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ELECTRONIC SYSTEMS DIV HANSCOM AFB MA  
LORAN WARPAGE COEFFICIENTS GENERATION PROGRAM (WARP).(U)  
FEB 81 M A MARCHAND, J L KENNEDY, L A KELLETT  
ESD-TR-81-116-3

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LORAN WARPAGE COEFFICIENTS GENERATION  
PROGRAM (WARP)

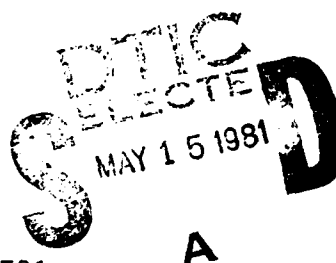
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February 1981

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# ABSTRACT

This report details the final test results of computer program WARP. This program generates coefficients of a least-squares LORAN grid warpage model for use in the AN/ARN-101 Digital Avionics System. The coefficients enhance the capability of the AN/ARN-101 to accurately convert from LORAN time differences to Latitude-Longitude pairs. Test results include, input error checks, boundary jump analysis, altitude effects and input data density.

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1.0 INTRODUCTION. This document is the Test Report for the Warpage Coefficient Generation Program (WARP). This off-line computer support program uses real world Loran time difference (TD) measurements to produce Loran grid warpage correction factors to enable precise AN/ARN-101 navigation and weapon delivery.

1.1 PURPOSE. The test of the Warpage Coefficient Generation Program was designed to define data requirements, evaluate program utility and measure Loran navigational accuracy. The test results provide a basis for formulating guidelines for the operational use of the coefficient generation program in a tactical environment.

1.2 SCOPE. The extensive data base collected during AN/ARN-101 flight testing at Eglin AFB, Florida was used to exercise WARP. The program input data consists of four altitude dependent sets of precise geodetic latitude longitude (LAT/LON) coordinates and the corresponding raw Loran time difference measurements within the Southeast USA Loran-C Chain coverage area. The test defines Loran accuracy as a function of WARP parameters, input data density, altitude, and size of the prime coverage area (PCA). The primary goal of this test activity is to qualify input data requirements and evaluate Loran navigational accuracy. The following test objectives are addressed:

- a. Identification of bad input data
- b. Selection of program constants
- c. Improper spheroid selection
- d. Effects of input data density/size of PCA
- e. TD predictions in void areas
- f. Altitude TD predictions
- g. Boundary conditions
- h. Average and saltwater impedances
- i. Photo reconnaissance data validation
- j. Software program documentation

1.3 TEST OVERVIEW. The data base for this test effort was established in fulfillment of Objective 18 of the Armament Division Test Directive No. 2239EA02, AN/ARN-101 Pave Tack Interoperability Flight Test (F-4 Advanced Avionics Phase II). This objective addressed the mapping of the Southeast USA Loran-C Chain for the purpose of generating Loran warpage coefficients. Four AN/ARN-101 equipped F-4E airborne missions were used to collect data at altitudes of 1500 ft MSL, 5000 ft MSL, 10000 ft MSL, and 15000 ft MSL. Mosaic flight profiles were flown throughout the PCA as shown in Figure 1.

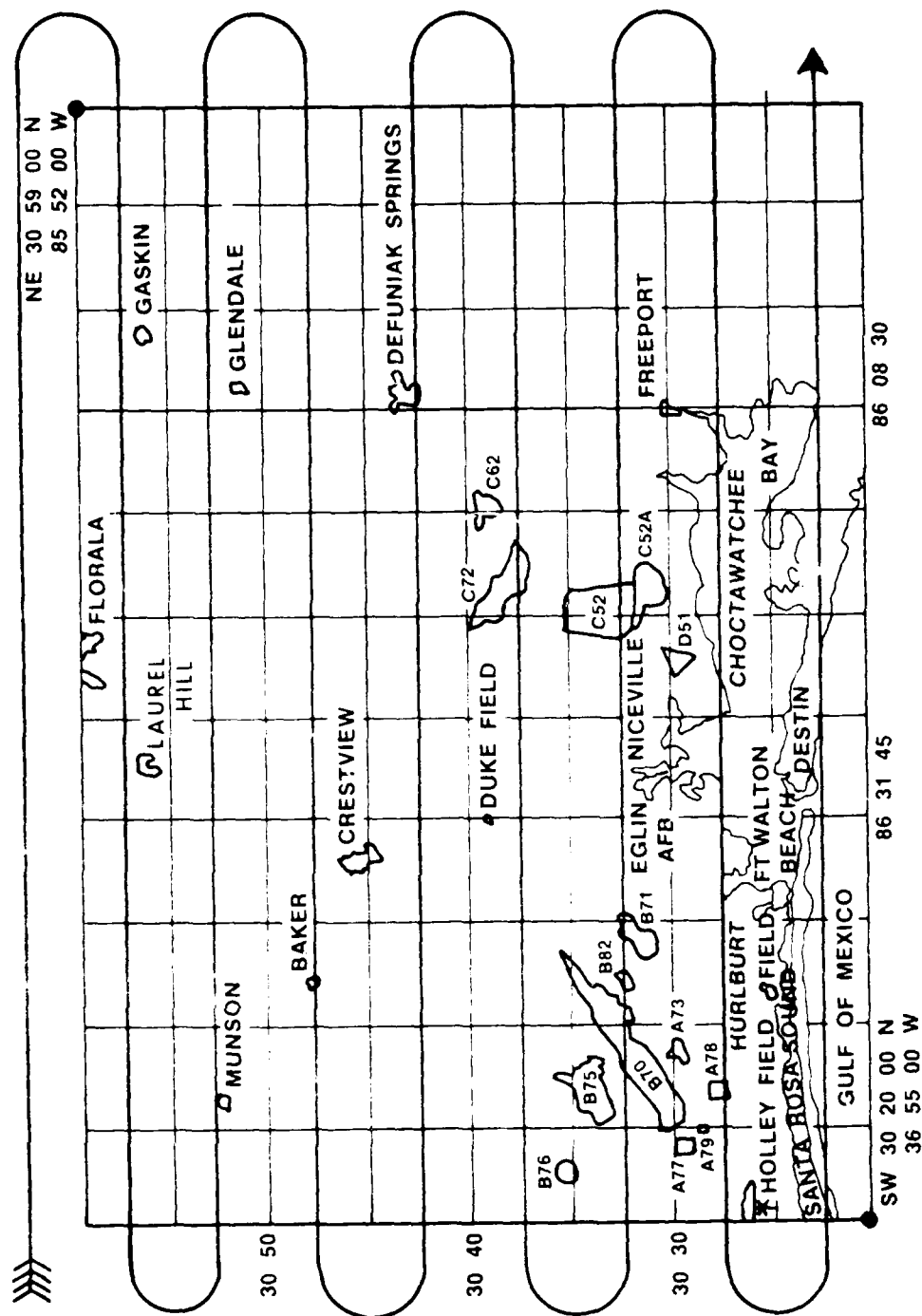


Figure 1. F-4E Aircraft Data Collection Flight Profile

Continuous dual FPS-16 radar and selective phototheodolite coverage was used for accurate space positioning of the aircraft. The aircraft post-flight instrumentation data with merged dual radar/phototheodolite positioning data were time sequenced and merged to provide the required WARP data. Data reduction techniques provided coordinate paired LAT-LONs, TDs, and altitude data points for each of the four flight levels. The selection of data points for use as WARP input was bounded by a 3-space aircraft position error of less than 100 ft. Only selected points, as necessary to satisfy the 5 nm distribution desirability, were chosen with position errors of 100-200 feet.

The revised WARP and the four altitude dependent data bases are currently resident on the Eglin AFB CDC 6600 computer. To each data file is attached additional WARP parameters which define the test area boundaries, Loran chain definitions, the earth spheroid model definition, and nominal program constants. A listing of these program parameters is given in Table I. A detailed analysis of Loran grid warpage and grid warpage correction, prepared by Mr J. L. Howard, the MITRE Corporation, specifically addresses the Eglin activity and is included as Appendix A.

**1.4 GENERAL TEST PROCEDURES.** A statistical evaluator was used to exercise the warpage model against a baseline set of measured LAT-LON/TD coordinate pairs. The evaluator consisted of two baseline data sets (A and B) for each of the required test altitudes. LAT-LON/TD and altitude data points were selected to develop equivalent sets with a density distribution of one point per 5 nm cell providing 98 cell points within the Eglin PCA. The two sets were determined to be statistically equivalent with respect to WARP mean error, standard deviation, and range computations. Once interchangeable, one set was identified as the WARP input data, and the other became the evaluation set used to determine modeling accuracy.

|                    |  | AREA DEFINITIONS |                |                  |                |
|--------------------|--|------------------|----------------|------------------|----------------|
|                    |  | SOUTHWEST CORNER |                | NORTHEAST CORNER |                |
|                    |  | LATITUDE         | LONGITUDE      | LATITUDE         | LONGITUDE      |
| AREA 1 (PRIME)     |  | 37 15 0.000 N    | 127 15 0.000 E | 38 8 0.000 N     | 128 37 0.000 E |
| AREA 2 (SOUTHWEST) |  | 34 15 0.000 N    | 130 15 0.000 E | 37 41 30.000 N   | 127 56 0.000 E |
| AREA 3 (SOUTHEAST) |  | 34 15 0.000 N    | 127 56 0.000 E | 37 41 30.000 N   | 125 37 0.000 E |
| AREA 4 (NORTHEAST) |  | 34 15 0.000 N    | 127 56 0.000 E | 41 8 0.000 N     | 125 37 0.000 E |
| AREA 5 (NORTHWEST) |  | 37 41 30.000 N   | 130 15 0.000 E | 41 8 0.000 N     | 127 56 0.000 E |

|                   |  | LORAN TRIAD PARAMETERS |                 | CODING DELAY PLUS |                              |
|-------------------|--|------------------------|-----------------|-------------------|------------------------------|
|                   |  | STATION LOCATION       |                 | ALTITUDE (METERS) | BASE-LINE LENGTH (MICRO-SEC) |
|                   |  | LATITUDE               | LONGITUDE       |                   |                              |
| MASTER: PHOANG    |  | 36 11 5.798 N          | 129 20 27.279 E | 0.0000            |                              |
| SLAVE A: HOKKAIDO |  | 42 44 37.080 N         | 143 43 10.500 E | 0.0000            | 15781.0600                   |
| SLAVE B: HAMPYONG |  | 35 2 23.871 N          | 126 32 26.741 E | 0.0000            | 31946.6800                   |

|  |  | GS-72 SPHEROID CONSTANTS |                    | PROPAGATION VELOCITY |  |
|--|--|--------------------------|--------------------|----------------------|--|
|  |  | SEMI-MAJOR AXIS          | SEMI-MINOR AXIS    |                      |  |
|  |  | 6378135.011 METERS       | 6356750.531 METERS | 299.69120 M/MICROSEC |  |

|  |  | MISCELLANEOUS INPUT                |            |
|--|--|------------------------------------|------------|
|  |  | EFFECTIVE IMPEDANCE (MASTER):      | .04000000  |
|  |  | INITIAL IMPEDANCE (SLAVE A):       | .03000000  |
|  |  | INITIAL IMPEDANCE (SLAVE B):       | .03000000  |
|  |  | ATMOSPHERIC VERTICAL LAPSE FACTOR: | .85000000  |
|  |  | ATMOSPHERIC INDEX OF REFRACTION:   | 1.00033800 |

TABLE I WAPP Input Parameters

## 2.0 APPLICABLE DOCUMENTS.

The following documents are applicable as defined.

### 2.1 METHOD OF TEST.

The basis for this report is the Method of Test (MOT) for the Loran Warpage Coefficient Generation Program (WARP). The MOT identifies ten (10) objectives for testing the software program. It was prepared by the Electronic Systems Division Operating Location -AF (ESD/OL-AF) at Eglin AFB, Florida. The MOT is dated 28 Dec 79 and is available through ESD/OCN-1, Hanscom AFB, MA.

### 2.2 USER'S MANUAL.

The Warpage Coefficient Generation Program was developed by Lear Siegler, Inc. (LSI) and provided to ESD. The program source listing was accompanied by a preliminary User's Manual LSI YV1007, 18 May 76. The User's Manual was updated by ESD/OCN-1. At the time of testing this manual (OCN 79-305, 1 Nov 79) comprised the most current program documentation.

Results of ESD testing include a revised Fortran program, a new User's Manual, and an Analyst's Manual (See Objective 10).

### 2.3 AN/ARN-101 SPECIFICATION.

The warpage correction requirements are determined by the Computer Program Development Specification for Operational Flight Program, RF-4C (F-4E) Digital Modular Avionics System AN/ARN-101(V), Contract Number F19628-76-C-0024, Document Number CB1001-004A (CB1001-010A).

### 3.0 TEST OBJECTIVES.

#### 3.1 OBJECTIVE 1. Bad Input Data.

3.1.1 DESCRIPTION. Demonstrate that the program is capable of identifying bad input data.

3.1.2 TEST PROCEDURE. Examine WARP to determine the capability to detect bad or erroneous data.

3.1.2.1 PROGRAM MODIFICATION. None

3.1.2.2 DATA REQUIREMENTS. Nominal program input data sets.

3.1.3 TEST RESULTS. Nominal program outputs.

3.1.4 EVALUATION CRITERIA. The input data set consists of correlated Loran time differences and geographical latitude/longitudes. The definition of bad or erroneous data is limited to mean those data points where the measured time differences do not correspond with their associated LAT/LON for reasons other than warpage. Since Loran warpage is defined to be the divergence of the Loran reference relative to a given earth reference due to physical earth properties, it is quite difficult to separate warpage from measurement error.

Within WARP the only error detection mechanism is a test to determine if a computed impedance lies within the real world range of .001055 Z .08. Impedances that fall outside this range are not found in nature and are therefore considered as bad data points.

3.1.5 TEST EVALUATION. The computer program estimates an impedance using a Newton-Raphson iterative scheme. When an interim value violates the prescribed limits, the iteration ceases and results in a non-zero error residual. This non-convergence error residual is used as the flag to identify bad data points. Since there are three unknown impedances and only two time difference equations, the selected approach within WARP sets the master station impedance to a constant value and iterates the slave impedances to reach a simultaneous equation solution. A poor choice of master impedance can cause the iteration scheme to attempt to select non-realizable impedance values for either slave. A look-up table limit value is then reached and a residual TD error results, thus identifying "bad" data. A range of master impedance values can generate a multiple number of valid solutions that may or may not represent real world values. Conversely, a poor choice may also generate TD residuals. (See also Objective 2.).

It is therefore concluded that an error residual flag is not necessarily an indicator of "bad" data, nor is the lack of an error flag a guarantee of "good" data.



3.1.6 RECOMMENDATIONS. A positive means of detecting bad data is to collect three data sets at the same altitude over the same area, thus providing a majority vote comparison to eliminate the "bad" data point. However, this is not expected to be operationally practical. Assuming only one data set is available, it would be appropriate to select an initial master impedance commensurate with the expected soil type. Should error residual flags occur, the master impedance should be iterated up or down one soil type away from the slave impedance limit that was previously flagged. If the residual TD error remains, it is then recommended that suspect data be removed pending further data gathering and analysis of the immediate vicinity of data points in question.

### 3.2 OBJECTIVE 2. Program Constants.

3.2.1 DESCRIPTION. Determine the effects of changes in the values of Master Impedance, Index of Refraction, and Vertical Lapse Factor on the accuracy of the warpage model.

3.2.2 TEST PROCEDURE. This test was performed in two parts. The first part examined the effects of selecting different values for the nominal program constants. These constants were varied one at a time over the ranges given in Table II. For comparison purposes the theoretical maxima and minima are included.

TABLE II  
Constant Ranges and Nominal Values

| Parameter             | Minima   | Test Range |          |        |        |
|-----------------------|----------|------------|----------|--------|--------|
|                       |          | Min        | Nominal  | Max    | Maxima |
| Master Impedance      | 0.001055 | 0.03       | 0.035    | 0.06   | 0.08   |
| Index of Refraction   | 1.0002   | 1.0001     | 1.000338 | 1.0004 | 1.0004 |
| Vertical Lapse Factor | 0.60     | 0.70       | 0.85     | 0.95   | 1.20   |

For the second part of this objective the Vertical Lapse Factor was fixed to the nominal value of 0.35 at the input to the program and varied over the range of 0.60 -1.20 in Overlay 5. This evaluated using the coefficients at values of vertical lapse other than the value used to produce the coefficients. In addition, a brief analysis of the effect of using coefficients at values of Index of Refraction other than what produced them was performed.

3.2.2.1 PROGRAM MODIFICATION. No modification was necessary for part one of this objective. For part two, the main program was augmented by the addition of multiple calls to Overlay 5 (the evaluation overlay). Each call was accompanied by a new value of Vertical Lapse Factor.

3.2.2.2 DATA REQUIREMENTS. 5K ft baseline input data set.

3.2.3 TEST RESULTS. The statistics of the first test are consolidated in Table III.

TABLE III  
Mean TD Errors as Function  
of Program Constants

| Parameter           | Mean Error (usec) |     |       |        |     |       |
|---------------------|-------------------|-----|-------|--------|-----|-------|
|                     | Min               | TDA | Max   | Min    | TDB | Max   |
| Master Impedance    | -.0010            |     | .0035 | -.0027 |     | .0021 |
| Index of Refraction | -.0005            |     | .0005 | .0005  |     | .0019 |
| Vertical Lapse      | -.0005            |     | .0015 | -.0003 |     | .0020 |

For the second test the results are given in Table IV and Figures 2 and 3. Figure 2 is a plot of the mean TD errors as a function of Vertical Lapse while Figure 3 is a plot of the mean error in feet. The latter figure is a direct result of the first. In Table IV the adjusted mean error is the difference between the raw error at each value of Vertical Lapse and the raw error at a lapse factor of 0.5.

