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FAA TECHNICAL CENTER LETTER REPORT

POSITION OF LORAN-C STABILITY VAN WITH RESPECT TO WGS-72 COORDINATES

by

Robert Erikson

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
TECHNICAL CENTER
Atlantic City Airport, N.J. 08405

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ABSTRACT*

These tests were conducted to establish a method to determine geodetic van position in WGS-72 coordinates to support the evaluation of LORAN-C short term stability as it pertains to non-precision approaches.

The author of this report is Robert Erikson, ACT-100B.1. He may be contacted for additional information at FTS-346-2750, (609) 641-8200, extension 2750.

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INTRODUCTION

PURPOSE

Establish a method to determine geodetic van position in WGS-72 coordinates to support the evaluation of LORAN-C short term stability as it pertains to non-precision approaches.

BACKGROUND

In order to evaluate LORAN-C accuracy, the position of the test van must be known with respect to the World Geodetic System of 1972 (WGS-72). One issue at hand is to determine how much error can be tolerated in the van position. The allowable position error is dictated by first the requirements needed to meet Advisory Circular (AC) 90-45A for non-precision approaches and to determine LORAN-C propagation errors. The Advisory Circular requires a total system error of less than 0.6 nautical mile (n.m.), two sigma (2σ) crosstrack and 0.3 n.m. (2σ) along track. Tradeoffs in the various errors making up the total system error are possible but an equipment error in crosstrack of 0.33 n.m. (2σ) and 0.3 n.m. (2σ) along track are the budgeted errors for this type of equipment. The above values translate into errors of 2006 feet (611 meters) and 1824 feet (556 meters) respectively (2σ). In general, the accuracy of a measurement system should be 10 times better than the system under test. Therefore, the measurement system should contain errors less than 200 feet (2σ) or 100 feet (30 m) one sigma. The second requirement to determine LORAN-C propagation related errors requires a position accuracy of 10 meters (Ref. 1). A 10 meter accuracy makes it possible to estimate the slope of the secondary phase delay versus range function with an accuracy of 0.5 nsec/km (1σ). Theoretical values of the scale factor vary from 2 nsec/km for sea water to 6 nsec/km for frozen ground.

Several techniques are available for determining geodetic position; conventional surveying techniques using horizontal control monuments, geodetic (satellite) receivers, and U.S. Geological Survey (U.S.G.S.) 7½ minute quadrangle maps.

Geodetic receivers (georeceivers) include such systems as TRANSIT and Global Positioning System (GPS) Geoceivers are the best choice because their positions are based only on information received from orbiting satellites, requiring no earth reference points and can be transformed into wGS-72 coordinates using standard equations. TRANSIT receivers are able to calculate the absolute position with errors less than 3 meters (vendor stated) but require one receiver to collect data on location 24 to 48 hours. If a second receiver is used in a translocation mode, the time may be reduced to 4 hours. Obstructions, local interference, and satellite orbits all effect the length of time to get a fix. For our project, each airport has up to 30 sites which require a position determination. Therefore, this technique is not practical. Use of GPS manpacks in a translocation mode or differential mode will produce accuracies approaching 10 meters. If only one receiver is used, as would be our case, the system accuracy would degrade. The GPS manpack would require only 10 to 15 minutes to obtain a position fix but typical illumination time in an area is only 2 to 3 hours during a 24 hour period. Again time is a problem. Additionally, GPS is still under evaluation and some may question the validity of the results.

Conventional surveying techniques yield accuracies better than one meter. However, chances of error as well as cost are increased as the distance from horizontal control monuments increase. In selecting sites to measure LORAN-C performance, the constraints of the measurement data were followed and where possible sites were selected close to existing horizontal control monuments. This technique produces accurate points but is still very costly. The last method to determine position would be to use U.S.G.S. 7½ quadrangle maps. Use of this technique would be the least expensive, is not limited to coverage windows and could be done as part of data collection at each site, adding only a few minutes more on location. Discussion with personnel from the U.S.G.S. indicate position errors from the map should be less than 200 feet (60 meters), possibly less than 100 feet (30 meters). Many factors effect the accuracy that is obtainable using the U.S.G.S. 7½ minute quadrangles to determine van position, they are:

1. Accuracy of terrain features on map.

2. Determination of van position on the map with respect to terrain features.

3. Reading the latitude and longitude of the van position with respect to the map.

4. Map bias.

5. Transformation of geodetic positions from North American Datum 1927 (NAD-27) to WGS-72.

Before discussing the expected errors, it is important to understand some history of map making and geodesy. Early map making (1800's) was done by sending people into the field to make observations but without standard measures of length or control points. It was found that everyone's observations were different and few maps agreed. Local communities, states, and the federal government established horizontal and vertical control points to produce more uniform maps. The federal government established a network of widely spaced points over a large area while local communities established many points in a small area. Eventually all the points were tied together so that local communities could be combined to produce a state map and states combined to produce a federal map. States generally produced maps on either transverse mercator or lambert conformal projections, thus allowing each state to operate on a flat plane instead of an ellipsoid. As distances are increased the shape of the ellipsoid becomes critical. Bessel in 1841 and Clarke in 1866, defined an earth ellipsoid but in 1927 a new reference was created which optimized the North America continent and was known as the North American Datum of 1927 (NAD-27). Mapping and geodesy have become much more scientific with the use of gravity measures, astronomical observations, aerial photography and satellite receivers. The most commonly used datum for long distance navigation is WGS-72. In fact, the NAD-27 datum is currently being modified to bring the parameters defining the ellipsoid to be approximately that of WGS-72 and will be known as NAD-83. What should become apparent is that map making and geodesy are now very scientific fields using many different independent techniques to establish and verify maps. The procedures should produce very accurate maps.

As stated earlier, five factors effect the accuracy of a position fix, but really can be grouped into three areas:

A. Map accuracy

B. Placement of point on map and reading of latitude and longitude

C. Geodetic datum transformation

Map Accuracy

Reference #2, "Map Accuracy" produced by the U.S.G.S. states that the horizontal accuracy for 90% of all points plotted on a map must be better than 1/30 of an inch. In general, well defined points will be within 1/100 of an inch. The $7\frac{1}{2}$ minute quadrangles are produced on a scale of 1:24,000 which means that one inch on the map is equivalent to 2,000 feet (606 meters). Conversion of plotter limits to error in distance (real world) would result in 90% of all points being within 66 feet (20 meters) and well defined points, 20 feet (6 meters) of actual position. Discussion with personnel from U.S.G.S. and Ohio Department of Transport, Aero Engineering Division believe most data on maps to be within 20 feet if the maps have been photorevised. Occasionally a 15 minute quadrangle will have to be used. Scales of these maps are 1:62,500, therefore, all errors described above would be multiplied by 2.6. As all quadrangles are produced with an NAD-27 overlay, it implies that survey work must be better than plotter errors and determined in NAD-27.

Geodetic Datum Transformation

Of major concern are the equations used to make the transformation from NAD-27 to WGS-72, their accuracy, and the bias contained in the quadrangles. No one document was found that addressed the problem directly, but the combined results of three separate documents imply an answer. The documents describe the expected errors and actual position shifts using the recommended transformation from NAD-27 to WGS-72, and the expected position shifts for transforming NAD-27 to NAD-83. Because the defining parameters for NAD-83 and WGS-72 are almost identical we can compare the results. Adding to the validity, is the fact that each transformation used different sets of data, collected over 10 years apart. The position shifts calculated for converting NAD-27 to NAD-83 are really for quadrangle position to NAD-83. Therefore, we are effectively measuring the shift from NAD-27 to WGS-72 and the shift from map coordinates to WGS-72. If the results are equal, one can conclude that no errors exist. If the results are not equal, it is impossible to estimate where the errors lie, but we can estimate the amount of uncertainity. Table 2 will summarize the results of the above comparison for a central point at each of five airports used for LORAN-C stability testing.

Reference 3 describes the methodology used to define the new ellipsoid for WGS-72 as well as how the transformation from NAD-27 to WGS-72 was established. In brief, 37 geoceivers were distributed across the continential United States to determine the datum shift. Up to 10 meters of variation exist between the mean NAD-27 to WGS-72 datum shifts and observed local shifts.

Table 1 shows the mean ΔX, ΔY, and ΔZ shift used for the transformation and the largest excursions from the mean observed in the area east of Indiana and north of Maryland.

TABLE 1

Parameter	Mean Value	Largest Excursion	Area
Δ X	-22	-4	Vermont
Δ Y	157	5	Vermont
Δ Z	156	4	East Penna.

