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PROBABILISTIC MODELING OF LORAN-C FOR NON-PRECISION APPROACHES

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by

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Abstract

A mathematical model of the expected position errors encountered from LORAN-C during a non precision approach was formulated. From this, position error ellipses were generated that corresponded to two time difference correction schemes. One involved relaying corrections to the pilot just before he initiated the approach, and the other involved publishing time difference corrections in the instrument approach plates.

It was found that the errors associated with both update scenarios were well within FAA AC90-45A accuracy standards for non precision approaches. The former scenario showed a significant improvement over the latter.

Flight tests were conducted in a general aviation airplane carrying an equipment test bed designed to take data from a LORAN-C receiver and an ILS localizer receiver. The results of the flight tests show that the LORAN-C had a maximum error (average plus one standard deviation) of 1.276 degrees deviation from the localizer path, and an average error (average plus one standard deviation) of .648 degrees.

It is concluded that LORAN-C is a suitable navigation system for non precision approaches and that time difference corrections made every eight weeks in the instrument approach plates will produce acceptable errors.

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Title: Professor of Aeronautics and Astronautics at MIT

Research Supervisor: Dr. Robert W. Simpson
Title: Director, Flight Transportation Laboratory

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Chapter 1

INTRODUCTION

1.1 THEORY OF OPERATION

LORAN-C is a high accuracy long range radionavigation system currently used by both the aviation and marine communities. It is a low frequency, pulsed system operating at 100 kilohertz. Position fixes are made by at least two hyperbolic lines of position formed from at least three transmitters. These transmitters are grouped into two categories: masters and secondaries.

The master transmits a signal which is followed by a signal from each of the secondaries. A coded time delay unique to each secondary identifies that transmitter and ensures that no two secondaries in the chain transmit signals simultaneously. Receivers measure the elapsed time between receiving the master's signal and any of the secondaries' signals. This gives one line of position for each secondary tracked. Two secondaries are enough for a position fix, and most receivers use only two although they generally track more. The intersection of the hyperbolic lines of position is the receiver's position. The sequence of master-secondary transmittion is repeated after the group repitition interval (GRI) which is typically between 0.05 and 0.1 seconds.

All transmitters are synchronized with cesium clocks as precise timing is the key to accurate information. The signal is a group of eight or nine pulses shaped so that 99% of the transmitted energy is kept within a bandwidth of 20 kilohertz (90 to 110 kilohertz).

1.2 PRACTICAL OPERATION

The LORAN-C receiver calculates position as the intersection of the two LOPs. This information is relayed to the operator by a number of means. Older sets display the actual time differences (TDs) which correspond to labeled LOPs on a special LORAN-C map. The operator must locate the LOPs on the map and find their intersection. State of the art receivers offer several options. These include latitude and longitude, cross track error from a specified course, and range and bearing to a specific destination. A detailed explanation of the theory behind LORAN-C is contained in reference one.

1.3 TRANSMITTER OPERATION

A LORAN-C chain consists of a master and at least two secondaries.

There are currently sixteen LORAN-C chains throughout the world, six of which cover some part of the CONUS, two cover all of Alaska and one covers Hawaii. Each chain is refered to by an identifying number which is the chain's GRI in microseconds (μs) divided by 10. For example, the North East United States chain GRI is 99600 μs, and is refered to as the 9960 chain. The numbers range from 4990 to 9990.

Some transmitters carry a double rating. That is their signals are used by two different chains. For example, Caribou, Maine is a secondary transmitter for the 9960 chain and is the master for the 5930 chain. The transmissions are timed such that there is no interference between the two chains.

1.4 ADVANTAGES OF LORAN-C

LORAN-C system navigation has several advantages which make it an attractive option for both the aviation and marine communities, however this section as well as the balance of this report deals in particular with the use of LORAN-C in the CONUS by general aviation users.

First of all, LORAN-C has a low user cost. Airborne units can be purchased for as little as $400 dollars. With the exception of antenna purchase and installation, that is the extent of the cost to the user. There are no user fees. References two and three site examples and show LORAN-C to be very cost effective and competative with other navigation systems.

Because of its mode of operation, the system is non saturable. An unlimited number of people can use the system with no effect on the quality of the service.