TABLE IV  
Mean TD Errors as Function of Vertical Lapse

| Vertical Lapse | TDA Error (usec) | TDB Error (usec) | Raw Mean Error (ft) | Adjusted Mean Error (ft) |
|----------------|------------------|------------------|---------------------|--------------------------|
| .60            | .214             | .401             | 505                 | 349                      |
| .70            | .129             | .240             | 321                 | 165                      |
| .80            | .043             | .081             | 175                 | 19                       |
| .85            | .000             | .032             | 155                 | 0                        |
| .90            | -.043            | -.078            | 135                 | 29                       |
| 1.00           | -.129            | -.238            | 326                 | 170                      |
| 1.10           | -.214            | -.397            | 501                 | 345                      |
| 1.20           | -.299            | -.557            | 689                 | 533                      |

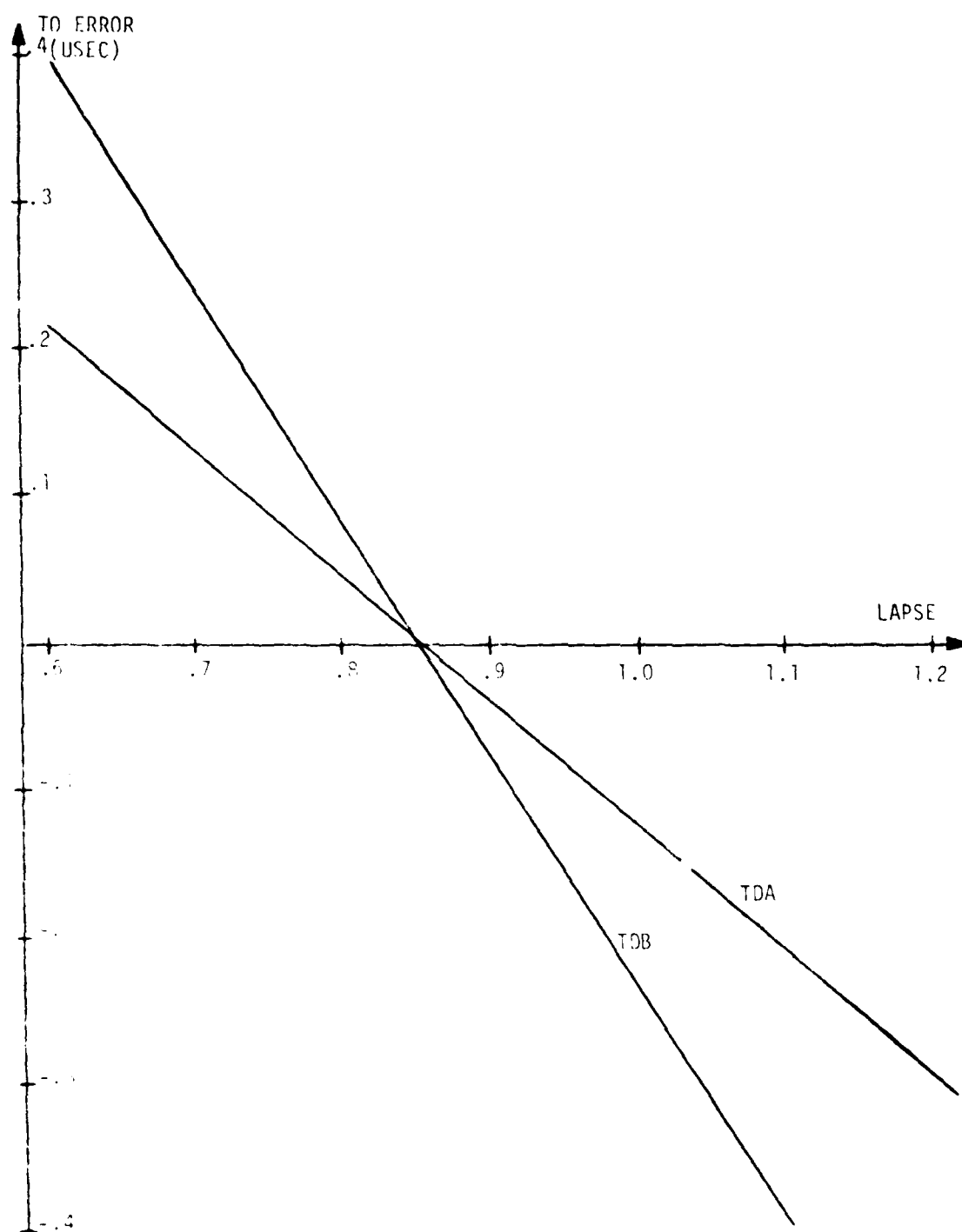


Figure 2. Mean TD Errors as a Function of Vertical Lapse

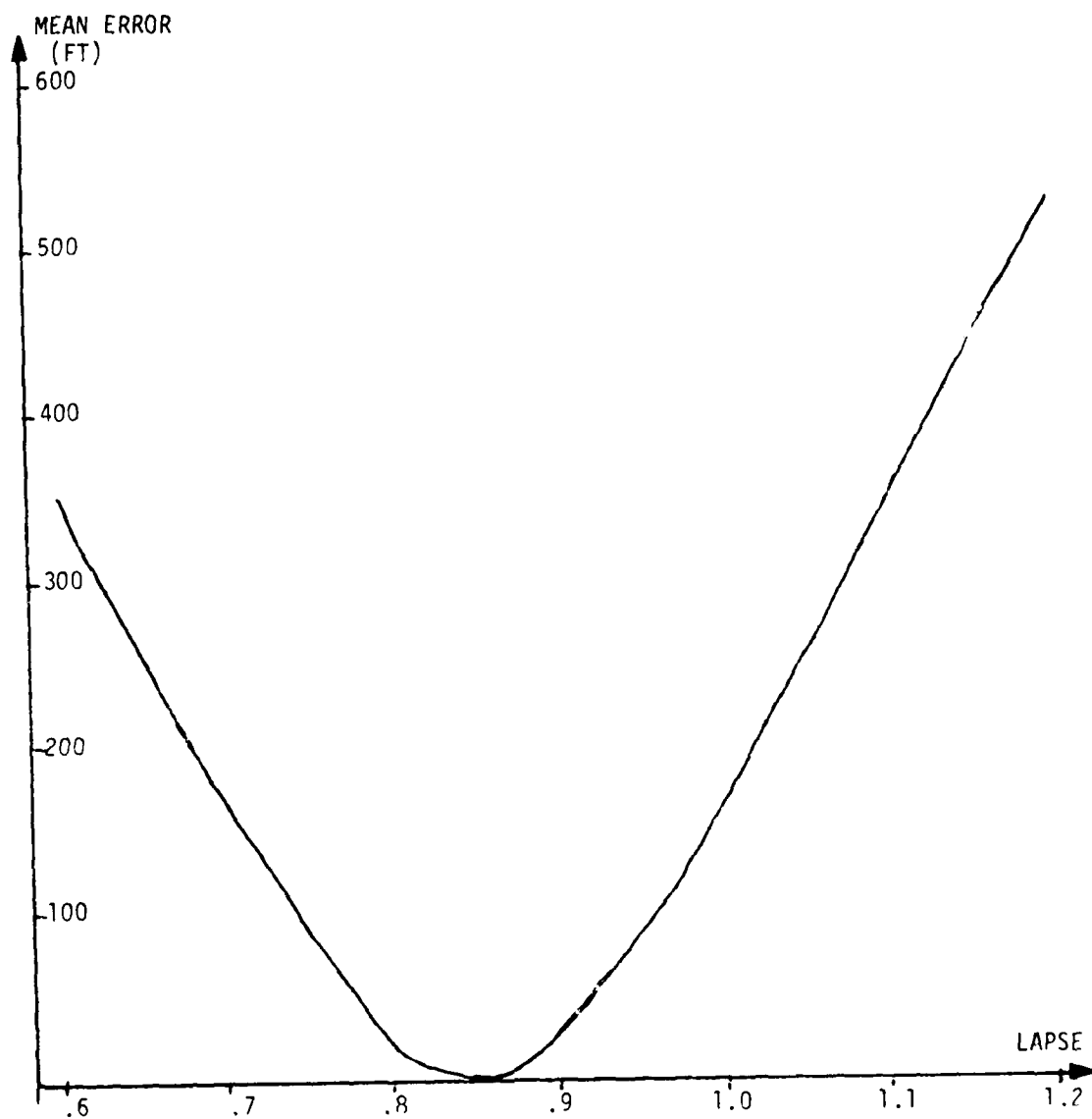


Figure 3. Mean Error (ft) as a Function of Vertical Lapse.

3.2.4 EVALUATION CRITERIA. Mean error is the only evaluation criteria.

3.2.5 TEST EVALUATION. The results given in Table III indicate that the choice of nominal values for the program constants is not a very critical decision. As observed elsewhere in this report, WARP does not drive towards a unique solution. The total range of errors in Table III is well under 10 nanoseconds. Program constants need not represent the real world values observed at the time of data collection. Any differences appear as warpage and are subsequently corrected for in the modeling process.

The second test essentially models the insertion in the AN/ARN-101 of values for Vertical Lapse which are different than the one used to produce the warpage coefficients. As can be seen from Table IV significant error is introduced by inconsistent values of the Vertical Lapse Factor. Since Vertical Lapse is a dynamic function subject to change both daily and seasonally, this test also models the effect of this change on the accuracy of the AN/ARN-101. Although the range of Vertical Lapse given in Table IV accurately models values which may be seen throughout the year, its effect on the AN/ARN-101 is unclear. This is because Loran chains are stabilized relative to fixed monitor locations. Changes in the real world parameters such as Master Impedance, Index of Refraction, and Vertical Lapse Factor are compensated for within the Loran coverage area by the manipulation of the emission delays. Variations in the program constants due to real world fluctuation then become transparent to the AN/ARN-101. This is true in the vicinity of the monitor stations. It is well beyond the scope of this test to attempt to determine the effects as a function of distance away from the monitor locations.

The Index of Refraction problem illustrates the problem of Chain variation and control. Variation of the Index of Refraction throughout its reasonable range of 1.0002 to 1.0004 can introduce an error of about 100 ft per station at a range of 1000 Km. This imposes a maximum upper bound on the position error to about 300 ft. Changes in the Index of Refraction cause a linear change with distance in the times of arrival of the wave fronts. These changes are compensated for at the monitor locations by adjusting the emission delays by a fixed amount. This step change is not equally valid everywhere in the coverage area.

3.2.6 RECOMMENDATIONS. The major findings of this objective clearly state the need for consistency of variable definitions between WARP and the AN/ARN-101. Choice of variables is non-critical as long as the values chosen allow the data to converge to acceptable solutions. Warpage coefficients then generated are valid for real world conditions similar to those that existed at the time of data collection.

It is firmly recommended that additional analysis and testing be undertaken to determine the long term validity of the warpage coefficients over seasonal changes as well as during adverse weather conditions. This will require a detailed investigation of the AN/ARN-101 coordinate conversion process in addition to further research into the relevance of the selection of constants to model variables.

### 3.3 OBJECTIVE 3. Improper Spheroid Selection.

3.3.1 DESCRIPTION. Determine the degradation of modeling accuracy as a function of incorrect and inconsistent spheroid selection.

3.3.2 TEST PROCEDURE. To limit the scope of this test, two cases were evaluated to determine the magnitude of positional error resulting from selection of inconsistent or incorrect spheroid (more precisely ellipsoid) earth models. The first test was to mismatch spheroid coordinate systems in processing the data within WARP, and the second test was to simulate an AN/ARN-101 operator error by selecting an inconsistent earth model in the AN/ARN-101.

Reference spheroids are implicitly or explicitly defined in four separate areas of the warpage correction process. These areas are the LORAN Chain coordinates, the LAT-LON data pairs, processes internal to WARP, and processes within the AN/ARN-101. In the AN/ARN-101, any one of seven spheroids may be selected and the defining parameters of these earth models are given in Table V.

TABLE V  
REFERENCE SPHEROIDS

| REFERENCE<br>SPHEROID* | SEMI-MAJOR AXIS<br>IN METERS | INVERSE OF<br>FLATTENING |
|------------------------|------------------------------|--------------------------|
| International          | 6378388.0000                 | 297.                     |
| Clark 1866             | 6378206.4000                 | 294.978698               |
| Clark 1880             | 6378249.1450                 | 293.464999               |
| Everest                | 6377276.3452                 | 300.801699               |
| Bessel                 | 6377397.1550                 | 299.152812               |
| Australian             | 6378160.0000                 | 298.25                   |
| WGS-72                 | 6378135.0110                 | 298.26                   |

\*The reference source for these spheroid models is the Program Development Specification for Navigational Computer of RF-4C Digital Modular Avionics System AN/ARN-101, Contract Number F19628-76-C-0024, CB1001-004, Page 804, Table 119, Charting Spheroids.

In the first test, the Loran chain and warpage data was modeled using the WGS-72 survey system. The seven different spheroid models were then used in generating warpage coefficients. Positional errors were noted, thus simulating improper WARP spheroid selection.

For test two, the warpage coefficients were generated using the consistent survey system (i.e., WGS-72 data and spheroid model), but the seven different spheroid models were then used to evaluate positional error, thus simulating ARN-101 operator selection of the wrong earth model.

3.3.2.1 PROGRAM MODIFICATION. WARP was modified to use the spheroid under test instead of the fixed Clark 1866 model. The only purpose of the reference spheroid is in the calculation of arc length distances from the data points to the stations. However, this calculation is done twice; first in Overlay 3, used in the generation of warpage coefficients; and second, in Overlay 5 used for evaluating the coefficients.

For the first test, WARP was modified so that both spheroids would simultaneously use the values in Table V. In the second test, the first spheroid was selected to be the WGS-72 model while the second was iterated through all the table values.

3.3.2.2 DATA REQUIREMENTS. One set of input data and the spheroid values defined in Table V.

3.3.3 TEST RESULTS. The test results are given in Tables VI and VII. In Table VI the spheroids are the same and in Table VII only the second spheroid is varied. Figure 4 is a plot of the normal probability curves for four different spheroids with the Australian, Clark 1880 and Clark 1866 being virtually identical to the WGS-72 plot.

3.3.4 EVALUATION CRITERIA. Evaluation criteria is the standard deviation and mean error of the total error function given in feet as shown in Tables VI and VII.

3.3.5 TEST EVALUATION. The results of the tests indicate that the accuracy of the warpage correction is not a function of spheroid choice as long as that choice is consistent. The WGS-72, Australian, Clark 1866, and Clark 1880, and to a lesser extent the International appear to be virtually interchangeable. From Table VII it is clear that the Bessel and Everest spheroids cannot be arbitrarily substituted for any other spheroid. The major hazard in the spheroid selection process is to select in the AN/ARN-101 either of these two spheroids when the warpage coefficients have been generated using a different one. There is also a potential hazard if the input data and the Loran chain are in different reference systems. This error source would be very difficult to measure because it would be a strong function of position on the earth.



TABLE VI

Positional Error Due to Inconsistent Spheroid Selection in Warpage Coefficient Generation Process.

| SPHEROID<br>MODEL | MEAN ERROR (USEC) |       | AVERAGE<br>ERROR (FT) |
|-------------------|-------------------|-------|-----------------------|
|                   | TDA               | TDB   |                       |
| INTERNATIONAL     | -.0003            | .0021 | 133.29                |
| CLARK 1880        | -.0002            | .0017 | 133.44                |
| EVEREST           | .0026             | .0000 | 134.49                |
| BESSEL            | .0021             | .0003 | 133.34                |
| AUSTRALIAN        | .0002             | .0018 | 133.44                |
| NGS 72            | .0003             | .0018 | 133.46                |
| CLARK 1866        | .0001             | .0017 | 133.45                |

TABLE VII

Positional Error Due to Incorrect Spheroid Selection in the AN/ARN-101.

| SPHEROID<br>MODEL | MEAN ERROR (USEC) |        | AVERAGE<br>ERROR (FT) |
|-------------------|-------------------|--------|-----------------------|
|                   | TDA               | TDB    |                       |
| INTERNATIONAL     | .0003             | .0018  | 133.46                |
| CLARK 1880        | -.0038            | -.0061 | 133.56                |
| EVEREST           | .1204             | .2313  | 296.46                |
| BESSEL            | .1456             | .2586  | 327.02                |
| AUSTRALIAN        | -.0356            | -.0007 | 134.86                |
| NGS 72            | -.0231            | .0022  | 134.09                |
| CLARK 1866        | -.0445            | -.0701 | 153.75                |

A - WGS-72  
 B - INTERNATIONAL  
 C - BESSEL  
 D - EVEREST

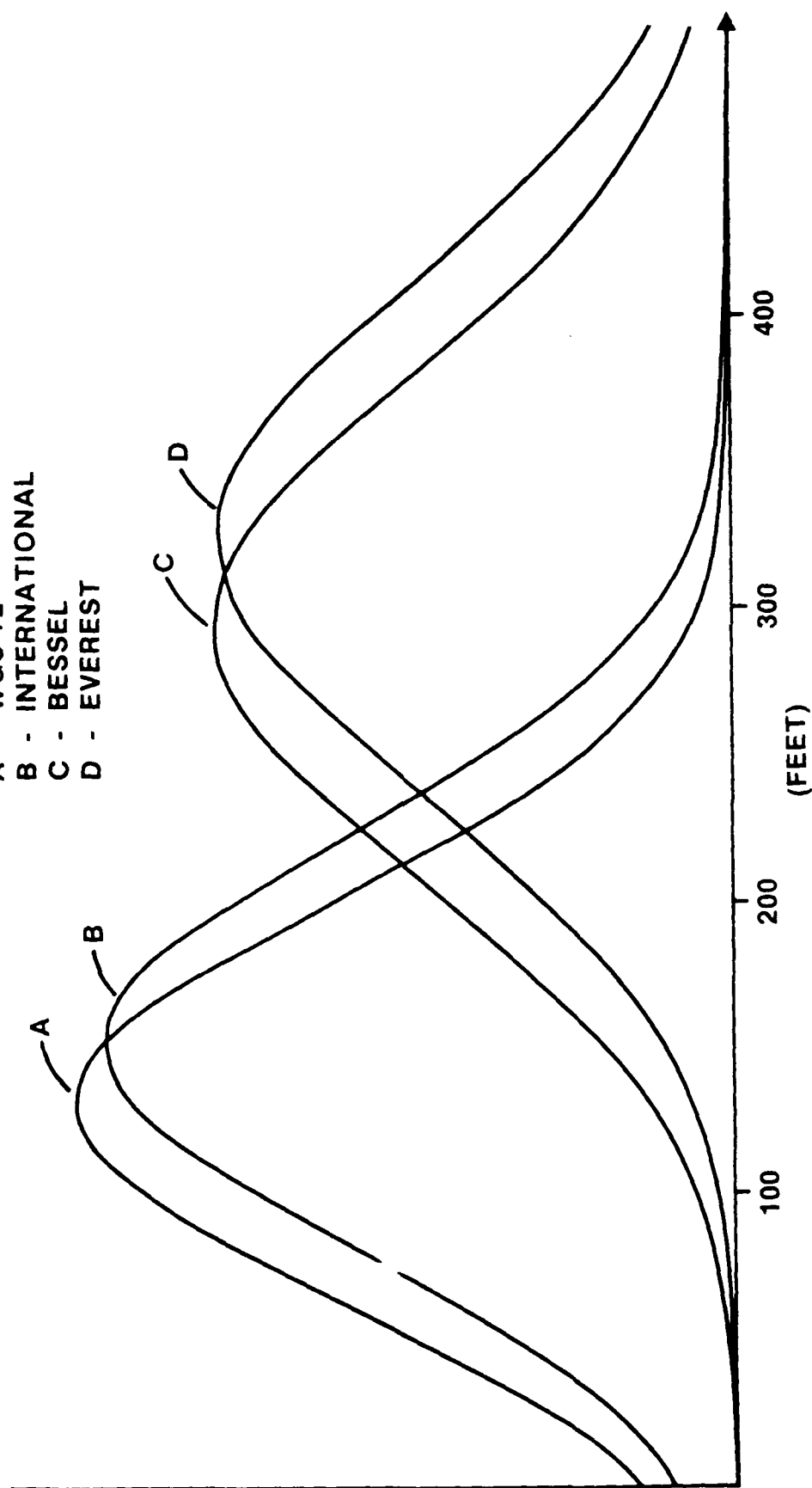


Figure 4. Spheroid Probability Functions.

3.3.6 RECOMMENDATIONS. WARP should be modified to perform the distance calculations only once. This will require that the distances be saved in common storage for use by additional overlays. In addition, the constants representing all the various spheroids should be added to the program. The program operator should be able to select any of the available spheroids. These changes will make WARP consistent with AN/ARN-101 operation.