All values in meters

Reference 3 recommended the use of either the Standard Molodensky Formulas or the Abridged Molodensky formulas with the above mean values. Column three in Table 2 lists the required position shift in meters to transform NAD-27 to WGS-72 using the Abridged Molodensky equation and mean datum shift parameters.

References 4 and 5 describe the expected position shift of each quadrangle map corner to correct map position (NAD-27) to NAD-83. The values in the correction tables must have their directions changed 180 degrees to account for the fact that a position on the map is being changed to NAD-83 and not a map corner. The transformation was based on 123 comparisons of Doppler and NAD 1927 positions within the continential U.S. (Ref. 5). The map corners have been shifted by different amounts between Reference 4 and Reference 5 because recent investigations have indicated that a correction of scale (-0.38 ppm) and origin of Doppler longitude (.80" west) are required. Columns 4 and 5 of Table 2 list the shifts based on this information. The remaining two columns on the table list the differences obtained by subtracting the NAD-27 - WGS-72 shift from NAD-27 - NAD-83 (1st prediction) and NAD-27 - WGS-72 (2nd prediction) shifts respectively. As can be seen from this table, all results agree to within 15 meters.

Airport	Geodetic Position NAD-27	NAD-27 to WGS-72 Shift	NAD-27 to NAD-83 1st Prediction	NAD 27 to NAD-83 2nd Prediction	Column 4 minus Column 3	Column 5 minus Column 3
Rutland, Vt.	N 43°30' W 72°52'30"	-3 +22.4	-4 +24	-4 +35	1 6	1 -12.6
Worcester, Ma.	N 42°15' W 71°52'30"	-2 +27	-6 +25	-6 +38	4 2	4 -11
Columbus, Oh.	N 40° W 82°50'30"	+2 -2.33	-3.5 -5	-2 +8	5.5 2.67	4 -10.33
Philadelphia Pa.	N 39°45' W 75°07'30"	+2 +17.7	-6 +18	-6 +32	8 0.3	8 -14.3
Atlantic City, N.J.	N 39°22'30" W 74°30'	2.4 20.3	-7 +20	-7 +3.4	9 0.3	9 -13.7

----------All Values in Meters----------

1 2 3 4 5 6 7 Column

TABLE 2

Procedure to Obtain Position Fix from U.S.G.S Quadrangles

The procedure must be divided into two steps, first determining the proper point on the map and second, reading the geodetic position of that point. At the bottom of each quadrangle is a scale to convert real world distances to map displacement; from this scale it is easy to read real world displacements to 50 feet and estimated to 20 feet. For this technique to work, it is imperative that in-field measurements are made from well defined points on the map to the van. Most points will be the intersection (at right angles) of two streets, but specific sites may require measuring from the center of a stream, railroad track, bridge or other prominant terrain feature. For the sake of accuracy the shortest direct distance from reference to van should be used, as non-straight lines increase error. Occasionally it is necessary to validate the position of a reference by measuring to other terrain features at some distance. The field party must make these extra checks, as well as observing the general lay of the land to make sure that measurements are from the correct points on the map and that the area has not been changed. Once this information is obtained, the data will be transferred to the quadrangles using the scale on each map. On a scale of 1:24,000 ($7\frac{1}{2}$ minute quadrangle), 1/16 of an inch is equal to 125 feet.

To determine the geodetic position, each selected point must be transferred to the edges of the map and then read. Transfer of the points must be made parallel to the edges of the map or additional errors will result. Each map has printed, 2.5 minute marks along each edge for altitude and longitude reference. Once the point is transferred to the edge, each 2.5 minute division is divided into even minutes. A Gerber rule (i.e. rubber ruler, divider) is used to facilitate the division.

If 10 divisions are used to cover the 2.5 minute distance, every 2 units will be equal to 30 seconds. Each minute can then be divided into 60 units, with each unit equal to a second. The point can now be read directly and estimated to a tenth of a second. To reduce the chance of error and improve reading accuracy three people will read each point. All results for each site will be verified to be within two seconds of each other. An average value for each of the three readings will be calculated and used at the correct geodetic position. Any set of readings varying more than 2 seconds will be re-read by all people until results are within this tolerance.