Coverage of the CONUS is another advantage of LORAN-C. At this writing, a large percentage of CONUS is covered by LORAN-C signals. The so-called 'mid-continent gap' which exists in middle CONUS is the only area currently uncovered. Plans to fill in this gap are currently being proposed and include boosting signals of nearby chains and the addition of a new chain or chains.

The system has been the object of many and varied studies which have proven it to be effective and reliable. The next section discusses some of these studies that are relavent to the content of this report.

1.5 BACKGROUND LITERATURE

This section presents some of the previous testing and studies completed whose results are of interest in the context of this report.

1.5.1 Signal Stability

The United States Coast Guard has been recording LORAN-C signals at numerous Harbor Monitor System (HMS) stations since 1980 for marine applications. They have installed five new sites in the Northeast section of CONUS in August, September, and October of 1984 for the FAA for the purpose of studying the stability of the signals. Each quarter, the Coast

Guard publishes a document which presents this long term stability data. Reference four is an example of this document. The data shows that a yearly pattern in the changes in the TDs exists. The data from 1980, 1981 and 1982 for example, all have the same shape when TDs are graphed as a function of time. Figure 1.1 shows an example of the data contained in an HMS quarterly report.

Reference five shows the repeatable accuracy of the existing LORAN-C system to be better than 40 meters, 2-drms, in 50% of the Northeast and Southeast United States (NEUS/SEUS) coverage area and better than 80 meters in over 90% of the same coverage area.

1.5.2 Operational Testing

Two major studies completed that examined the operational effectiveness of LORAN-C were conducted by the USCG, and a joint effort by the DOT and the state of Vermont.

The study completed by the USCG is contained in reference six. This study focused on four program objectives. First, the suitability of LORAN-C as a navigation system for USCG search and rescue (SAR) missions in relation to operational requirements and constraints was examined. Second, accuracy data was gathered to examine LORAN-C suitability for use in USCG surveillance and enforcement missions. Third, to evaluate the suitability and compatibility of LORAN-C in the current VOR/DME