Additional analysis needs to be done on the requirement for the AN/ARN-101 to model seven different spheroids. Table VI implies that the choice of spheroid is irrelevant. If the reference spheroid is only used to compute arc lengths between the data points and the LORAN stations, then selectable spheroids could be eliminated in favor of one spheroid. This would probably increase the apparent warpage but it would be a self-correcting process. As long as WARP and the AN/ARN-101 are consistent there should be no degradation in the overall model accuracy. The operation of the AN/ARN-101 and WARP would be simplified. Additionally, some savings in AN/ARN-101 program size and execution time would be realized.

The Defense Mapping Agency Aerospace Center (DMAAC) has the initial responsibility to exercise WARP and generate warpage coefficients. DMAAC has the capability to translate LAT/LONs from one coordinate system to another so it is not particularly important to fix the choice of reference before the input data is gathered. It is, however, most important that the user specify the spheroid(s) that is desired for his operational area. For the best accuracy the AN/ARN-101 must use the same spheroid that was used to generate the coefficients.

### 3.4 OBJECTIVE 4. Input Data Density/Size of PCA.

3.4.1 DESCRIPTION. Investigate the degradation of position accuracy as a function of input data density.

3.4.2 TEST PROCEDURE. Input data sets were generated at the following densities: 5mm sq, 10mm x 5mm, 10mm sq, 15mm x 5mm, and 15mm sq. The data set at the 5mm density was the evaluator data set. The other four data sets were input to WARP and warpage coefficients generated. Each set of coefficients was retained and evaluated using the evaluation data set. This consisted of rerunning program Overlays 1, 2, 3, and 5 with the evaluator data set as input to the basic program. This enabled evaluation of coefficients at a data point density greater than the input point density.

3.4.2.1 PROGRAM MODIFICATION. Two program modifications were made. The first change was to add the ability to attach two input files, with different names, to the Batch Job control file. The second modification was made to WARP itself. Specifically, Overlay 0, the program executive routine, was extended after the original final overlay call to redefine the input data file to the second data file attached by the Batch Job Control file. Then all overlays except Overlay 4 were called again. Since the coefficients were generated by Overlay 4 and remained in common storage, this had the effect of evaluating the second data set using the coefficients as generated by processing the first data set.

3.4.2.2 DATA REQUIREMENTS. From a master data set, an evaluator data set of points at a density of approximately 1 point per 5mm square was generated. The independent data sets listed above were also created. Less than 10% common points were allowed between the test and evaluation data sets.

3.4.3 TEST RESULTS. The test results are given in Table VIII. The asterisks in the table indicate errors greater than that allowed by the computer program.

3.4.4 EVALUATION CRITERIA. The evaluation criteria is the change in the composite mean error function in feet for the test data sets as compared to the error of the evaluator data set.

3.4.5 TEST EVALUATION. From Table VIII, it is concluded that data gathered at a density of less than 1 point every 5mm does not adequately model the coverage area. There is also some empirical data which indicates that with a larger prime area, a lesser data density may be tolerable. Unfortunately, no data over such a large area exists but some observations may be made.

Contour plots of the various data sets show that uniform data coverage is very important. Void areas do not constrain the modeled surface and many may actually produce very radical behavior of the model. Evaluation of the model only at the data points will not detect this.

TABLE VIII  
LORAN WARPAGE MODEL ACCURACY AS A FUNCTION OF POINT DENSITY

| POINT<br>DENSITY | NORTH (FT) |         | EAST (FT) |         | COMPOSITE<br>AVERAGE<br>ERROR (FT) |
|------------------|------------|---------|-----------|---------|------------------------------------|
|                  | AVE        | STD DEV | AVE       | STD DEV |                                    |
| 5mm Sq           | 2          | 130     | 0         | 60      | 114                                |
| 10mm x 5mm       | -386       | 1086    | -76       | 130     | 779                                |
| 10mm Sq          | 1624       | 12095   | *         | 73253   | 13343                              |
| 15mm Sq          | *          | *       | *         | *       | *                                  |

The data at Eglin AFB was gathered over a region about 40 X 50mm. At the preferred density of 1 point/5mm square, this gave 33 points organized 3 x 11. A prime area of 100mm per side will have 400 points at the same density organized 20 x 20. Doubling the interval between the data points will give 4 x 6 and 10 X 10 points over the respective coverage areas. Although the two areas differ greatly in size, this distinction is meaningless within WARP and within the AN/ARN-101 system as well. Every prime area is normalized into a region of fixed dimensions regardless of its size. Since the warpage model is preordained to be of order four it would seem that mathematically the number of data points constraining the two dimensions would be very important. However, further investigation of the mathematical requirements verses the geophysical realities of the earth is considered to be beyond the scope of this test effort.

**3.4.6 RECOMMENDATIONS.** Although there is some evidence to the contrary, the lack of data over a large area forces the conclusion that data should be gathered on 5mm centers. Since void areas caused unbounded errors to occur, it is recommended that WARP be modified to fill in empty cells with reasonable impedance values. This will tend to constrain the warpage polynomial to reasonable warpage correction values and further aid in "smoothing" the modeling process.

3.5 OBJECTIVE 5. T.D. Prediction in Void Areas.

3.5.1 DESCRIPTION. Determine the ability of the program to predict time differences in regions of the prime area that are devoid or nearly devoid of input data points.

3.5.2 TEST PROCEDURE. N/A

3.5.2.1 PROGRAM MODIFICATION. N/A

3.5.2.2 DATA REQUIREMENTS. N/A

3.5.3 TEST RESULTS. N/A

3.5.4 EVALUATION CRITERIA. N/A

3.5.5 TEST EVALUATION. At the time the method of test was written it was felt that a prediction capability might exist within the program. The results of Objective 4 and an analysis of the computer program clearly shows that no such capability exists.

3.5.6 RECOMMENDATIONS. See Objective 4.

### 3.6 OBJECTIVE 6. Altitude Time Difference Effects.

3.6.1 DESCRIPTION. Determine if a data set gathered at one altitude can generate coefficients which are usable at other altitudes.

3.6.2 TEST PROCEDURE. Four sets of data were gathered over the Eglin Prime Coverage Area at the following approximate altitudes: 1000, 5000, 10000, and 15000 ft MSL. These sets were independently edited to a density of one point per five nautical miles square. The evaluation of the data proceeded similarly to the method used for the Input Point Density, Objective 4. That is, each data set generated a warpage model which is completely described mathematically by the warpage coefficients and the area boundaries. All four data sets were processed against each of the four models and the effects on each was measured. These sixteen combinations of data and warpage models gave a comprehensive view of the altitude effects for the prime coverage area under test.

3.6.2.1 PROGRAM MODIFICATION. This test objective used the same version of WARP as did Objective 4.

3.6.2.2 DATA REQUIREMENTS. Four sets of LAT-LON/TO data pairs gathered within the following altitude boundaries: 0-2500 ft, 2500-7500 ft, 7500-12500 ft, and 12500-17500 ft.

3.6.3 TEST RESULTS. Table IX shows the average positional error and normal standard deviation of the data as well as the quartile boundaries. The table is organized in four parts. In each part a different coefficient-generating input data set is held constant and all four data sets are evaluated against it. Table IX does not include data collection error as part of the data.

TABLE IX

#### LORAN WARPAGE POSITIONAL ERROR

##### a. WARPAGE MODEL GENERATED FROM 1K INPUT DATA

| ALT<br>FT | ERROR (FT) |        |     | QUARTILES (FT) |        |     |
|-----------|------------|--------|-----|----------------|--------|-----|
|           | AVE        | ST DEV | MAX | 1/4            | MEDIAN | 3/4 |
| 1K        | 152        | 91     | 434 | 93             | 136    | 196 |
| 5K        | 144        | 105    | 558 | 75             | 115    | 193 |
| 10K       | 149        | 99     | 462 | 74             | 134    | 193 |
| 15K       | 198        | 136    | 673 | 107            | 177    | 251 |

b. WARPAGE MODEL GENERATED FROM 5K INPUT DATA

| ALT<br>(FT) | ERROR (FT) |        |     | QUANTILES (FT) |        |     |
|-------------|------------|--------|-----|----------------|--------|-----|
|             | AVE        | ST DEV | MAX | 1/4            | MEDIAN | 3/4 |
| 1K          | 153        | 112    | 548 | 81             | 121    | 216 |
| 5K          | 124        | 98     | 461 | 54             | 110    | 165 |
| 10K         | 132        | 80     | 332 | 77             | 111    | 179 |
| 15K         | 186        | 107    | 521 | 115            | 167    | 236 |

c. WARPAGE MODEL GENERATED FROM 10K INPUT DATA

| ALT<br>(FT) | ERROR (FT) |        |     | QUANTILES (FT) |        |     |
|-------------|------------|--------|-----|----------------|--------|-----|
|             | AVE        | ST DEV | MAX | 1/4            | MEDIAN | 3/4 |
| 1K          | 191        | 129    | 767 | 103            | 156    | 236 |
| 5K          | 160        | 107    | 627 | 96             | 134    | 198 |
| 10K         | 102        | 62     | 379 | 57             | 95     | 135 |
| 15K         | 153        | 89     | 389 | 81             | 137    | 195 |

d. WARPAGE MODEL GENERATED FROM 15K INPUT DATA

| ALT<br>(FT) | ERROR (FT) |        |     | QUANTILES (FT) |        |     |
|-------------|------------|--------|-----|----------------|--------|-----|
|             | AVE        | ST DEV | MAX | 1/4            | MEDIAN | 3/4 |
| 1K          | 254        | 139    | 876 | 112            | 218    | 335 |
| 5K          | 214        | 161    | 744 | 97             | 180    | 254 |
| 10K         | 165        | 107    | 475 | 33             | 145    | 223 |
| 15K         | 91         | 52     | 271 | 53             | 87     | 123 |



**3.6.4 EVALUATION CRITERIA.** The primary evaluation criteria is the average error in feet. Contour plots are used to support several general observations, but they are not sufficiently rigorous to permit precise evaluation by themselves.

**3.6.5 TEST EVALUATION.** Figures 5 through 8 are a series of warpage contour plots for the Slave A or Grangeville, Louisiana station. Figures 9 through 12 are a similar series of plots for Slave B or Jupiter, Florida station. Contour plots of plots are ordered from lower to higher altitude in a similar fashion to Table IX. These plots are in time units and represent the difference between a homogeneous Earth and the real one. As such, the plots illustrate the secondary phase correction factor ( $T_c$ ) or warpage that must be taken into account when converting from time differences to latitude/longitude. The important purpose for having the contour plots is to provide one measure of quality control check in the data collection process. In the absence of significant terrain features, such as hills or mountains, the variation in  $T_c$  as a function of altitude should be fairly linear up to 4-5 miles. The light prime average error varies from sea level to about 300 ft MSL, so it is reasonable to model the region as being of uniform elevation.

Examination of the contour plots reveals that the rate of change of  $T_c$  between 10K to 15K feet is apparently much greater than the change between any other adjacent data sets. There are a number of possible explanations to account for the behavior of the 15K data set. Among them are: incorrect data in the data collection process, weather fronts in the coverage area, and a possible variation in the local chain for all or part of the data gathering session. The only means of validating the 15K data set, short of repeating the data gathering process for this altitude, is to examine it in relation to the other data sets. Table IX includes the results of the 15K data but that portion should be viewed with suspicion.

The results shown in Table IX indicate that data gathered at a higher altitude generates warpage coefficients that are accurate at higher altitudes. Although the data doesn't strongly support the conclusion that data gathered at 100 feet is usable to 15K feet, the incremental error introduced at 15K is not unreasonable. It is concluded, therefore, that data gathered at 10 to 5K ft/s generates coefficients that are accurate from the collection level to at least 15K feet MS. This conclusion is limited to prime coverage areas that are functionally flat. Insufficient data exists to clearly define the necessary degree of flatness.

Examination of Table IX also shows that data gathered at higher altitudes does not describe the warpage at lower altitudes quite as well as the reverse situation. Two probable causes of this are due to local warpage being predominately a surface phenomena and by the way in which the warpage is modeled. Local signal warpage is caused by the electrical properties of the earth from the surface down to perhaps 100 meters. Its effect dissipates as a function of altitude above the ground. At some elevation well above 15K, the earth appears to be a uniformly conducting body. Over a given region the warpage smooths out as a function of altitude. The warpage coefficient generation program is a least-squares fit to measured data with the warpage coefficients being the result of this fitting process. Fitting curves or surfaces to data by the method of least-squares causes the description of the data to be smoother than the raw data.

It is seen that the smoothing function of the modeling process complements the smoothing function of moving away from the earth's surface. It is probably not possible to begin with smoother high level data and try to roughen it sufficiently to describe warpage at lower altitudes because there might be local anomalies which are evident at lower altitudes only. Metal structures, power lines, and fences produce effects, for example, that may be important at 1K feet but not 5K feet.

3.6.6 RECOMMENDATIONS. In flat terrain, one or two low altitude data sets should adequately describe the warpage as a function of altitude. Additional levels of data tend to be functionally redundant but can be very valuable for data validation purposes. Three levels of data are sufficient to provide for a majority vote means of validation. Validation is very important because of the extreme difficulty of separating measurement error from warpage. Data gathered at lower altitudes is more descriptive of the total vertical profile than data gathered at higher altitudes.

To insure the most precise navigation solutions, data should be gathered at as many altitude levels as specified. Realizing that available resources may dictate that fewer altitudes be flown, it is strongly recommended that data be collected at the same altitude at which subsequent operational missions are to be flown.