No document was found describing the above procedure or expected results so a small test sample was taken and results analyzed. A surveyor was contracted to survey 33 van positions in New Jersey. The survey error for these points was stated by the contractor to be less than several feet. All surveying was done in N.J. Grid coordinates and converted to NAD-27 by the contractor. The Technical Center also computed the geodetic position using the map method just described and the results are presented in Table 3. Listed in the table are the site numbers, and the results of subtracting the map calculated latitude/longitude from the surveyor calculated latitude/longitude presenting the differences in both seconds and feet. Conversion from seconds to feet was done assuming one second of latitude at 39°N was equal to 101 feet while one second of longitude was equal to 78 feet.

Observation of the data shows most to be within 60 feet while several points were obviously larger than the normal but in no case did any difference exceed 180 feet. The mean error for latitude was 1.37 feet and longitude -1.92 feet with standard deviations of 48 feet and 35 feet respectively.

CONCLUSIONS

At the beginning of this paper it was stated that the position reference accuracy required to evaluate AC 90-45A was 30 meters (1σ) and evaluate propagation effects 10 meters (1σ). It is not presently known how the errors contributed by the map technique and the datum conversion should be added. If the magnitude of the results are simply added as a worst case estimate, the latitude components would be 14m (map) + 9m (conv) or 25 meters while the longitude would be 10.6m (map) + 15m (conv) or 25.6 meters. This is within the 30 meters for AC 90-45A but does not meet the requirements for propagation. Propagation related errors are, however, grouped into two areas, T.D. Bias and local effects. T.D. bias is the problem of not being able to compute the exact additional phase delay from the transmitters to the receiver. Path lengths will typically exceed 200 nm but should affect all points within a 10nm radius equally. To determine a bias for each airport all sites would be averaged together, therefore, the errors associated with map errors would cancel each other out and only the 15 meter maximum shift in datum conversion would influence the results. On the other hand, if only the local (10nm radius) area around an airport were of concern a bias could be computed to correct for datum conversion errors as well as long distance propagation effects, leaving only the local effects. At this point, only the mapping errors would influence the results. With one sigma errors of 14 meters in latitude and 11 meters in longitude due to mapping we are greater than the error budget but can still look at the effects.

Comparison of Surveyed Position and Map Position

Site #	Δ Latitude Seconds	Δ Latitude Feet	Δ Longitude Seconds	Δ Longitude Feet
ACY				
1	-0.1001	-10.1101	+0.3650	28.4700
2	-0.6463	-65.2763	-0.2114	-16.4892
3	-0.0166	- 1.6766	-0.3826	-29.8428
4	-0.2446	-24.7046	+0.4421	34.4838
5	-0.2668	-22.9068	-0.0988	- 7.7064
6	+0.5718	57.7518	-0.7969	-62.1582
7	-0.0920	- 9.2920	-0.1209	- 9.4302
8	-0.2054	-20.7454	-0.0107	- 0.8346
9	+0.2716	27.4316	+0.1621	12.6438
11	+0.0047	0.4747	+0.7065	55.1070
12	+0.1342	13.5542	-0.0461	3.5958
13	-0.4529	-45.7429	-0.5094	-39.7332
14	-0.1232	-12.4432	-0.0050	-0.3900
15	-0.1701	-17.1801	+0.3386	26.4108
16	-0.4252	-42.9452	-0.2243	-17.4954
17	-0.0934	-9.4334	-0.5177	-40.3806
18	-0.4658	-47.0458	-0.1988	-15.5064
19	-0.4996	-50.4596	-0.6822	-53.2116
20	+0.2536	25.6136	-0.7590	-59.2020
21	-0.2640	-26.6640	-0.2844	-22.1832
22	-0.8039	-81.1939	+0.1059	8.2602
23	+0.0934	9.4334	+0.1671	13.0338
25	+0.1014	10.2414	+0.2855	-18.6420
27	-0.2396	-24.1996	-0.2390	-18.6420
PHL				
1				
01	-0.0394	-3.9794	+0.4009	31.2702
02	+0.0797	8.0497	+0.2289	17.8542
03	-0.2243	22.6543	-0.2531	19.7418
04	+0.2366	23.8966	-0.4091	31.9098

Site #	Latitude Seconds	Latitude Feet	Longitude Seconds	Longitude Feet
05	+0.7218	72.9018	+0.0580	4.5240
06	+0.3583	36.1883	-0.0191	1.4898
07	+0.1643	16.5943	+0.5958	46.4724
08	-0.2059	20.7959	+1.2246	95.5188
18	+1.7757	179.3457	+1.1339	88.4442

Note:

1. Δ values are calculated by subtracting map position from surveyed position.

TABLE 3

References

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