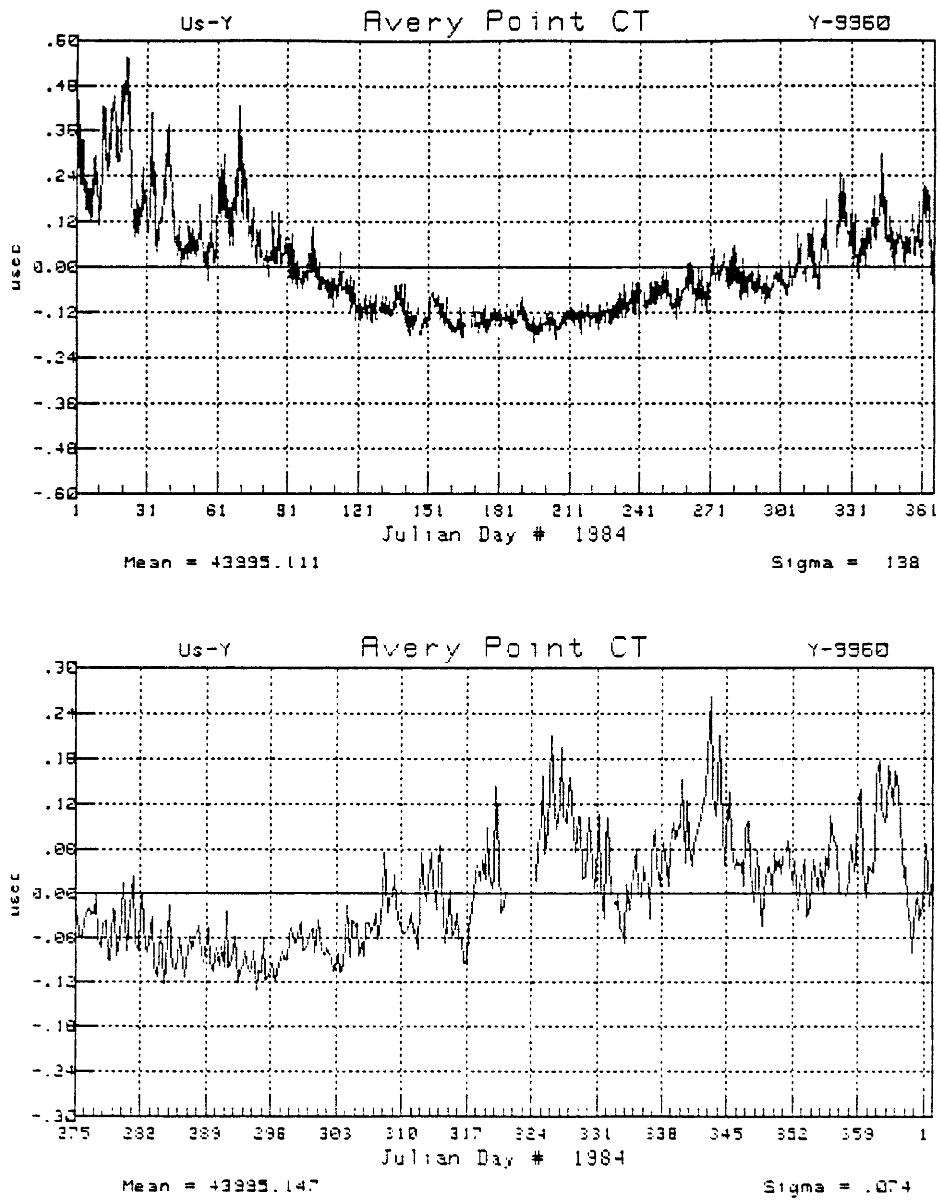

Figure 1.1: Quarterly And Yearly Data From USCG HMS Reports

NAS enroute navigation environment as well as existing and planned NAS area navigation constraints. Finally, to demonstrate the applicability of LORAN-C for use where VOR/DME coverage in inadequate, such as in offshore helicopter operations.

The results of the study showed that LORAN-C accuracy met FAA AC 90-45A specifications for all phases of flight. AC 90-45A is an FAA Advisory Circular first published in 1975 entitled: "Approval Of Area Navigation Systems For Use In The U.S. National Airspace System". It lists accuracy specifications that must be met for a navigation system to be approved by the FAA for enroute, terminal area, and non-precision approach use. LORAN-C was found to be compatible with RNAV routes and procedures and the current VOR/DME environment. Finally, the system performed adequately over water in absence of VOR/DME coverage and for USCG SAR and surveillance missions.

The second major study performed by the DOT and the state of Vermont examined the accuracy of LORAN-C as an enroute, terminal area, and approach navigation system in the state of Vermont where mountaineous terrain restricts conventional line of sight (LOS) systems such as VOR/DME. This is contained in reference seven.

The results of this study showed that LORAN-C met all accuracy requirements of AC 90-45A for all three phases of flight. In addition, the reliability of the receiver was found to be 99.5%, and no degredation in accuracy was found due to the mountaineous terrain.

Two additional, smaller scale but more recent studies done in Ohio and Massachusetts are contained in references eight and nine respectively. These studies confirm the conclusions of the USCG and Vermont reports.

1.6 SOURCES OF ERROR

The sources of error in a position fix can be divided into two categories: those resulting from signal and propogation anomalies, and those resulting from receiver error. Any error in a position fix is going to have components of error from both categories, but for the purposes of explanation, it is convienent to deal with the two separately.

1.6.1 Signal and Propogation Anomalies

As is shown in the USCG HMS quarterly reports, a seasonal drift in the TD values at a single, stationary point exists. This causes an error or TD bias in the LORAN position fix. The true TD value is not constant over long periods of time, resulting in what is called TD bias and grid warpage. If the hyperbolic grid consisting of the LOPs was drawn over an area once a week, the picture would be constantly changing.

Additionally, a short term variation in the TD values is present. This can be seen in standard deviations in TD values on the order of 5 to 50 nanoseconds over a five minute period. This is caused by changing terrain and atmospheric characteristics over and through which the LORAN signal travels.

1.6.2 Receiver Error

Once the signal is received by the LORAN-C receiver, further errors can be introduced by the receiver itself. Poor signal to noise ratios make it difficult for the receiver to accurately track the signal.