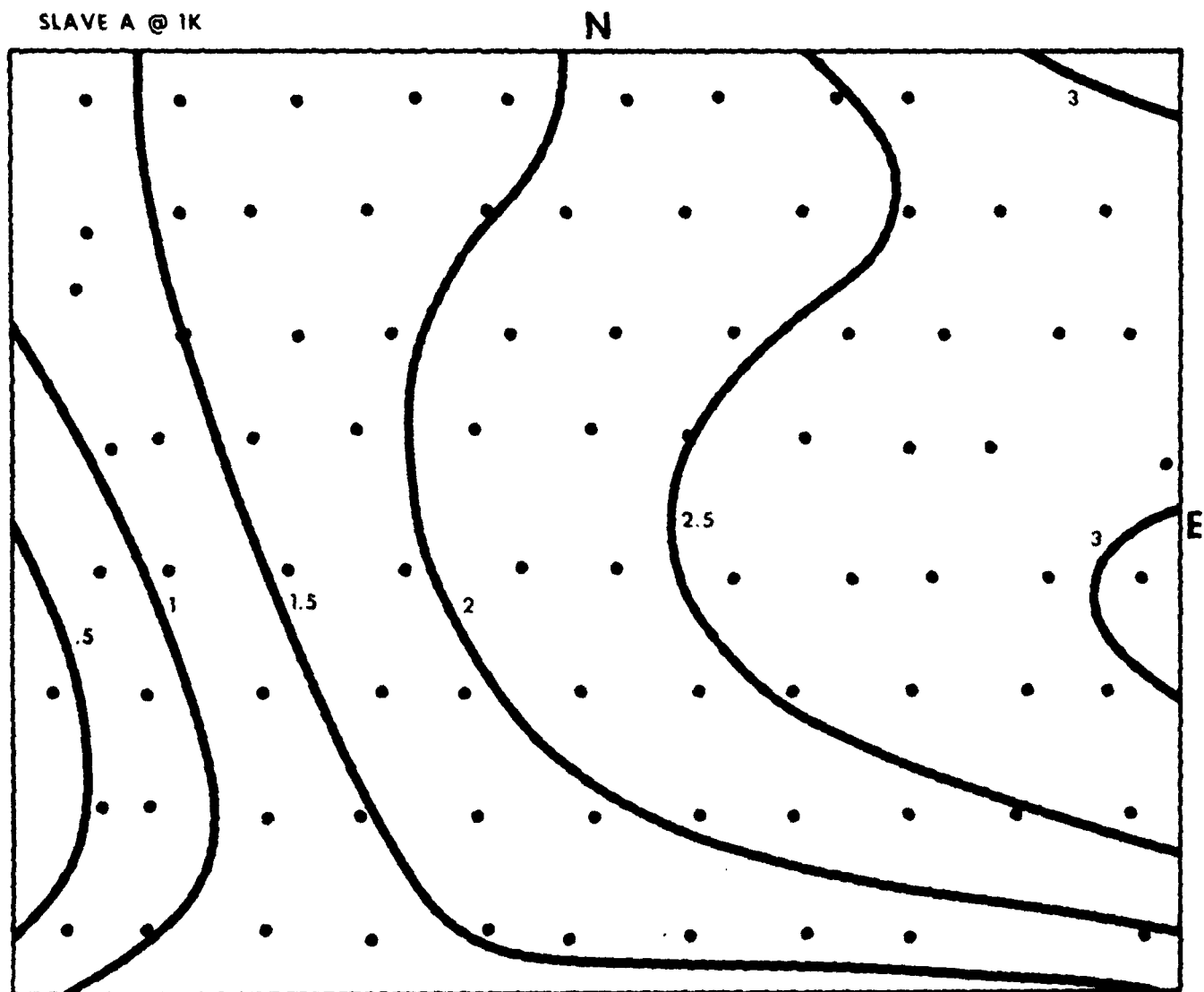


Figure 5. Warpage Contour Plot (case) - Slave A, 1K

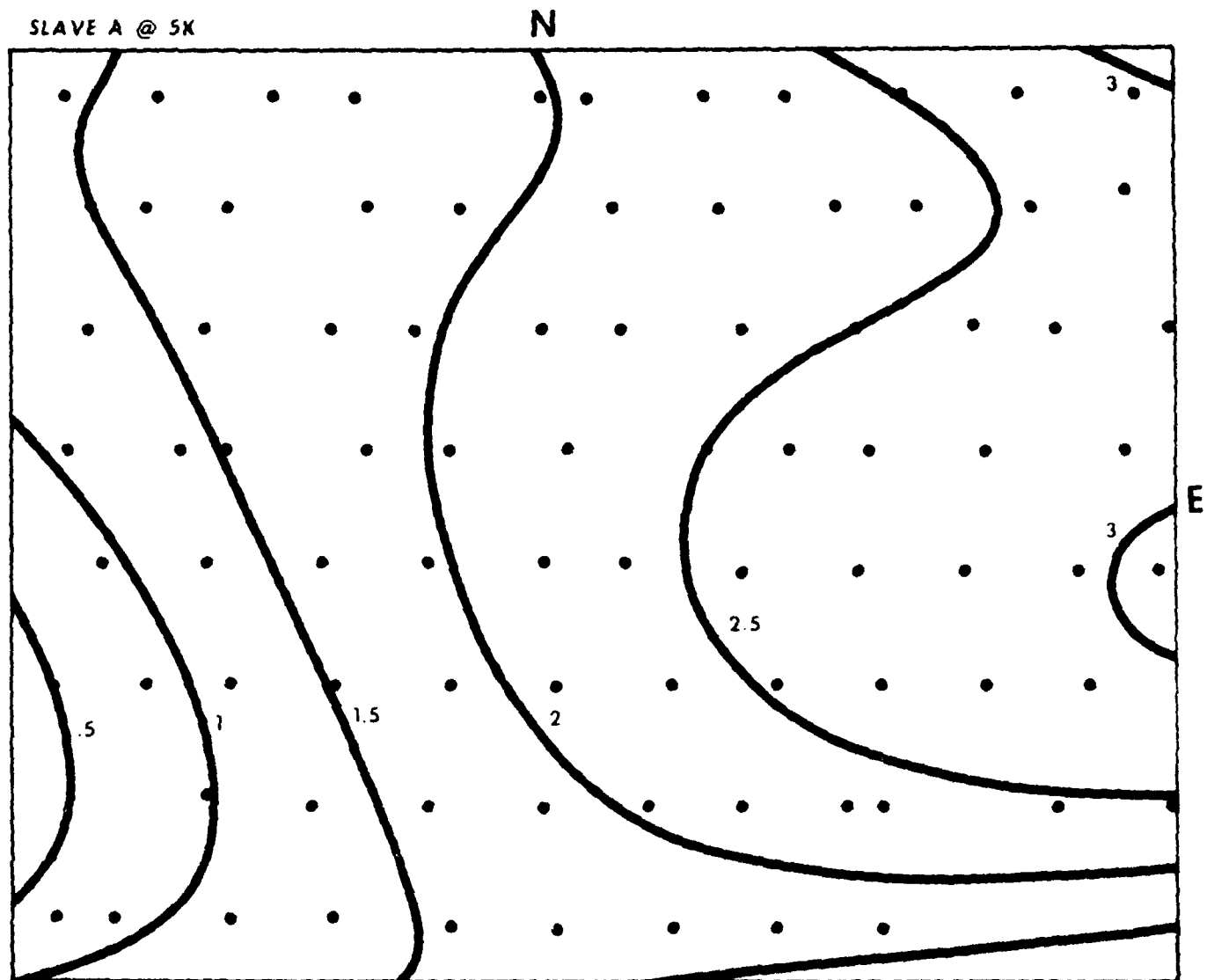
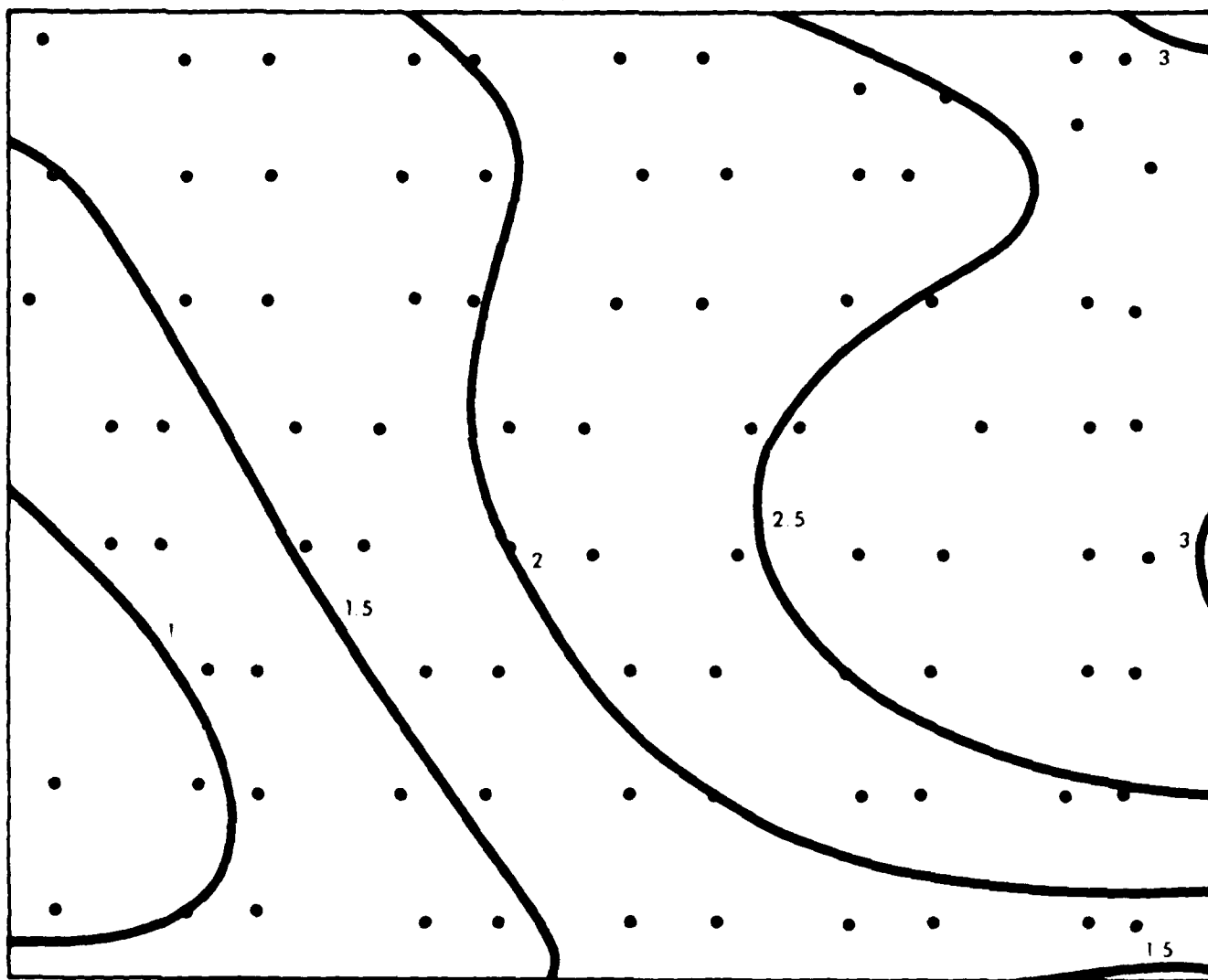


Figure 6. Water level distribution, Slave A, 5K

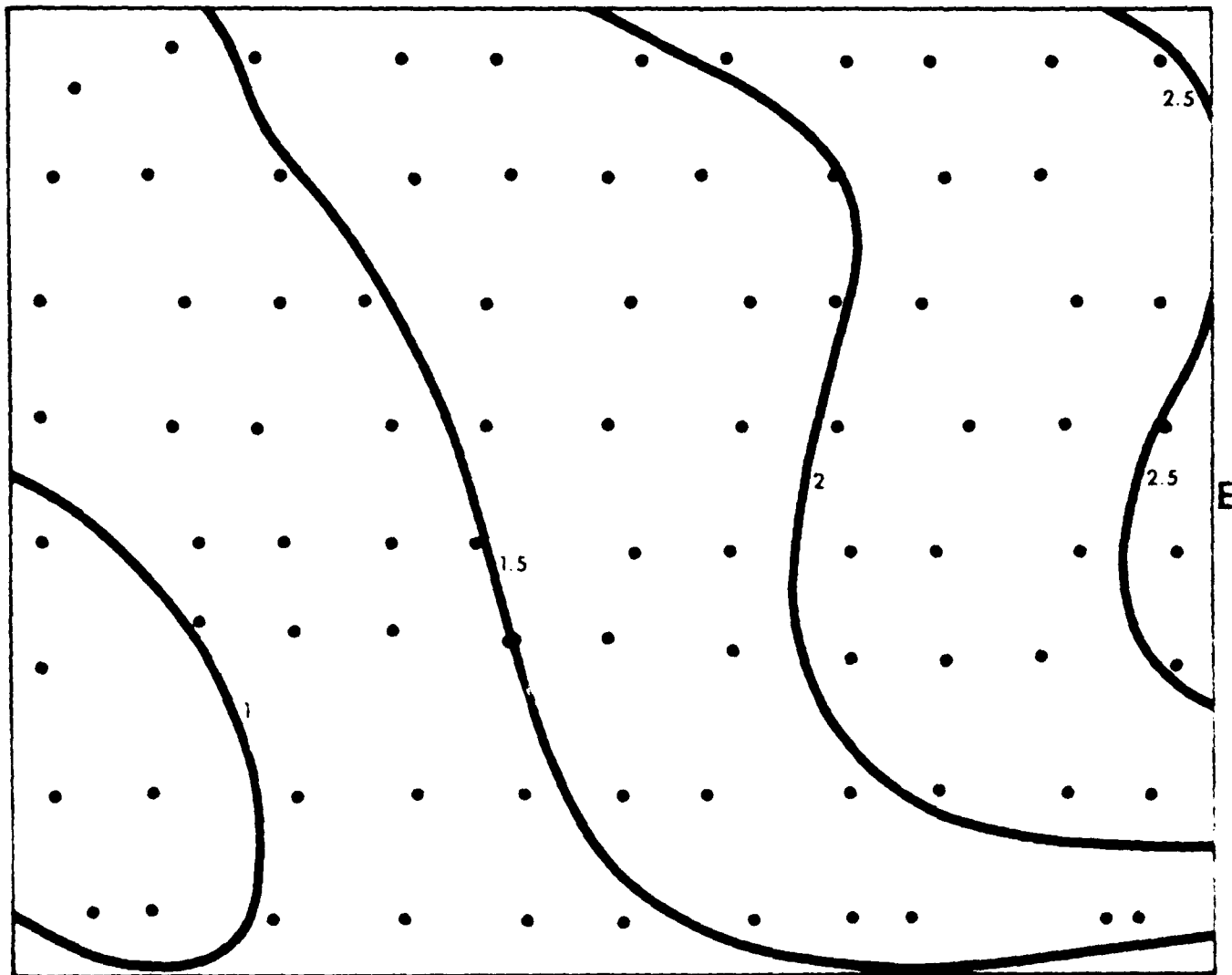
SLAVE A @ 10K

N



SLAVE A @ 15K

N



SLAVE B @ 1K

N

2.5

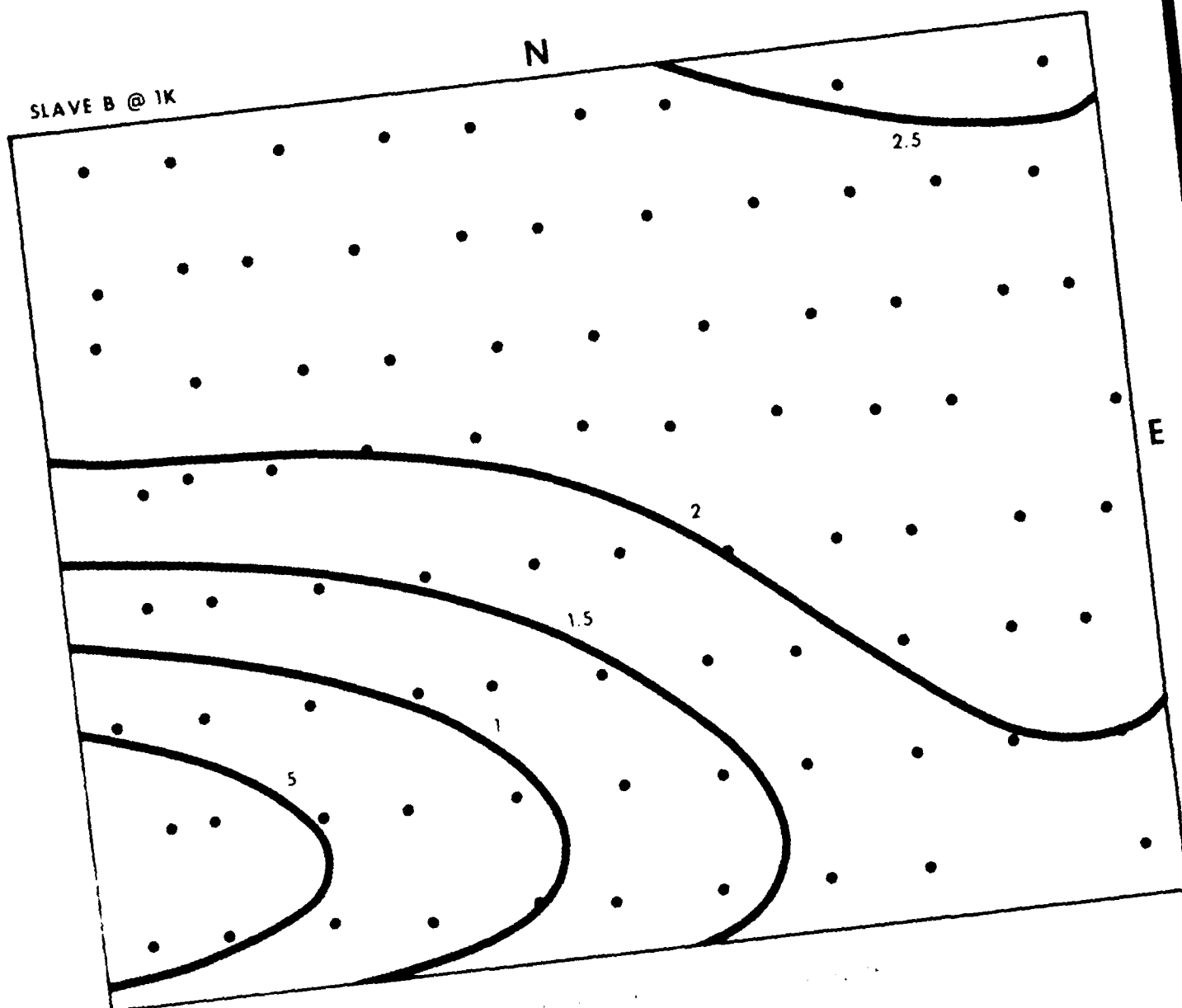
E

2

1.5

1

5



SLAVE B @ 5K

N

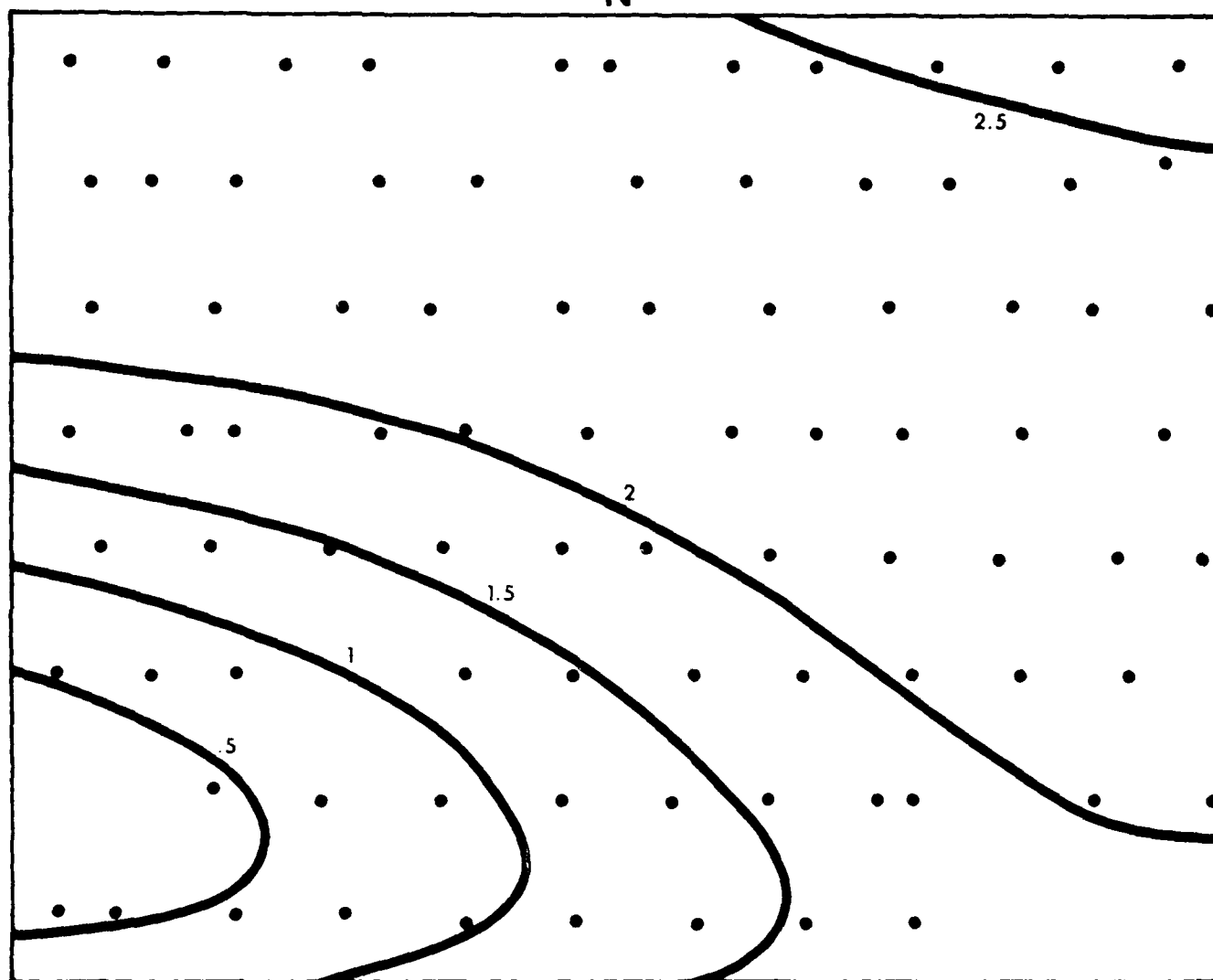
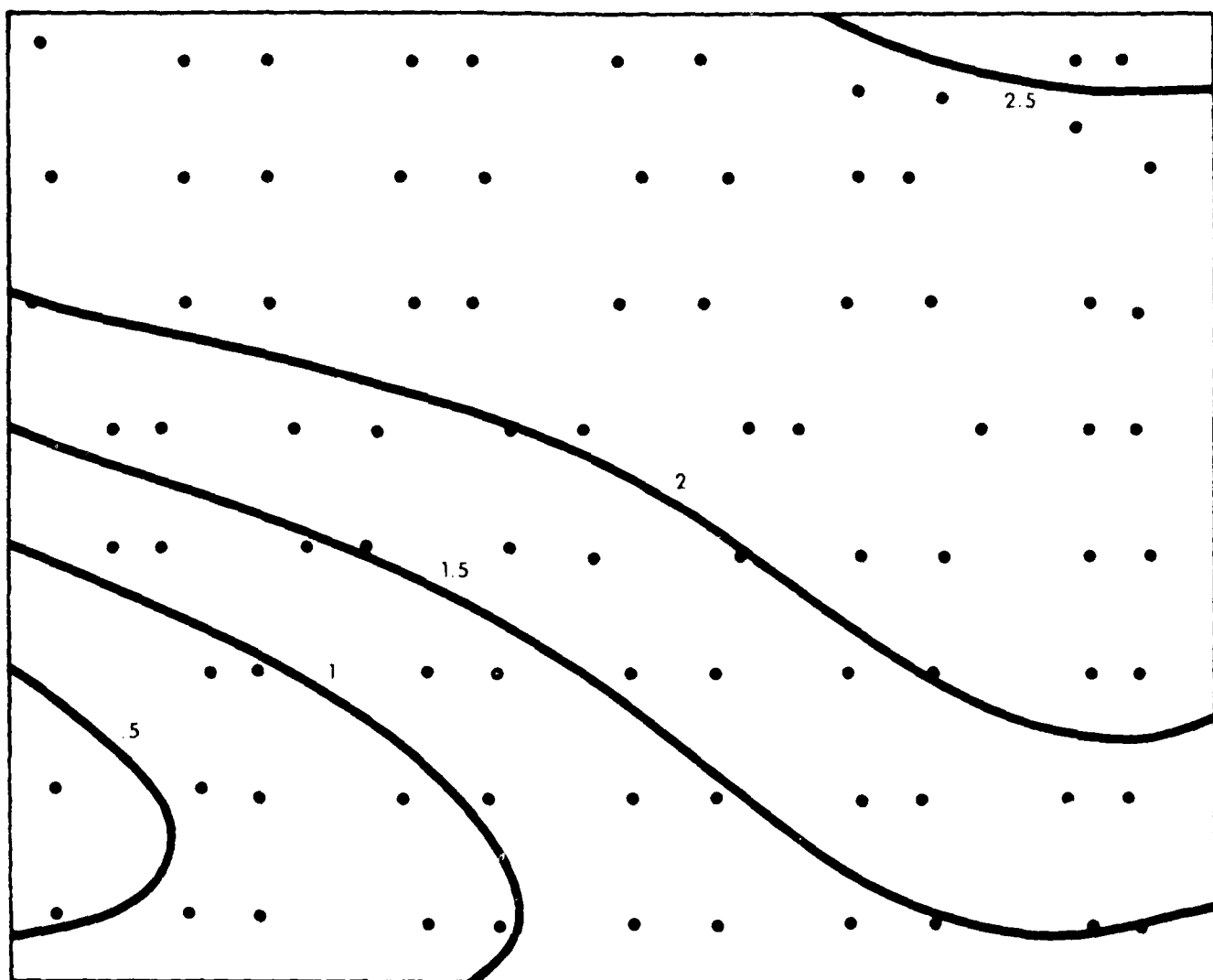


Figure 10. Contour plot of the output of the model.



