONG
C
      DO 650 I=1,16,1
      WRITE(6,201)
      DO 600 J=1,26,1
      IF(INO1(I,J) .EQ. 0) GO TO 580
      ASFCR1(I,J) = ASFCR1(I,J) / INO1(I,J)
580   IF(INO2(I,J) .EQ. 0) GO TO 590
```

```
      ASFCR2(I,J) = ASFCR2(I,J) / INO2(I,J)
590   IF(ASFCR1(I,J) .EQ. 0.0) ASFCR1(I,J) = 9.99
600   IF(ASFCR2(I,J) .EQ. 0.0) ASFCR2(I,J) = 9.99
650   CONTINUE
C
C     WRITE THE CORRECTORS IN MATRIX FORMAT
C
C
      IF(ID1 .EQ. 1) WRITE(6,1000)
      IF(ID1 .EQ. 2) WRITE(6,1001)
      IF(ID1 .EQ. 3) WRITE(6,1002)
      WRITE(6,201)
C
      WRITE(6,300) ((ASFCR1(I,J),I=1,16),J=1,26)
      DO 700 L=1,5,1
      WRITE(6,201)
201   FORMAT(1H )
700   CONTINUE
C
      IF(ID2 .EQ. 1) WRITE(6,1000)
      IF(ID2 .EQ. 2) WRITE(6,1001)
      IF(ID2 .EQ. 3) WRITE(6,1002)
      WRITE(6,201)
      WRITE(6,300) ((ASFCR2(I,J),I=1,16),J=1,26)
300   FORMAT(16F6.2)
1000  FORMAT(' TABLE FOR 9940-W ')
1001  FORMAT(' TABLE FOR 9940-X ')
1002  FORMAT(' TABLE FOR 9940-Y ')
      STOP
      END
C=============================================================
      SUBROUTINE SECFAC(UTDIST,SF)
C-------------------------------------------------------------
C
```

```
C     THIS ROUTINE WILL COMPUTE THE SEA SECONDARY FACTOR
C        UTDIST = TOTAL DISTANCE
C        SF = SECONDARY FACTOR
C
      IMPLICIT REAL*8 (A-H,O-Z)
C
C
C     COEFFICIENTS
C
      A0 =  129.04323
      A1 = -0.40758
      A2 =  0.00064576813
C
      B0 =  2.741282
      B1 = -0.011402
      B2 = .00032774815
C
      IF(UTDIST .GT. 537) GO TO 10
      SF = ( B0 / UTDIST) + B1 + ( B2 * UTDIST)
      GO TO 20
10    SF = ( A0 / UTDIST) + A1 + ( A2 * UTDIST)
C
20    CONTINUE
      RETURN
      END
C=====================================================================
      SUBROUTINE ASSIGN(RLAT,RLON,I,J)
C---------------------------------------------------------------------
C
C     SUBROUTINE ASSIGN SELECTS THE COLUMN AND ROW FOR
C     THE LATITUDE AND LONGITUDE OF THE RECORD.
C        RLAT = POSITION LATITUDE IN SECONDS
C        RLON = POSITION LONGITUDE IN SECONDS
C        I    = COLUMN
```

```
C         J    = ROW
C
      IMPLICIT REAL*8 (A-H,O-Z)
      DATA RHOSEC,PI/2.062648062471D05,3.14159265358 98D0/
C
      TWOPI = PI * 2.0
C     CONVER RLAT AND RLON TO SECONDS
C
      HLAT = RLAT * RHOSEC
      HLON = TWOPI - RLON
      HLON = HLON * RHOSEC
C
C     STARTING LAT AND LONG FOR SEARCH
C        LAT = 37/05/00.0    LONG = 122/05/00.0
C
      SLAT = 133200.0
      SLON = 439500.0
C
C     LATITUDE
C
      J = 0
      DO 10 IC = 1,26,1
      SLAT = SLAT - 60.0
      RULAT = SLAT +  30.0
      RLLAT = SLAT -  30.0
10    IF(HLAT .LT. RULAT .AND. HLAT .GE. RLLAT) GO TO 15
15    J = IC
C
C     LONGITUDE
C
      I = 0
      DO 20 IC = 1,16,1
      SLON = SLON - 60.0
      RLLON = SLON +  30.0
```

```
      RRLON = SLON -  30.0
20    IF(HLON .LT. RLLON .AND. HLON .GE. RRLON) GO TO 25
25    I = IC
      RETURN
      END
C=====================================================================
      SUBROUTINE INVER1(A,FINV,GLAT1,GLON1,GLAT2,GLON2,FAZ,
     1 BAZ,S)
C---------------------------------------------------------------------
```

See Appendix B for subroutine INVER1.

DATA SET EXAMPLE - PROGRAM ASFSEL

TABLE FOR 9940-Y

122° / 00'

50'						
						-0.41
				-0.53		-0.44
45'	-0.56	-0.51		-0.46	-0.40	
		-0.39	-0.54	-0.39	-0.55	-0.45
				-0.63	-0.57	-0.49
					-0.54	-0.50
						-0.62
40'						
35'						
36°						

TABLE FOR 9940-Y

121° / 55' 121° / 50'

50'								
	-0.45	-0.47	-0.41	-0.37	-0.60			
45'	-0.51	-0.50			-0.43	-0.44	-0.47	-0.44
	-0.38	-0.49	-0.50	-0.46	-0.52	-0.46		
	-0.54	-0.51	-0.49					
	-0.54	-0.57	-0.49					
	-0.55	-0.55	-0.50					
40'	-0.67	-0.61	-0.50					
		-0.64	-0.65					
35'								

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