There is no written standard that manufacturers must follow when choosing receiver bandwidths, tracking loop time constants, and other important parameters so that each set may have a different set of characteristics and tracking errors. The most noticable of these is the conversion from TDs to lattitude and longitude. Since no standard exists, each set will have its own conversion algorithm and corresponding errors.

It is the intent of this study to investigate the effect signal propogation anomalies have on actual position accuracy. Specifically this involves reducing the seasonal drift and grid warpage by giving the pilot TD correction factors. The two correction scenarios to be investigated are: 1) radio TD corrections to the pilot as he approaches the airport much like altimeter corrections are currently done, and 2) publish TD corrections or TD values at runway touchdown points on the bimonthly approach plates.

Chapter 2

EXPERIMENTAL OBJECTIVES

This study was undertaken with four specific test objectives in mind:

1) Develop a mathematical model that takes into account station geometry, receiver location, and runway heading to produce a bivariate normal distribution position error ellipse. Chapter three explains in more detail the position error ellipse. In the context of LORAN-C and this report, given the location of the receiver and the TD standard deviation error (or a predicted value for the standard deviation) an ellipse can be drawn with a known probability of being within the boundaries. The ellipse semi diameters are given in distance units such as feet.

2) Using this model, investigate different update frequencies for the touchdown TDs necessary to make a non-precision approach within AC 90-45A or other standards. As mentioned in chapter one, two update scenarios will be investigated for relaying TD corrections to the pilot: updating and

publishing TDs in the bi monthly instrument approach plates, and giving the pilot LORAN-C corrections from the airport tower prior to the initiation of his approach, much like altimeter settings are accomplished today. TD errors will be predicted for each of the two scenarios and error ellipses will be generated to predict position error.

3) Compare these two update scenarios with different accuracy standards to see if they are accurate enough for standard practice. Once the error ellipses are generated, these can be compared with any accuracy standard to see if the scenario meets the standard.

4) Perform flight tests to investigate the validity of the model in terms of real flight applications. The model used to generate the ellipses is a known and accepted methodology, and thus I am not trying to verify its correctness. Rather, I am trying to investigate if flight data, gathered in *real* flight tests and in a moving plane fit the model. In addition, by following the flight organization and testing outlined in chapter four, I hope to show that LORAN-C is accurate enough to be a certified approach aid.

Chapter 3

MATHEMATICAL MODEL

This chapter outlines the mathematical model used to predict the errors associated with the two update schemes described in chapter two. More detailed development of the mathematical model shown in this chapter can be found in references 1, 10, and 11. In the LORAN hyperbolic coordinate system, the LOPs and their associated gradients (∇_n) can cross at an infinite number of angles. In other words, the crossing angle of the ∇_ns could be any angle between $0 + \epsilon$ and $180 - \epsilon$ degrees where ϵ is a very small value. Given the two gradients, for example, in ft/μs, and the respective TD errors in μs, by multiplying the two quantities together, a position error in feet is computed.

The final output of the model presented here is a position error ellipse. This is an ellipse of specified size such that the probability of being within or on the boundaries of the ellipse is a known or desired value. Given a desired probability of being within the ellipse, the size of the semi-diameters can be set so that the probability is reached. Conversely, given the size of an ellipse, the probability of being within the boundaries can be computed.

The probability distribution of position within the ellipse is defined by a bivariate normal distribution with a correlation coefficient of zero (this means that the axes are principal axes). The probability distribution function for the position along each axis is a normal distribution. Because these axes are principal axes, the correlation coefficient is zero, and movement along one axis does not influence position on the other. In other words, the errors along the axes are independent.

By definition, the semi diameters of an ellipse cross at a right angle. Because the gradients do not as a rule cross at 90 degrees, simply multiplying the TD error times the gradient and traveling out along the gradient direction the multiplied distance does not produce an ellipse. The gradients and the respective TD errors must be split into components whose intersection is a 90 degree angle. The directions of the components can be any direction that is convienent as long as the directions are known and meet at a 90 degree angle. This is the *arbitrary axis coordinate system.*

The first step in the computation of the position error ellipse is to generate a covariance matrix of position error (in this report, the units of position error are *feet*) in the *arbitrary coordinate system.* I choose for the most part, a North and East *arbitrary coordinate system.* This first step would be then, to generate a covariance matrix of position error in feet where the axes are **North-South** and **East-West**.