SLAVE B @ 10K

N



SLAVE B @ 10K

SLAVE B @ 15K

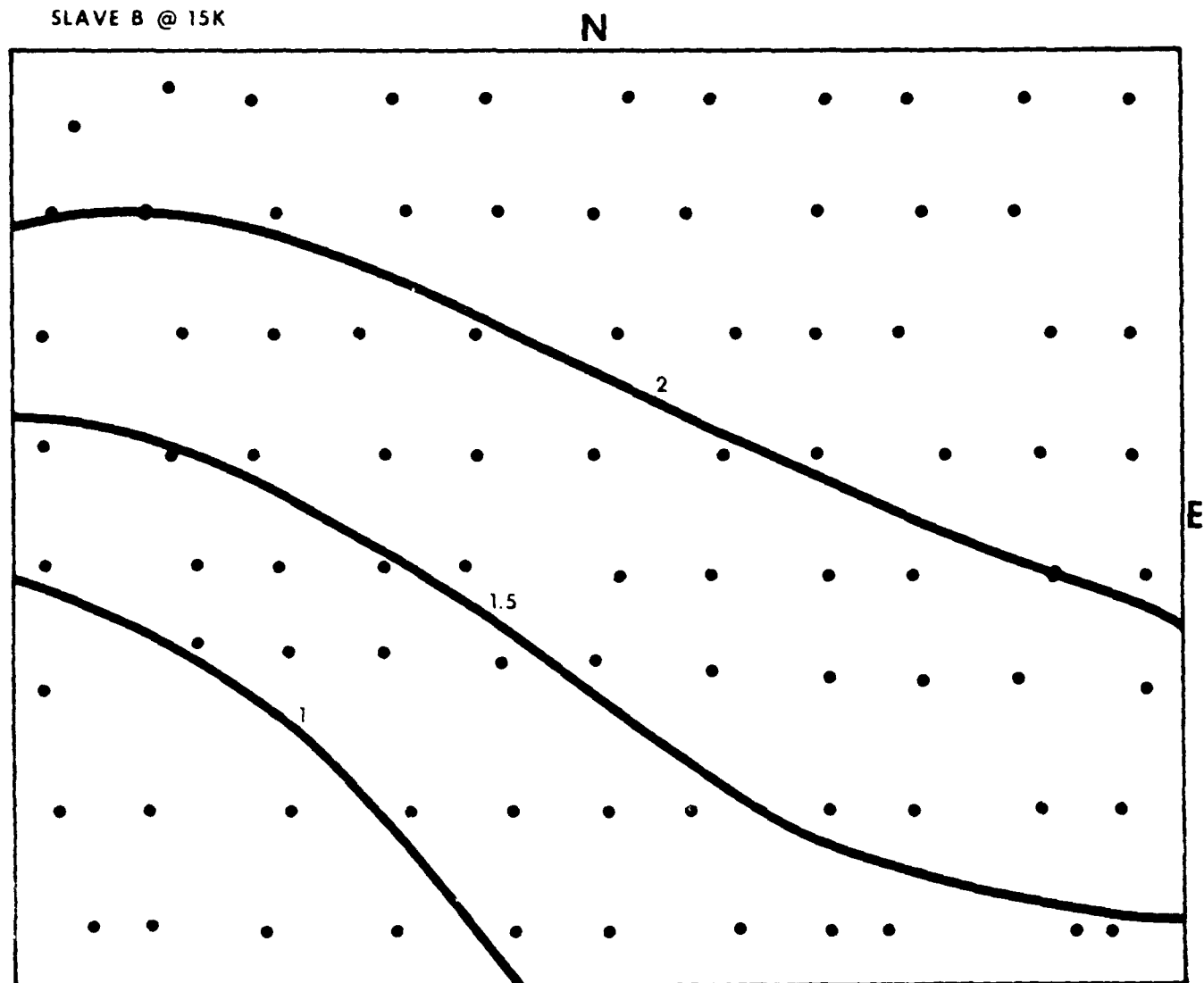


Fig. 6.14. Warpage Contour Plot (Case 1) - Slave B, 15K

### 3.7 OBJECTIVE 7. Boundary

3.7.1 DESCRIPTION. Interior and exterior impedances of a secondary boundary conditions.

3.7.2 TEST PROCEDURE. WARP was used to generate two sets of data points consisting of paired TDA's. The first set was generated at a fixed distance across the prime area boundary. The program then calculated interior point TDs from the prime area coefficients and the exterior impedances. The calculated constant impedances of the appropriate secondary areas. The difference between the interior and exterior TDs was used to determine the relative value of the position jump at the boundary.

3.7.2.1 PROGRAM MODIFICATION. Overlay 5 of WARP was altered to create ten pairs of data points equally spaced along each of the four prime area boundaries. Each data pair consisted of a point in the interior of the prime area within 300 ft of the boundary and a corresponding point the same distance across the boundary into a secondary area. The approximate relative locations of the data points are illustrated in Figure 13. Additional program modifications were implemented to compute TDs as follows:

$$TDA = TDA \text{ (exterior)} - TDA \text{ (interior)}$$

$$TDB = TDB \text{ (exterior)} - TDB \text{ (interior)}$$

3.7.2.2 DATA REQUIREMENTS. Low altitude data set processed by normal Overlays 1-4 and a modified Overlay 5.

3.7.3 TEST RESULTS. Test data is compiled in Tables X through XIII. Each table is organized by secondary area number and contains TDs, northerly and easterly position jumps in feet, and absolute magnitude of the relative position jumps.

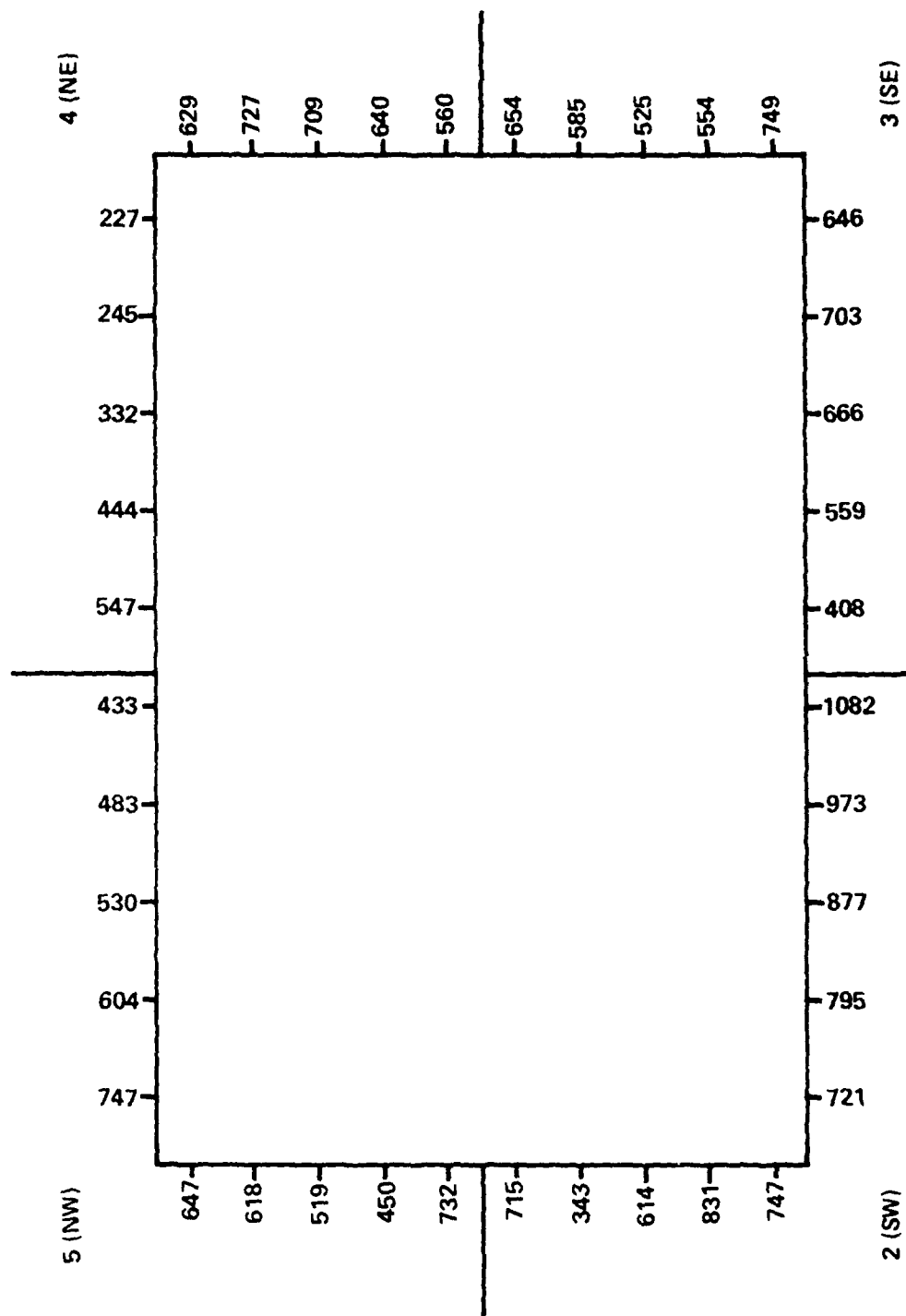


Figure 13. Boundary Jump Errors.

TABLE X

## AREA 2 BOUNDARY CONDITIONS

| POINT<br>PAIR | TDA<br>(usec) | TDB<br>(usec) | N JUMP<br>(ft) | E JUMP<br>(ft) | MAG<br>(ft) |
|---------------|---------------|---------------|----------------|----------------|-------------|
| 2.1           | -.439         | -1.107        | -1082          | - 1            | 1082        |
| 2.2           | -.542         | - .958        | - 969          | - 94           | 973         |
| 2.3           | -.600         | - .828        | - 863          | -157           | 877         |
| 2.4           | -.588         | - .723        | - 775          | -175           | 795         |
| 2.5           | -.477         | - .642        | - 708          | -137           | 721         |
| 2.6           | -.875         | .437          | 535            | -521           | 747         |
| 2.7           | -.630         | .575          | 721            | -413           | 831         |
| 2.8           | -.585         | .377          | 501            | -355           | 614         |
| 2.9           | -.680         | - .019        | 13             | -343           | 343         |
| 2.10          | -.858         | -.493         | - 613          | -367           | 715         |

TABLE XI

## AREA 3 BOUNDARY CONDITIONS

| POINT<br>PAIR | TDA<br>(usec) | TDB<br>(usec) | N JUMP<br>(ft) | E JUMP<br>(ft) | MAG<br>(ft) |
|---------------|---------------|---------------|----------------|----------------|-------------|
| 3.1           | .596          | -.520         | -483           | 441            | 654         |
| 3.2           | .538          | -.487         | -417           | 411            | 585         |
| 3.3           | .610          | -.383         | -299           | 431            | 525         |
| 3.4           | .866          | -.226         | -139           | 537            | 554         |
| 3.5           | 1.320         | -.052         | 44             | 747            | 749         |
| 3.6           | .568          | -.608         | -433           | 475            | 646         |
| 3.7           | .546          | -.671         | -524           | 468            | 703         |
| 3.8           | .473          | -.631         | -525           | 409            | 666         |
| 3.9           | .362          | -.524         | -462           | 315            | 559         |
| 3.10          | .230          | -.380         | -352           | 207            | 408         |

TABLE XII  
AREA 4 BOUNDARY CONDITIONS

| POINT<br>PAIR | TDA<br>(usec) | TDB<br>(usec) | N JUMP<br>(ft) | E JUMP<br>(ft) | MAG<br>(ft) |
|---------------|---------------|---------------|----------------|----------------|-------------|
| 4.1           | .172          | .332          | 543            | 68             | 547         |
| 4.2           | .060          | .268          | 444            | 16             | 444         |
| 4.3           | -.078         | .189          | 328            | - 48           | 332         |
| 4.4           | -.232         | .108          | 214            | -121           | 245         |
| 4.5           | -.366         | .041          | 126            | -189           | 227         |
| 4.6           | 1.277         | .172          | 75             | 625            | 629         |
| 4.7           | 1.456         | .265          | 182            | 703            | 727         |
| 4.8           | 1.422         | .226          | 145            | 694            | 709         |
| 4.9           | 1.270         | .134          | 70             | 636            | 640         |
| 4.10          | 1.081         | .050          | 13             | 560            | 560         |

TABLE XIII  
AREA 5 BOUNDARY CONDITIONS

| POINT<br>PAIR | TDA<br>(usec) | TDB<br>(usec) | N JUMP<br>(ft) | E JUMP<br>(ft) | MAG<br>(ft) |
|---------------|---------------|---------------|----------------|----------------|-------------|
| 5.1           | - .595        | .418          | 641            | -353           | 732         |
| 5.2           | - .821        | .060          | 163            | -419           | 450         |
| 5.3           | -1.027        | -.163         | -150           | -497           | 519         |
| 5.4           | -1.194        | -.220         | -225           | -575           | 618         |
| 5.5           | -1.315        | -.098         | - 4            | -647           | 647         |
| 5.6           | .002          | .412          | 747            | - 26           | 747         |
| 5.7           | .016          | .378          | 604            | - 13           | 604         |
| 5.8           | .015          | .300          | 530            | - 11           | 530         |
| 5.9           | - .010        | .274          | 482            | - 21           | 483         |
| 5.10          | - .065        | .243          | 431            | - 46           | 433         |

**3.7.4 EVALUATION CRITERIA.** The key parameter evaluated was the magnitude position error shown in Tables X through XIII. This position error is the result of the northerly and easterly errors and represents the instantaneous change in Loran position observed by the AN/ARN-101 as the prime area boundary limit is crossed.

**3.7.5 TEST EVALUATION.** Although the test results shown in Tables X through XIII are valid for the data gathered at Eglin AFB, they are generally applicable to other operational areas as well. At Eglin there is a wide variation in apparent impedance ranging from near saltwater along the southern boundary to poor soil in the north. This large variation in impedance over the region of interest is probably typical of virtually all areas of operation for the AN/ARN-101, with the possible exception of rugged coastal mountainous terrain.

As indicated by the data in Objective 3, the uncorrected warpage contributes about 1500 ft position error. The price of enjoying a 200 ft Loran navigation accuracy in the prime area must be paid at the boundary crossing because of the switch from a precise to an average impedance. Therefore, it is reasonable to predict worst case position jumps on the order of 1000 ft or more for almost all prime area boundaries. This jump is most severely reflected in the LORAN/LORAN mode of the AN/ARN-101 operation. The Kalman filtering action in the other AN/ARN-101 modes will not allow instantaneous position jumps.

Because WARP is designed to be used with as many as four different data sets, four slightly different sets of constants and coefficients are probable. Each set would result in somewhat different boundary conditions. Although the AN/ARN-101 can handle four altitude sets of polynomial coefficients, only one constant impedance is stored for each secondary area. The choice of secondary impedance values is relatively unimportant since the altitude effects of warpage are at least an order of magnitude less than the boundary effect (as shown by Eglin data). For this reason, any secondary area constant impedance generated by a valid set of data will suffice.

Although not directly related to the quantification of the boundary conditions, several program limitations were noted. At least one real data point must reside in any cell adjacent to a secondary area border in order for the program to calculate an impedance for the area. Also, data points in a secondary area do not contribute to the calculated secondary area impedance. All data points are used in the calculation of the PCA polynomial coefficients whether they are interior or exterior to the PCA.

**3.7.6 RECOMMENDATIONS.** Several improvements to reduce the boundary effect can be made. One is to change WARP and the other is to carefully select the secondary area constant impedances to be inserted in the DMAS computer.

As currently implemented, WARP searches the perimeter cells of the prime area. An average impedance for each secondary area is calculated from the data points resident in the perimeter cells. However, the program could be modified to include data points in the secondary areas near the border (i.e., 5nm or less). If the additional points are well distributed, a better average impedance should result. No special effort to gather data outside a prime area should be made for this purpose as the improvement would be small. However, prime areas are not expected to be isolated and if data earmarked for one prime area is available for use in a different PCA secondary zone it could be used. This approach is flawed by requiring engineering judgement and data base management not currently envisioned for WARP operation. WARP should be modified to detect, reject and list all data points outside the PCA. This would simplify WARP and provide an additional error check on the input.

There does exist a cumbersome but very effective method of suppressing the boundary jump. It requires, however, A PRIORI knowledge of where the boundary crossing will occur. If this is known then the impedance of the data point nearest the crossing can be substituted for the calculated secondary impedance. The necessary data is available as part of the current program output but it isn't formatted to this end. It is recommended that the WARP program output be modified to add a table or plot of the boundary impedances so that the users have the freedom to select the values that best suit their needs. How such a selection process would be implemented in the field is unknown, but the proposed AN/ARN-101 Mission Data Transfer System is powerful enough that this capability could indeed be added.



### 3.8 OBJECTIVE 8. Average and Saltwater Impedances.

3.8.1 DESCRIPTION. Determine and compare the positional accuracy within the prime area using saltwater and average impedances instead of the polynomial warpage model impedances.

3.8.2 TEST PROCEDURE. Three sets of constant impedances were evaluated to determine their relative merit in correcting for Loran warpage within the prime area. This was accomplished by modifying WARP to use selected values of impedances in lieu of the warpage model impedances calculated from the input data set. Table XIV compares the various impedance values used for the master and two slaves ( $Z_m$ ,  $Z_1$ ,  $Z_2$ ).

TABLE XIV  
CONSTANT IMPEDANCE VALUES

| NAME           | $Z_m$   | $Z_1$       | $Z_2$       |
|----------------|---------|-------------|-------------|
| Saltwater      | .001055 | .001055     | .001055     |
| Millington     | .040    | .028500     | .014410     |
| Best Ave @ 1K  | .040    | .0431456052 | .0233970566 |
| Best Ave @ 5K  | .040    | .0439589757 | .0233413305 |
| Best Ave @ 10K | .040    | .0450740286 | .0230334424 |
| Best Ave @ 15K | .040    | .0431774379 | .0223470084 |

The Saltwater impedance model represents an ideal case which assumes the entire Loran coverage area is homogeneous with an equivalent impedance to that of saltwater.

Millington's impedances were calculated by a manual method of fractional parts. Basically, each arc length distance from the data point to the stations was subdivided into elements of homogeneous impedance. After each fractional length was assigned an impedance value, they were weighted by their fractional contribution to the total propagation path under consideration. The weighted impedances were simply totaled to obtain the final impedance value. The data point used for these calculations was the center of the prime area.

The four sets of Best Ave impedances were computed by WARP using the baseline input data sets for each altitude. These values are identical to the average of the impedances represented by the coefficients.

3.8.2.1 PROGRAM MODIFICATION. Several modifications to Overlay 5 were made. The first change caused WARP to compute the average impedance for each slave station within the prime area region. The second modification forced Subroutine Wave to use selected impedances instead of calculating them from the coefficients.

3.8.2.2 DATA REQUIREMENTS. Four sets of altitude dependent input data and impedance values defined by Table XIV.

3.8.3 TEST RESULTS. Table XV shows the results obtained by using the three types of constant impedances. Each altitude set is compared to the position errors predicted by the coefficient model. Figure 11 is a plot of the normal probability functions using the 1K ft altitude portion of the data in Table XV.

3.8.4 EVALUATION CRITERIA. All input data points were required to have real world values of calculated impedance ( $.001055 \leq Z \leq .08$ ). For comparison purposes only, the WARP model generated at each altitude was used as the standard.

3.8.5 TEST EVALUATION. Of the three sets of constant impedances evaluated, the Best Ave set provided the best warpage modeling. Unfortunately, this requires that correlated TD/LAT-LON data be gathered and processed to obtain a set of impedances over a geographical area of interest. This data set does, however, indicate a practical limit of the accuracy of the Millington method in estimating constant impedances.

As can be seen from Table XV, no set of constant impedances corrects for warpage with any degree of precision. Only an approximate 50% improvement is noted from the saltwater model to the best average. The large mean error is attributed to independently averaging the slave impedances instead of ascertaining values which minimize the total error.

Millington's estimation procedure will not greatly improve warpage correction as compared to the saltwater impedance. In terms of the AN/ARN-101 operation, the ability to select constant impedances for the prime area in lieu of saltwater or WARP model generated impedances is virtually redundant.

3.8.6 RECOMMENDATIONS. Should it be necessary to use constant impedances for the prime area, two methods have practical utility. The first method is to acquire data using a mobile or portable receiver in the field. Impedances can be hand calculated and averaged using well defined techniques. The most difficult computational load is obtaining or calculating the arc length distance from the data point to the Loran stations.

Another method of using constant impedances is to "point fit" the impedances at a known location. To do this the AN/ARN-101 receiver must be at the desired spot with well known coordinates (i.e., second order survey point). If constant impedances are inserted into the AN/ARN-101, the computer will use them in the coordinate conversion process to generate a LAT-LON. By iterating the appropriate slave impedances, the computed position can be made to converge to the known location. No A PRIORI Loran knowledge is necessary and the impedances generated will be valid in the vicinity of the data point. The major hazard to this approach is possible warpage due to strictly local phenomena. This type of warpage may be caused by metal buildings, fences, telephone lines, power lines, etc. If a point fit is done in an area clear of locally disturbing influences, usable results should be obtained.

TABLE IV  
 SUMMARY OF DATA  
 FOR THE 1960-1961  
 FISHING SEASON

| FISHING AREA    |  | TOTAL CATCH |       | TOTAL WEIGHT |       | TOTAL LENGTH |       |
|-----------------|--|-------------|-------|--------------|-------|--------------|-------|
|                 |  | NUMBER      |       | POUNDS       |       | INCHES       |       |
| SOUTH ATLANTIC  |  |             |       |              |       |              |       |
| SOUTH ATLANTIC  |  | 1,412       | 1,412 | 1,412        | 1,412 | 1,412        | 1,412 |
| MIDDLE ATLANTIC |  | 1,412       | 1,412 | 1,412        | 1,412 | 1,412        | 1,412 |
| NORTH ATLANTIC  |  | 1,412       | 1,412 | 1,412        | 1,412 | 1,412        | 1,412 |
| MIDDLE ATLANTIC |  |             |       |              |       |              |       |
| MIDDLE ATLANTIC |  | 1,412       | 1,412 | 1,412        | 1,412 | 1,412        | 1,412 |
| NORTH ATLANTIC  |  | 1,412       | 1,412 | 1,412        | 1,412 | 1,412        | 1,412 |
| SOUTH ATLANTIC  |  | 1,412       | 1,412 | 1,412        | 1,412 | 1,412        | 1,412 |
| NORTH ATLANTIC  |  |             |       |              |       |              |       |
| NORTH ATLANTIC  |  | 1,412       | 1,412 | 1,412        | 1,412 | 1,412        | 1,412 |
| MIDDLE ATLANTIC |  | 1,412       | 1,412 | 1,412        | 1,412 | 1,412        | 1,412 |
| SOUTH ATLANTIC  |  | 1,412       | 1,412 | 1,412        | 1,412 | 1,412        | 1,412 |
| TOTAL           |  |             |       |              |       |              |       |
| TOTAL           |  | 1,412       | 1,412 | 1,412        | 1,412 | 1,412        | 1,412 |
| MIDDLE ATLANTIC |  | 1,412       | 1,412 | 1,412        | 1,412 | 1,412        | 1,412 |
| NORTH ATLANTIC  |  | 1,412       | 1,412 | 1,412        | 1,412 | 1,412        | 1,412 |
| SOUTH ATLANTIC  |  | 1,412       | 1,412 | 1,412        | 1,412 | 1,412        | 1,412 |
| TOTAL           |  |             |       |              |       |              |       |
| TOTAL           |  | 1,412       | 1,412 | 1,412        | 1,412 | 1,412        | 1,412 |
| MIDDLE ATLANTIC |  | 1,412       | 1,412 | 1,412        | 1,412 | 1,412        | 1,412 |
| NORTH ATLANTIC  |  | 1,412       | 1,412 | 1,412        | 1,412 | 1,412        | 1,412 |
| SOUTH ATLANTIC  |  | 1,412       | 1,412 | 1,412        | 1,412 | 1,412        | 1,412 |

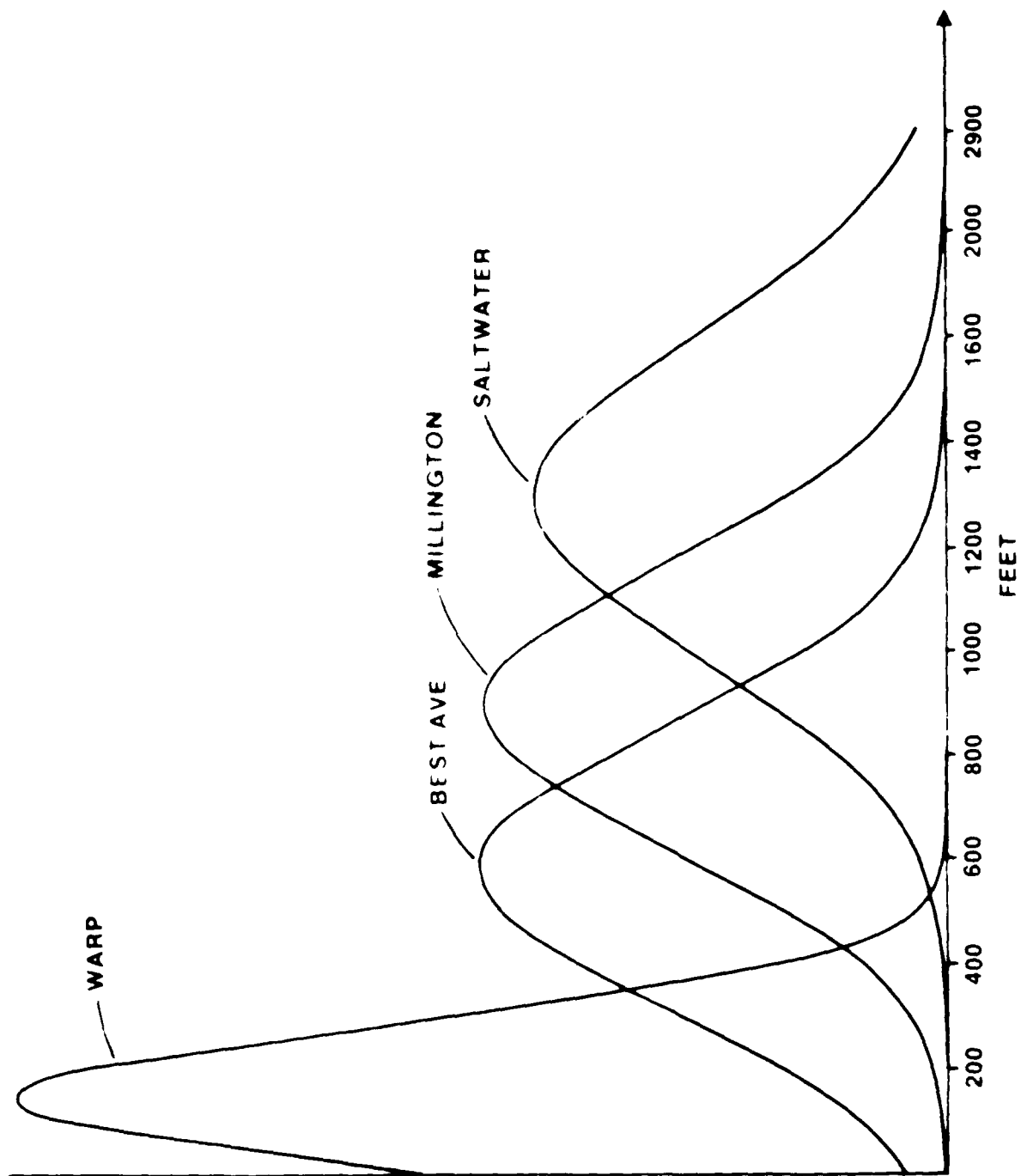


Figure 10. Vertical temperature profile at 1 ft.

3.9 OBJECTIVE 9. Photo Reconnaissance Data Validation.

3.9.1 DESCRIPTION. Validate the real world data collection and Loran warpage correction process using photo reconnaissance data.

3.9.2 TEST PROCEDURE. Using the 5K baseline data as a reference, compare the navigational accuracy within the Eglin PCA using data retrieved from proposed RF-4C photo reconnaissance flight missions. Compare reconnaissance data with time merged radar/phototeodolite and RF-4C instrumentation data.

3.9.2.1 PROGRAM MODIFICATION. None.

3.9.2.2 DATA REQUIREMENTS. Photo reconnaissance data and time merged radar/phototeodolite and RF-4C instrumentation data.

3.9.3 TEST RESULTS. Although flight missions at Eglin were flown to complete this objective, the reconnaissance film was evaluated by DMAAC and deemed unusable for this prediction.

3.9.4 EVALUATION CRITERIA. None.

3.9.5 TEST EVAL ACTION. None.

3.9.6 RECOMMENDATIONS. None.

3.10 OBJECTIVE 10. Software Program Documentation.

3.10.1 DESCRIPTION. Identify computer software deficiencies and program modifications to provide a more user-oriented operation.

3.10.2 TEST PROCEDURE. The identification of program deficiencies and necessary user documentation resulted in a Statement of Work given as Appendix B.

3.10.2.1 PROGRAM MODIFICATION. As defined in Appendix B.

3.10.2.2 DATA REQUIREMENTS. Not applicable.

3.10.3 TEST RESULTS. The tasks identified in Appendix B were accomplished by Armament Systems, Inc. through a contract effort by the Naval Weapons Center, China Lake, California.

The results of this effort include a revised source program, a User's Manual, and an Analyst's Manual.

3.10.4 EVALUATION CRITERIA. Not applicable.

3.10.5 TEST EVALUATION. Not applicable.

3.10.6 RECOMMENDATIONS. Final resolution is required to establish the responsible organization for software operation and maintenance of this program.

4.0 CONCLUSIONS. The rationale in testing the Warpage Coefficient Generation Program has been to specify the program limitations, identify possible pitfalls or problem areas, and to gauge the level of expertise necessary to provide operational grid warpage support. The major conclusions of this test activity utilizing Eglin PCA data are briefly summarized in this section.

1. Editing input data and selecting an appropriate master station impedance requires a high level of program interaction and demands a high degree of Loran expertise (i.e. program flags do not conclusively identify "bad" data since it is extremely difficult to distinguish measurement error from grid warpage). - Objective 1.

2. Identified "bad" data points should be removed pending further data gathering and investigation in the immediate vicinity of the points in question. - Objective 1.

3. "Bad" data points may appear as a result of poor initial selection of master station impedance. - Objective 2.

4. WARP adequately models warpage data throughout a large range of values for index of refraction and vertical lapse, but these program constants must be the same in the AN/ARN-101. Inconsistent vertical lapse factor can produce positional errors greater than 500 feet. Inconsistent index of refraction values can contribute incremental positional errors up to 100 feet per station. - Objective 3.

5. The best positional accuracy is achieved when the earth model selected in the AN/ARN-101 matches the model used in WARP. An inconsistent selection of spheroid models for the input data and WARP will not measurably alter the positional accuracy. - Objective 3.

6. Choosing an improper earth model (in the AN/ARN-101) for the PCA can contribute up to 194 feet of additional positional error. (i.e. Bessel spheroid selected when WGS72 should be used). - Objective 3.

7. The WARP input data and Loran chain data should be relative to the same survey system coordinates. - Objective 3.

8. A 100 X 100 nautical mile prime coverage area with the uniform data point density of 1 point per 5 nautical mile cell is highly recommended. Reducing the data density to 10 X 10 nautical miles produced a composite positional error of 779 feet, while maintaining a 5 X 5 nautical mile density produced only a 114 foot composite error. - Objective 4.

9. WARP is currently limited to 400 input data points. There is no physical limitation to the size of the PCA.

10. The AN/ARN-101 requires 4 sets of warpage coefficients for system altitudes of below 2500 feet, 2500-7500 feet, 7500-12500 feet, and above 12500 feet. The greatest positional accuracy will be achieved with 4 independent altitude data sets collected within the appropriate altitude ranges. AN/ARN-101 data loading requirements may be satisfied with duplicate or redundant data, however, degraded Loran navigational accuracy will result. Test results indicate an average positional error of 107 feet throughout the PCA from 0-15000 feet when



using 4 independent altitude sets of warpage coefficients. When only one set of coefficients was used (i.e. either the 1K, 5K, 10K, or 15K data) for all system altitudes, the resulting average error ranged from 127 to 158 feet. - Objective 6.

11. In the LORAN/LORAN AN/ARN-101 navigational mode the system may experience instantaneous position jumps of greater than 1000 feet when transitioning the PCA boundary. In higher order navigation modes Kalman filtering of INS/LORAN position will prohibit the instantaneous jumps. - Objective 7.

12. When a saltwater propagation model was used (i.e. No PROP K in the AN/ARN-101), the average positional error throughout the PCA was 1251 feet. The Millington method of determining a single constant impedance value reduced the overall error to 833 feet. The ideal constant value (Best Ave) further reduced the error to 523 feet. When utilizing the full warpage polynomial model the overall positional error was 117 feet. - Objective 3.

13. Software program modifications were incorporated throughout the period of this test activity. The SOW (Attachment B) lists the detailed tasks that were accomplished and a brief highlight of the major program changes includes the following:

- \* Detailed program comments
- \* Improved software coding
- \* Extensive program diagnostics
- \* Improved prediction error summaries
- \* New plotting and data smoothing techniques
- \* Comprehensive user and analyst manuals

## 5.0 RECOMMENDATIONS

During the preparation of this test report an improved version of the Warpage Coefficient Generation Program (WARP) was nearing completion. As a result, many of the program recommendations that would have been described in this section will be incorporated in the revised program and, therefore, will not be discussed here.

During this test effort several areas were noted for improving the AN/ARN-101 software. It is recommended that future efforts be made to streamline the data requirements of the LORAN initialization structure within the AN/ARN-101. The interaction required between the WARP user and the AN/ARN-101 operator is relatively high. Unless further work simplifies data inputs to the AN/ARN-101, the transfer of WARP data will remain subject to operator error.

It is recommended that the feasibility of eliminating the intermediate step of using impedances to determine Loran warpage be investigated. Preliminary tests indicate that WARP can be simply modified to model warpage in time units instead of impedance with no loss of accuracy. As many as 300-500 words of AN/ARN-101 core memory may be saved by eliminating the impedance look-up tables. A small savings in AN/ARN-101 program execution could also be expected.

Much analysis remains to be done pending receipt of additional operational data. It is probable that the input data density can be expressed as a mathematical limit and not as a geographical one. This can significantly reduce the data collection requirement. It is also probable that the data collection requirements as a function of altitude can be more clearly delineated if the effects of terrain are better understood. Failure to extend the analysis will force very conservative and perhaps redundant data collection.

It is recommended that the utility of WARP to introduce "real world" warpage data to the Loran grid prediction process be investigated. At present, the process of collecting "real world" Loran grid data and subsequent operation of WARP is an independent effort from Loran grid prediction. This testing has determined that WARP has essentially no prediction capability even though the warpage process is "smooth" by filling in neighboring data for void area. Data obtained from "friendly" territory could be used to initiate the prediction process into "unfriendly" territory and also to aid in verifying the prediction results. It is strongly felt that an eventual marrying of the WARP program and the grid prediction program is realizable. A tremendous savings in current computer operation for the prediction program could be achieved. In addition, the overall grid data management system would be enhanced.

Although the current version of WARP has been tailored to aid AN/ARN-101 Loran data requirements, continuing operational support is required. It is felt that the operational commands will need technical assistance in establishing prime coverage areas, determining required altitude levels for data collection, estimating the severity of expected Loran grid warpage, and computing intermediate constant impedance values (in lieu of full polynomial). It is therefore imperative that a central office be established as the focal point for engineering support to aid the user in data gathering, data reduction, and analysis of WARP outputs. Only by providing such a grid warpage manager, can we expect to achieve the specified AN/ARN-101 performance accuracy for navigation and weapon delivery.

APPENDIX A  
LORAN WARPAGE DATA BASE REQUIREMENTS

by

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Abstract

Differences between LORAN time differences (TDs) measured with a receiver and TDs calculated using secondary phase corrections from a homogeneous LORAN conductivity model, can be interpreted as irregularities in the actual hyperbolic lines of position (LOP). This condition is referred to as warpage. LORAN warpage occurs for two reasons. First, warpage occurs whenever the propagation medium is not uniform. Second, warpage occurs when LORAN signals travel over two or more different propagation mediums i.e. from land to sea and back to land. The presence of Loran warpage affects the normal coordinate conversion relationship between the regular LORAN hyperbolic grid and the corresponding geodetic (latitude, longitude) grid commonly used for navigation.

The effect of Loran warpage is corrected by the AN/A 4-101 LORAN system in a two part algorithm. The first part operates off-line and uses a paired data base of measured LORAN and geodetic coordinates to generate a set of 15 coefficients for each LORAN station. These coefficients are used in the second part of the algorithm each coordinate conversion cycle. The warpage is corrected during coordinate conversion by using the coefficients to estimate an effective wave impedance for the secondary phase correction of each LORAN time of arrival. This paper describes the considerations and methodology needed to obtain a useable data base that meets the requirements for coordinate conversion accuracy. The recent calibration of the Southeast U.S. LORAN-C chain at Eglin AFB, Florida is used as an example of the procedure.

## Introduction

For many applications, the usefulness of Loran depends on conversion from hyperbolic navigation to geodetic navigation. The process of coordinate converting Loran time differences to latitude longitude can introduce a significant amount of positional error. This error is caused by the simple fact that the Loran grid is not directly related to the geodetic grid. Non-cancelling signal propagation errors cause a shift or bend in the smooth regular hyperbolic lines of position. This is called Loran warpage and is a function of the propagation path or medium the Loran signal crosses.

Loran warpage can be corrected during coordinate conversion by using an appropriate model for the secondary phase correction term. Most coordinate conversion algorithms assume a regular homogeneous Loran grid and model a single type of propagation medium for the entire coverage area. This assumption is not valid for accurate navigation over land where more than one type of propagation medium is involved with a Loran signal path. For very accurate coordinate conversion over land areas, the influence of each propagation medium must be considered. In areas of severe warpage, such as mountainous, this requires a detailed piecewise addition of all contributing factors to arrive at an effective delay or impedance value. This process must be repeated for all three Loran stations (M, A, B) in the triad. For regions where less coordinate conversion accuracy is required, average impedance values can be selected for each Loran station. These values are selected based on the average propagation medium for that signal path.

The U. S. Air Force has demonstrated very accurate coordinate conversion over areas of severe Loran warpage. This procedure uses a two part algorithm for determining the secondary phase correction\*. This algorithm is implemented in the AN/ARN-101 Digital Avionics System. The first part of the algorithm uses a paired data base of measured Loran time differences and geodetic latitude longitude coordinates to generate a set of coefficients. The coefficients are then used in the second part of the algorithm each coordinate conversion cycle to compute the secondary phase correction term. Thus, the accuracy of the final coordinate conversion depends on the selection and corresponding accuracy of the measured data base. This paper presents the general procedure for obtaining an accurate data base for the AN/ARN-101 coordinate conversion algorithm.

## General Data Requirements

The LORAN coordinate conversion data base consists of LORAN time differences (TDs) and corresponding geodetic positions (Latitude/Longitude). Measured (observed) data is desired but interpolated, derived, or calculated data can be used if it meets the accuracy requirements of the system.

The warpage coefficient generation program requires that five geographic areas be defined as shown in Figure 1. The prime coverage area is centered over the desired operational region. The size of the prime area is variable but it is normally limited to 100 nautical miles by 100 nautical miles or smaller. Within the central prime area, the warpage coefficient generation program uses the LORAN data base in a regression model to calculate coefficients. These coefficients are then used in an interpolation equation which calculates the effective wave impedances as a function of position in the prime area.

---

\*Reference 1

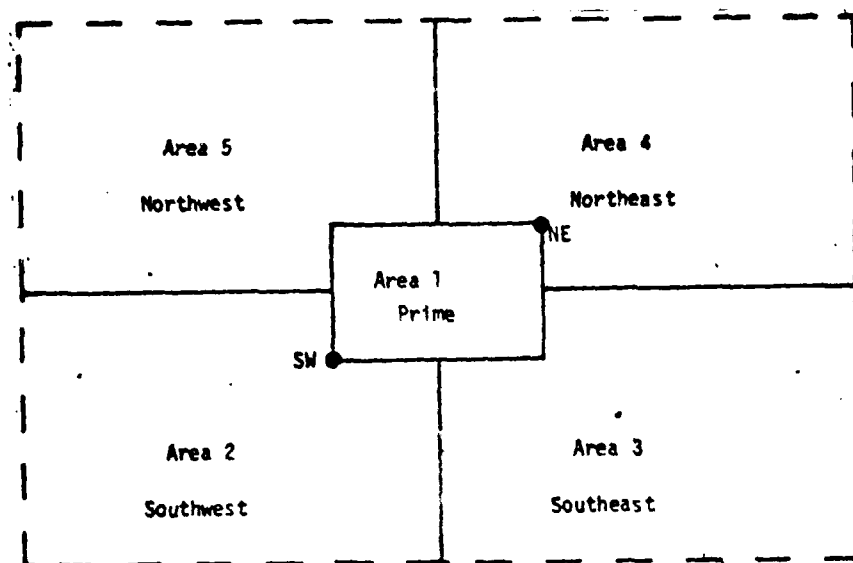


Figure 1. AN/ARN-101 Warpage Correction Areas

The uniform distribution of data points within the prime area is very important. Ideally, when the prime area is divided into square cells which are 5 nautical miles by 5 nautical miles in size, each cell should contain at least one data point. This distribution insures that the prime area will be accurately modeled. This is a minimum density requirement. More data points per cell in the prime area will generally result in a more accurate model. Locations outside the designated prime area are used to calculate an average wave impedance for the four areas outside the prime area. Usually data points at a distance of 10 to 20 nautical miles from the edges of the prime area are sufficient for a good effective impedance model for the outlying areas. More data points may be required if severe warpage is encountered.

The AN/ARN-101 LORAN warpage model was designed for aircraft and requires LORAN warpage coefficients at four altitude levels in the prime area. Each altitude level must have a separate data base according to the following table:

| Level      | Altitude Range for Data Point |
|------------|-------------------------------|
| Ground     | 0 to 2500 feet                |
| 5000 feet  | 2500 to 7500 feet             |
| 10000 feet | 7500 to 12500 feet            |
| 15000 feet | 12500 to 17500 feet           |

Data points for geodetic locations at other than ground level, are not required to be the same geodetic locations as the ground level point. However, the requirement for a minimum of one data point per cell does apply. For other applications such as vehicle monitoring, only ground level data is required.

### Data Base Requirements

This section presents specific requirements to develop a LORAN warpage data base. The Southeast U.S. LORAN-C chain at Eglin AFB Florida is used as an example, and the following procedures will be covered.

- Selection of the Prime Area
- Selection of Secondary Stations
- Estimate of LORAN Warpage
- Data Collection Requirements
- Generation of Warpage Coefficients

### Selection of the Prime Area

The Eglin AFB prime coverage area used with the old East Coast LORAN-C chain was a 42 by 72 nautical mile rectangle. The size of this prime area requires a minimum of 126 data points evenly distributed over the entire area. The previous data base provided 126 data points, but they were not evenly distributed. These data points were concentrated over the west and east land ranges of Eglin AFB with a scattering of points in the other areas. This uneven distribution of data points caused problems with coordinate conversion at some edges of the prime area. From this, it is concluded that it is better to reduce the prime area to a manageable size and collect data points that are evenly distributed. Figure 2 is a map of the Eglin AFB land ranges showing approximately a 35 by 52 nautical mile rectangle located by the Northeast and Southwest corners shown below.

NE 30° 50.00'N

85° 55.00'W

SW 30° 15.00'N

86° 55.00'W

This represents a reasonable sized prime area for the Southeast U.S. LORAN-C chain at Eglin AFB, Florida. The map is delineated by a grid every 5 minutes of angle. Thus, if each square of grid contains at least 1 calibration point the minimum distribution requirements have been satisfied.

### Selection of Secondary Stations

The Southeast U.S. LORAN-C chain offers different combinations of slave stations which can provide coverage for Eglin AFB. The complete data for this chain is contained in Table 1.

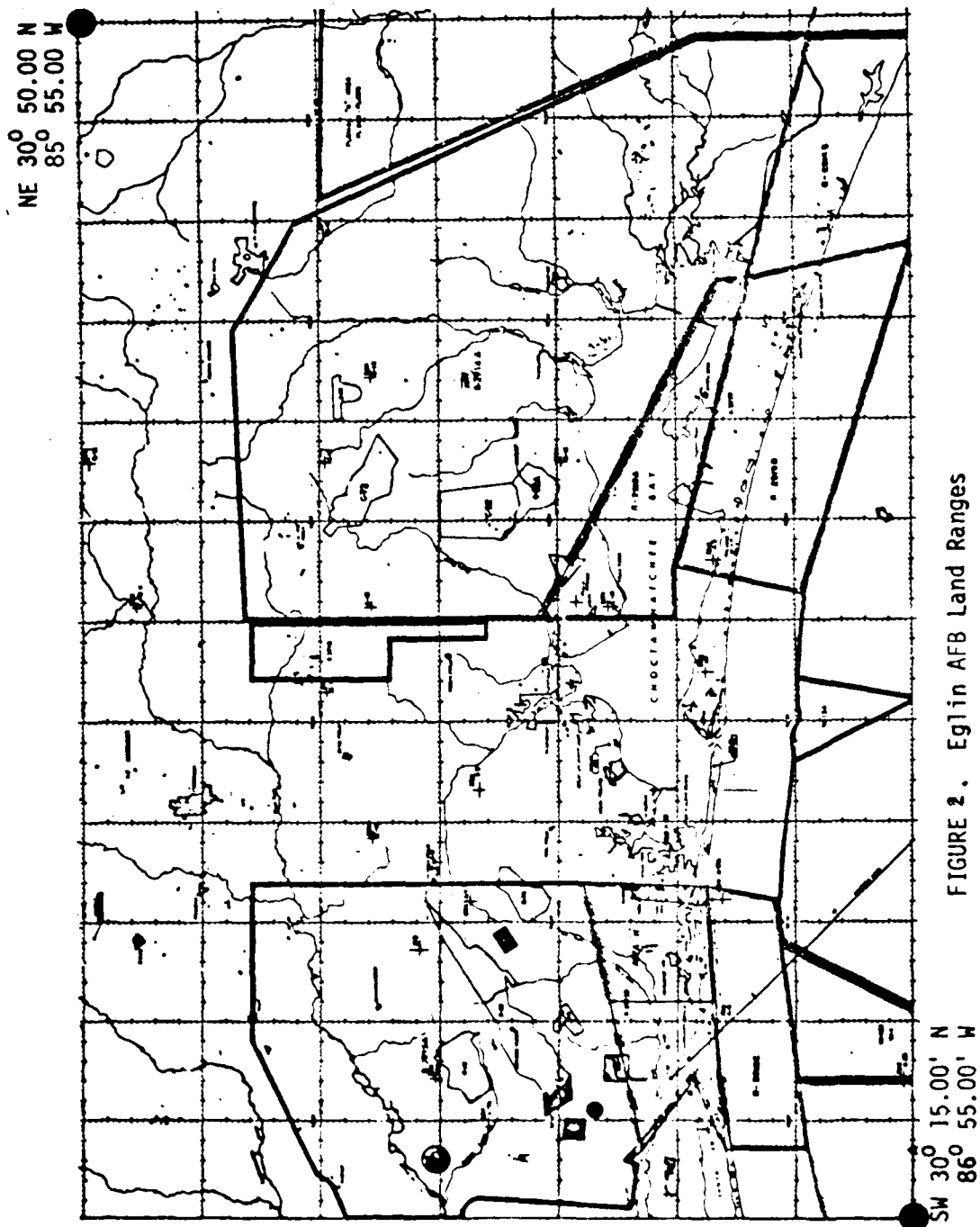


FIGURE 2. Eglin AFB Land Ranges

TABLE I  
SOUTHEAST U.S. LORAN-C CHAIN - RATE 7980(SL2)

| Station                     | Latitude & Longitude         | Station Function | Coding Delay & Baseline Length    | Radiated Peak Power |
|-----------------------------|------------------------------|------------------|-----------------------------------|---------------------|
| Malone, Florida             | 30-59-38.74N<br>85-10-09.30W | Master           | - - -                             | 1.0 MW              |
| Grangeville, Louisiana      | 30-43-33.02N<br>90-49-43.60W | W<br>Secondary   | 11,000 $\mu$ s<br>1809.54 $\mu$ s | 1.0 MW              |
| Raymondville, Texas         | 26-31-55.01N<br>95-50-00.09W | X<br>Secondary   | 23,000 $\mu$ s<br>4443.38 $\mu$ s | 400 kW              |
| Jupiter, Florida            | 27-01-58.49N<br>80-06-53.52W | Y<br>Secondary   | 43,000 $\mu$ s<br>2201.88 $\mu$ s | 300 kW              |
| Carolina Beach, N. Carolina | 34-03-46.04N<br>77-54-46.76W | Z<br>Secondary   | 59,000 $\mu$ s<br>2542.74 $\mu$ s | 700 kW              |

Computer generated mpas showing the Geometric Dillution of Precision (GDOP) for all master-slave combinations of the Southeast LORAN-C chain were computed to help select the best secondary stations. Analysis of this data indicates that the Raymondville slave (X) generally provides a lower GDOP over Eglin AFB. But its baseline goes directly through the selected prime area. This will result in rapid changes in GDOP over the Northeast corner of the Eglin prime area. For this reason the Malone-Grangeville-Jupiter triad (M-W-Y) is selected to provide the best overall coverage for Eglin AFB. Figure 3 shows the location of Eglin AFB in relationship to the Southeast U.S. LORAN-C chain (7980) and the old East Coast LORAN-C chain (9930).

#### Estimate of LORAN Warpage

Rough estimates of the effective impedance for each station are needed to determine if warpage in the prime area is mild or severe. These estimates are also initially used in the AN/ARN-101 for all areas and at all altitudes until a sufficient data base is available and warpage coefficients are computed.



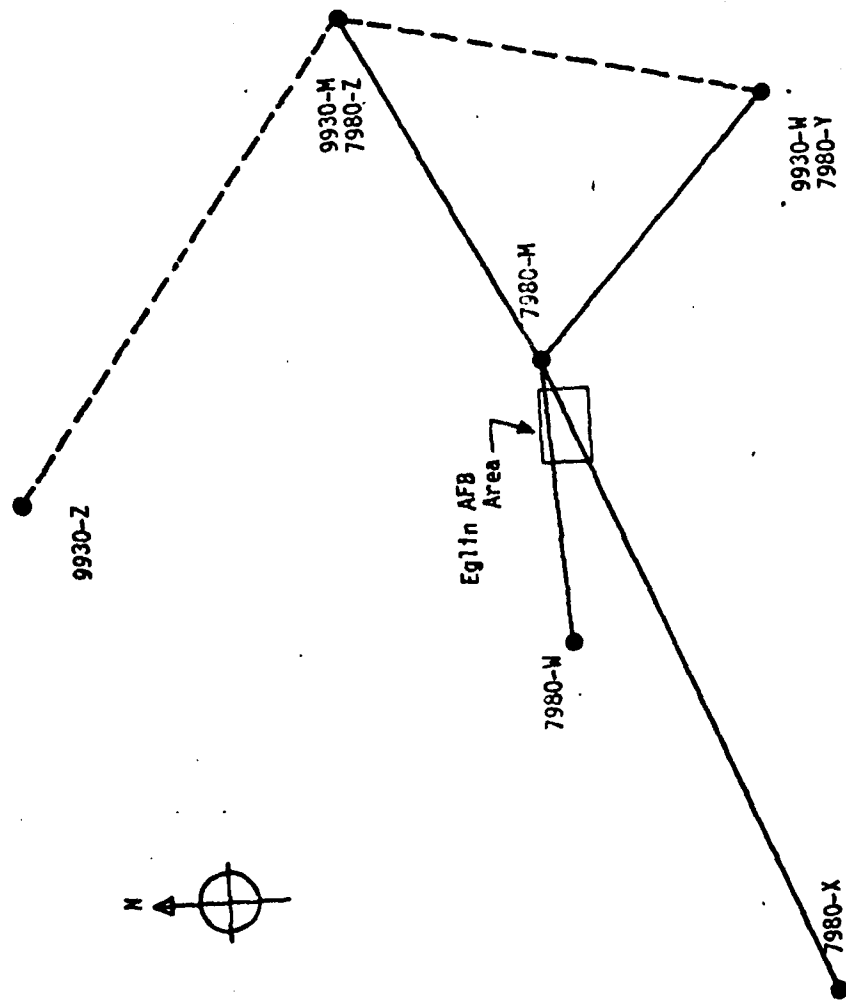


FIGURE 3. Southeast U.S. LORAN-C Chain Configuration

These initial estimates of effective impedance can be made using the following procedures:

- (1) Using a map that covers the prime area and the three transmitters (Master, Slave A, Slave B), select a point approximately in the center of the prime area.
- (2) Draw the line from the selected point to the Master station and estimate the fraction ( $x_{\text{sea}}$ ) of this path that is seawater, the fraction ( $x_{\text{normal land}}$ ) of this path that is normal land, and the fraction ( $x_{\text{rough/dry land}}$ ) of this path that is rough/dry land. Note that  $x_{\text{sea}} + x_{\text{normal land}} + x_{\text{rough/dry land}} = 1$ . The estimated impedance ( $\Delta_{\text{estimate}}$ ) is then calculated by evaluating:

$$\Delta_E = (0.001055) (x_{\text{sea}}) + \\ (0.03) (x_{\text{normal land}}) + \\ (.05) (x_{\text{rough/dry land}})$$

- (3) Repeat step 2 for Slave A.
- (4) Repeat step 2 for Slave B.

The three estimates can be used in the AN/ARN-101. This is accomplished for the prime area by setting the constant term  $\alpha_0$  to the estimate of effective impedance and setting the other 14 warpage coefficients for each transmitter to zero ( $\alpha_1$  through  $\alpha_{14}$ ). This must be done at each of the four altitude levels. This procedure provided the following estimates of effective impedance:

Master - Malone, Florida

100% normal land

$$\Delta_{E_m} = (0.03 * 1) = 0.03$$

Secondary W - Grangeville, Louisiana

5% sea

95% normal land

$$\Delta_{E_w} = (0.001055 * .05) + (0.03 * .95) \\ = 0.0285$$

Secondary Y - Jupiter, Florida

55% sea

45% normal land

$$\Delta_{E_y} = (0.001055 * .55) + (0.03 * .45) \\ = 0.01441$$

The effective impedance estimate for Jupiter (Slave X) has the greatest uncertainty. Severe warpage is expected due to the changing ratio of land and sea interfaces as the straight line path to Jupiter is swept across the Eglin AFB area. This changing land/sea interface for the Jupiter path is exactly the same as when Jupiter was used with the East Coast LORAN-C chain. Within the East Coast chain, the Jupiter slave was determined to be responsible for the majority of all LORAN warpage. Since the transmission path for the Southeast U.S. chain is identical for the Jupiter slave, the same severe warpage is expected for the Southeast U.S. LORAN-C chain.

This assumption is substantiated by comparing the differences between measured and calculated values of Jupiter's TD in both the East Coast and Southeast LORAN-C chains. This comparison was done for the points shown in Table II and the resulting error was the same direction and nearly the same magnitude in each case.

The data in Table II was calculated to estimate the expected positional accuracy of the AN/ARN-10<sup>1</sup> coordinate converter (Q factor)\*, the path of the time difference line of position (LOP direction), and relative range and bearing to each station. This data shows excellent geometric coverage for the Eglin AFB area. The instantaneous (planar) path of a TD LOP was calculated from the azimuths to the LORAN stations by the following equation:

$$LOP_S = \tan^{-1} \frac{\cos \psi_S - \cos \psi_M}{\sin \psi_M - \sin \psi_S}$$

where:  $\psi_M$  = Bearing to master station

$\psi_S$  = Bearing to secondary station

Figure 3 shows the TD Lines of Position from Table II overlaid on a map of Eglin AFB. Based on these calculations it is concluded that the LORAN coverage from the Southeast U.S. LORAN-C chain will be uniform with TD crossing angles of approximately 72 to 77 degrees.

#### Data Collection Requirements

The prime area is usually sufficiently large that the data base will be collected over a long period of time. TD measurements taken for the data base must be compensated for weather, diurnal, and seasonal effects in order to be consistent and accurate. Ground monitors are needed to accumulate a history of TD data and establish standard TDs associated with the monitor. TDs collected in the field are then corrected by an amount determined from the following equation:

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\*Q factor is the absolute value of the determinate of the coordinate conversion gradient matrix. Absolute values greater than 0.1 are required for conversion.

TABLE II  
LORAN WARPAGE DATA  
SOUTHEAST U.S. LORAN-C CHAIN EGLIN AFB, FL

| Location                                                        | AN/APS-101<br>Q Factor |       | Station LOP and TD Data |           |            |               |           |            |
|-----------------------------------------------------------------|------------------------|-------|-------------------------|-----------|------------|---------------|-----------|------------|
|                                                                 | TD                     | Q     | ID                      | LOP       |            | TD            |           |            |
|                                                                 |                        |       |                         | Direction | Range (nm) | Bearing (Deg) | Observed  | Calculated |
| N 30.47483334°<br>W 86.51061667°<br>Bldg 100<br>Simulator Lab   | W-X                    | -1.85 | M                       | —         | 75.94      | 65.83         |           | 13726.116  |
|                                                                 | W-Y                    | 1.76  | M                       | 103.04    | 243.68     | 273.85        | 13728.119 | 30950.462  |
|                                                                 | X-Y                    | 1.67  | X                       | 157.13    | 642.69     | 248.44        | 30950.435 | 47176.908  |
|                                                                 |                        |       | Y                       | 93.65     | 394.97     | 121.47        | 47176.907 |            |
| N 30.53706389°<br>W 86.74996389°<br>B-70 Target<br>New Corbelle | W-X                    | .86   | M                       | —         | 86.08      | 71.46         |           | 13587.039  |
|                                                                 | W-Y                    | 1.60  | M                       | 172.27    | 211.23     | 273.07        | 30822.771 | 47192.215  |
|                                                                 | X-Y                    | 1.50  | X                       | 159.58    | 632.20     | 247.69        |           |            |
|                                                                 |                        |       | Y                       | 96.23     | 407.59     | 121.00        |           |            |
| N 30.63666°<br>W 86.30888334°<br>C-72 Target<br>C-5             | W-X                    | -1.79 | M                       | —         | 62.58      | 70.00         |           | 13871.355  |
|                                                                 | W-Y                    | 1.70  | M                       | 170.66    | 233.68     | 271.31        | 13871.442 | 31113.619  |
|                                                                 | X-Y                    | 1.59  | X                       | 158.99    | 655.72     | 247.97        | 47233.543 | 47234.860  |
|                                                                 |                        |       | Y                       | 96.76     | 390.59     | 123.51        |           |            |

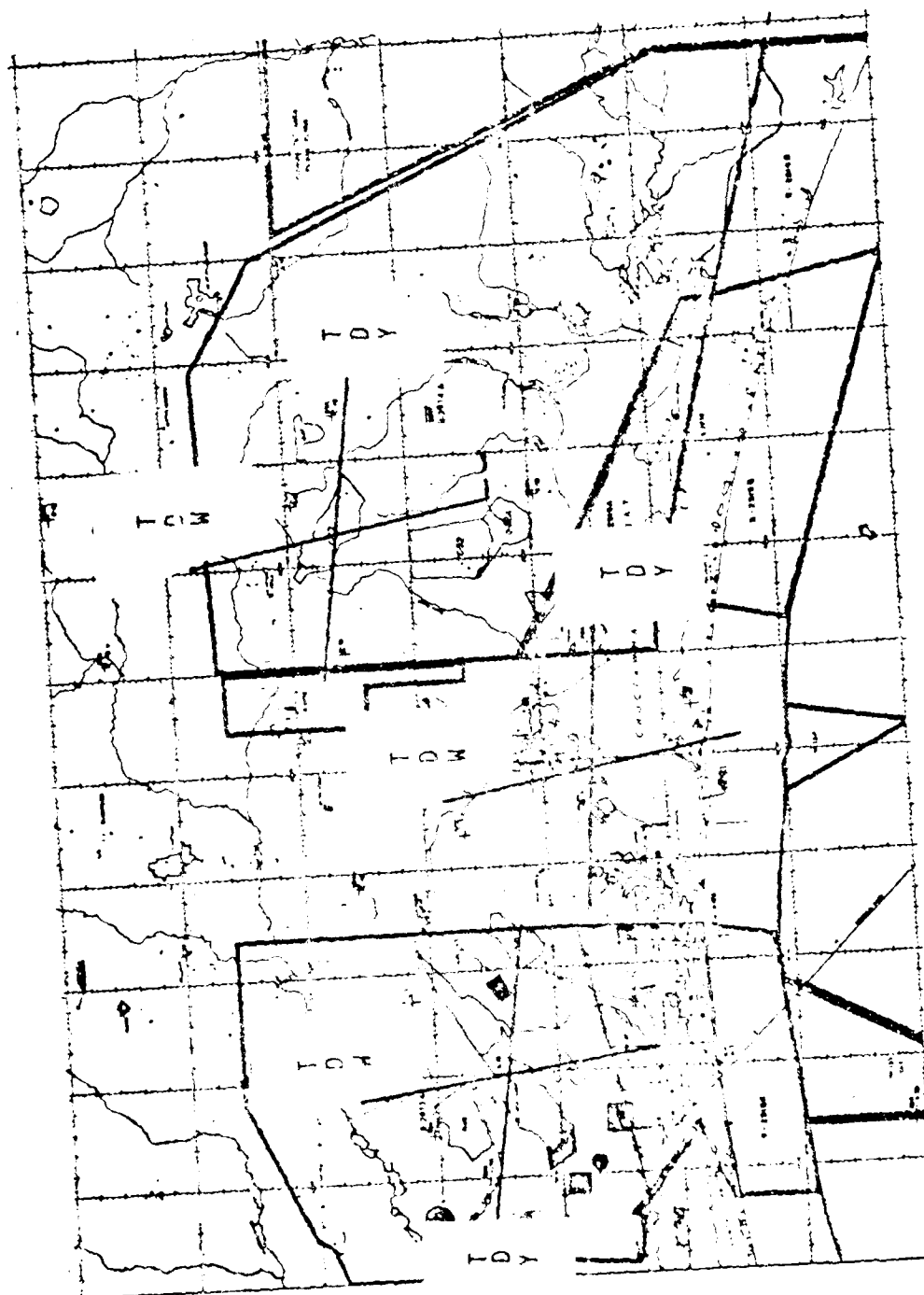


FIGURE 4. TD Lines of Position

$$TD = TD_{\text{meas}} + TD_{\text{inst}} - TD_{\text{std}}$$

where:  $TD_{\text{meas}}$  = Raw measured TD from the field

$TD_{\text{inst}}$  = Instantaneous TD of the Monitor

$TD_{\text{std}}$  = Standard TD of the Monitor.

The data base may be collected by ground mobile receivers at known benchmaks, geodetic survey points, or by an aircraft equipped with LORAN and other equipment for independent ground position location. When aircraft are used to collect the data base, the instantaneous aircraft locations should be accurate to 150 feet (1σ) or better. Measurements with position uncertainties of up to 300 feet (1σ) may be used, but only if more accurate measurements cannot be obtained. When positional measurements cannot be made to accuracies better than 300 feet (1σ), then the data point should not be used. If this condition is prevalent over the prime area, then the prime area cannot be adequately modeled and "average" values of effective impedance will usually provide the same statistical accuracy.

#### Generation of Warpage Coefficients

Collection of the data base is only the first step in the procedure to correct for the effects of LORAN warpage. The data base must be processed by the warpage coefficient generation program to calculate a set of fifteen coefficients for each LORAN secondary station. This program requires the following data as an input:

- The Northeast and Southwest corners of all 5 correction areas
- LORAN station locations
- Slave emission delays
- Spheroid Model
- Transmission ranges
- Program constants
  - Effective impedance of master station (estimated average)
  - Atmospheric vertical lapse factor (0.85)
  - Atmospheric index of refraction (1.000338)
- Data base for the area of interest.

Currently, the warpage coefficient generation program is in IBM card format and the above data is entered on IBM punch cards. The format for this data is specified in the program users manual\*.

The input data base is used by the warpage coefficient generation program to model the warpage and estimate the effective impedance for coordinate conversion of each data point. Once the effective impedances are determined to the accuracy of the data base, warpage coefficients are generated. The current version of the program uses only one coefficient to model the master station. The estimated value of master impedance used for input is also the coefficient for the master station. For each secondary station, one of the 15 coefficients is the average effective impedance for that station while the remaining 14 coefficients are constants for a 4th order polynomial. This polynomial is used to adjust the average effective impedance as a function of position within the prime area. With this method, the coefficients can effectively model the warpage and provide the wide range of impedances needed for correction. This process is implemented in the second part of the AN/ARN-101 coordinate conversion algorithm.

#### Summary

For many applications LORAN must be coordinate converted to latitude and longitude. Changes in the propagation medium over land signal paths warps the smooth hyperbolic lines of position and affects the accuracy of LORAN coordinate conversion. The effects of warpage can be corrected by proper selection of the secondary phase correction term but the selection is complicated by the severity of the warpage. Mild warpage can be approximated by a regular smooth LORAN grid and a single effective impedance correction model. Correction for severe warpage depends on location and requires an individual correction for each station and each location. Precision coordinate conversion in areas of mild and severe warpage requires an accurate data base of known geodetic positions and measured TDs. This data base is then used to model the LORAN warpage. In the AN/ARN-101 algorithm, warpage coefficients are developed in a warpage coefficient generation program. These coefficients transfer the warpage model to the second part of the algorithm which selects the proper secondary phase correction for coordinate conversion. This algorithm has demonstrated the ability to accurately model both mild and severe warpage as well as the rapidly changing warpage encountered with multiple land-sea-land interfaces.

#### References

1. "AN/ARN-101 Computer Program Development Specification, RF-4C", CB1001-004, Lear Siegler, Inc., Contract F19628-76-C-0024.
2. "Warpage Coefficient Generation Program Users Manual", YV1007, Lear Siegler, Inc., 18 May 1976, Contract F19628-76-C-0024.
3. "Wild Goose Association Radionavigation Journal", 1978.

## APPENDIX B

### STATEMENT OF WORK

#### UPDATE OF DOCUMENTATION OF

#### WARPAGE COEFFICIENT GENERATION PROGRAM

##### 1.0 INTRODUCTION

The purpose of the Warpage Coefficient Generation Program (WCGP) is to transform LORAN grid calibration data (Loran time difference measurements at known geodetic positions) into ARN-101 warpage coefficients. This function is necessary to define the ARN-101 Loran warpage model to provide necessary navigation and weapon delivery accuracy.

##### 2.0 SCOPE

This effort covers the update, modification, documentation, and checkout of all program functions within the Warpage Coefficient Generation Program. All non-required program logic will be eliminated, necessary logic streamlined, required capabilities added, program variables standardized, and user and analyst manuals prepared providing complete and up-to-date documentation of the program capability. All options retained within the updated program will be executed by means of a sample problem, results assessed, and if required, further modifications made to produce desired results.

##### 3.0 GENERAL BACKGROUND

The Warpage Coefficient Generation Program was developed by Lear Siegler, Inc. (LSI) as a support program for the AN/ARN-101 Loran function. It was provided to the Armament Division (AD) for support of the AN/ARN-101 RF-4C/F-4E DTAE/IDTAE test program. Delivery consisted of a card deck, source listing, and User's Manual (LSI YV1007). The program resided at AD until November 1978. The original LSI program was then provided to HQ ESD/CCN-1, Hanscom AFB, MA where it was made operational. ESD Operating Location-AF at Eglin AFB, Florida 32542, received the program in 1979 for use with the Eglin AFB calibration of the new Southeast USA Loran C Chain.

The Warpage Coefficient Generation Program is currently operational, but its operation is complex and requires evaluation by an engineer well-versed in Loran. The current implementation includes subroutines taken directly from other functional programs which results in unnecessary duplication of routines, calculations, and extensive arrays. The program is much larger and takes longer to execute than is necessary for the generation and evaluation of warpage coefficients. In addition, the program analysis required for successful utilization is difficult to perform using the minimal documentation available.



#### 4.0 TASK/TECHNICAL REQUIREMENTS:

The contractor shall perform the tasks specified herein. All tasks shall be performed during the period of time specified in the schedule. Priorities for assigned tasks shall be as directed by the government.

4.1 Minimize and simplify input/output data requirements necessary to execute the program.

4.1.1 Provide definition of all input parameters with format specifications.

4.1.1.1 Identify sensitive input parameters and provide nominal values.

4.1.1.2 Consolidate data point input onto one card by eliminating the original function and reformatting the remaining data.

4.1.1.3 Reformat output to duplicate input file format.

4.1.1.4 Provide logic to identify and eliminate data points outside the prime area.

4.1.1.5 With the coordination and approval of the government, delete all extraneous and outdated logic and streamline required logic to provide more flexible and up-to-date programming techniques. All code must be written in FORTRAN as per ANSI STD X 3.10 - 1978.

4.1.1.6 Modify the cell creation process to accommodate residual regions within the prime coverage area.

4.1.1.7 Standardize all variable names and reorganize COMMON to achieve consistency between routines to provide easier flow of program logic.

4.1.2 Provide definition of program variables, variable names, units of measurement, and expected ranges.

4.1.3 Specify conventions to consistently maintain numerical significance.

4.1.4 Allow for selectable spheroid models and allow for user selection of error model. Reference Specification CP1001-004 of Contract AF33(68)2-0001 (V): Computer Program Development Specification for the General Computer of RF-4C Digital Modular Avionics System.

4.1.5 Allow for input transmitter elevation and use it in calculations.

4.1.6 Implement an algorithm to compute all areas boundaries given only the perimeter of the prime area.

4.1.8 Modify matrix conversion algorithm to convert time difference (TD) errors to units of linear measure.

4.1.9 Implement histogram plotting capability for selected program data.

4.1.10 Implement additional overlay to include selectable plots of:

a. Data points within the prime coverage area showing grid with cell boundaries and cell numbers.

b. Contour plots of calculated and estimated impedances for each master/slave combination.

c. Contour plot of impedance error measurements.

4.1.11 Add to the program listing comments to fully describe program logic and computations being performed. (include description of program coding assumptions, and mathematical modeling techniques employed).

4.2 Following completion of Task 4.1, the contractor shall conduct a checkout of all program controls, options, and input/output formats.

4.2.1 In coordination with and with the approval of the government, the contractor shall prepare sample problems which will exercise every program element thereby demonstrating, to the satisfaction of the government, the integrity of the completed program. Test data will be supplied by the government not later than 30 days prior to test date.

4.2.2 Following the government's review of the results produced in Task 4.2.1, the contractor shall conduct further modification work, as required, to correct any remaining program deficiencies as identified by the government. Modifications may take the form of additions and/or changes to program logic and input/output formats.

4.3 The contractor shall conduct a documentation effort consisting of replacement of the present Warrage Coefficient Generation Program documentation (LSI YV1607, May 1976) with the following:

4.3.1 User's Manual - This manual shall:

4.3.1.1 State the objective of the computer program, its potential applications, and provide concise description of the major elements appearing in the program (i.e., overlays, programs, subroutines, and subfunctions). Narrative discussions and illustrations shall be used as appropriate.

4.3.1.2 Describe in detail the inputs necessary to use the program and obtain results.

4.3.1.2.1 Specify and define input parameters required for each execution and their location and format on the input data cards.

4.3.1.2.2 Illustrate the data deck setup for all major options.

4.3.1.2.3 State the output options available and define the output parameters.

4.3.1.2.4 Define output items giving dimensions and units for each output option.

4.3.1.2.5 Show examples of each output option.

4.3.1.2.6 Illustrate and describe each output plot option.

4.3.1.3 Present an example of how to exercise the program using a test case.

4.3.1.4.1 Describe the problem including assumptions and constraints.

4.3.1.4.2 Include a tabular listing of the input parameters with the numerical values to be used.

4.3.1.4.3 Illustrate the total punched data card setup.

4.3.2 Analyst's Manual - This manual shall:

4.3.2.1 State the objectives of the computer program, state its potential applications, and provide a concise description of the major elements appearing in the Analyst's Manual.

4.3.2.2 Provide a section which describes the application considerations for the PMS-10000 Damage model.

4.3.2.3 Describe the data collection requirements.

4.3.2.4 Describe the uncalibrated grid operation.

4.3.2.5 Describe the monitoring procedures to be used to determine effects of grid damage.

4.3.2.6 Provide a section which describes the mathematical and spheroid models contained in the updated computer program.

4.3.2.7 Present the mathematical equations used in each model.

4.3.2.8 Discuss all the assumptions used in each model.

4.2.2.2.3 Define all symbols and abbreviations used in each model and provide the units of each constant and variable used.

4.2.2.2.4 Describe coordinate systems and transformations for mathematical models.

4.2.3 Provide a section which defines the basic design philosophy describing the implementation scheme applied to the math models.

4.2.3.1 Provide a functional block diagram indicating the major components of the program, their interrelationships and their interfaces with other components. Includes overlays, programs, subroutines, and functions.

4.2.3.1.1 Provide a logic diagram that depicts the structure and logic of each overlay routine and subroutine contained in the updated computer program.

4.2.3.2 Include a glossary of symbols and terms used in the software documentation.

4.2.3.3 Provide a section which completely describes the procedures for exercising and documenting the program.

4.2.3.3.1 Provide operational instructions for the program. Include input requirements and limitations, as well as interpretations of all possible outputs.

4.2.3.4 Describe diagnostics and explain all error code messages.

4.2.3.5 Include a listing of the computer program in source language.

4.2.3.5.1 Describe all source card formats identifying their purpose and function.

4.3.2 Following the government's review of the results produced in Tasks 4.3.1 and 4.3.2, the contractor shall conduct further modification work, as required, to correct any deficiencies identified by the government.

4.4. The contractor shall install and exercise the computer program on the J-10 (60) computer at Eglin AFB, FL. This task will be completed when the computer program, running on the Eglin computer, is able to duplicate the output results obtained during the program checkout phase, Task 4.2 above. The government will arrange for the use by the contractor of the Eglin AFB computer.

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