The second step is to perform a coordinate transformation on the position covariance matrix to principal axes. Reference 10 gives an explicit example of this type of transformation. The end result of this is a covariance matrix of position errors in principal axes. This matrix is used to compute the position error ellipse semi diameters and orientation.

The final step is to examine the sizes of the ellipses and compare them to accuracy standards for non-precision approaches. The following section outlines in more detail the procedure for generating a position error ellipse.

3.1 COVARIANCE MATRIX

In order to produce a position error ellipse, a covariance matrix for the situation under study must be calculated. In the context of LORAN-C, this matrix will contain the variances of the two secondaries and their covariance in units of feet squared.

3.1.1 Arbitrary Axis Matrix

For any given position, a covariance matrix must first be calculated with reference to any *arbitrary axis*. The components of this matrix are computed through the following development.

A change or error in the TD (ΔT_n) can be related to the error in position

(δr) by:

$$\Delta T_n = \nabla_n \cdot \delta r \tag{3.1}$$

where (∇_n) is the signal gradient in units of μs/foot. Since we are dealing with a two LOP fix, n=2. If we let H represent the 2 by 2 gradient matrix, then

$$\Delta T_n = \mathbf{H} \cdot \delta r \tag{3.2}$$

This basic relationship can be applied to the covariance matricies of the TDs, gradients, and position as well. This gives:

$$\overline{\Delta T \Delta T^T} = \overline{H \cdot \delta r \delta r^T \cdot H^T} \tag{3.3}$$

and

$$\mathbf{E} = \overline{\delta r \delta r^T} = H^{-1}(\overline{\Delta T \Delta T^T})H^{T^{-1}} \tag{3.4}$$

where **E** is the covariance matrix of error in position. For the purposes of this study, the covariances of the TDs are assumed to be zero. Thus

$$\Delta T \Delta T^T = \begin{pmatrix} \sigma_{TD1} & 0 \\ 0 & \sigma_{TD2} \end{pmatrix} \tag{3.5}$$

When the position of interest is a runway, the *arbitrary* coordinate axes will be parallel and perpendicular to the runway direction. If the position of interest has no directionality then the arbitrary axes will be North/South and East/West. For the purposes of this section, we will assume that the point of interest is a runway. Table 3-1 lists the nomenclature for the gradient components in the H matrix.

r_1 is the component of ∇_1 parallel to runway
r_2 is the component of ∇_2 parallel to runway
p_1 is the component of ∇_1 orthogonal to runway
p_2 is the component of ∇_2 orthogonal to runway

Table 3.1: Gradient Components in the H matrix

This then gives rise to

$$H = \begin{pmatrix} r_1 & p_1 \\ r_2 & p_2 \end{pmatrix} \tag{3.6}$$

With the listed components in the position covariance equation 3.4, the covariance matrix becomes

$$\mathbf{E} = \begin{pmatrix} \alpha & \beta \\ \beta & \gamma \end{pmatrix} \tag{3.7}$$

where

$$\alpha = \frac{p_2^2\sigma_1^2 + p_1^2\sigma_2^2}{p_2r_1 - p_1r_2} \tag{3.8}$$

$$\beta = \frac{-r_2p_2\sigma_1^2 - r_1p_1\sigma_2^2}{p_2r_1 - p_1r_2} \tag{3.9}$$

and

$$\gamma = \frac{r_2^2\sigma_1^2 + r_1^2\sigma_2^2}{p_2r_1 - p_1r_2} \tag{3.10}$$

The matrix **E** is then the covariance matrix for position error in arbitrary runway coordinate axes.

3.1.2 Principal Axis Matrix

The covariance matrix **E** could produce an error ellipse, but because the axes are not principal, the two ellipse semi-diameters would be jointly Gaussian. A true position error ellipse is plotted in its principal axes such that the correlation coefficient is identically zero. To do that, a coordinate transformation is performed on the **E** matrix. This consists of a rotation about the position origin and a recomputation of the principal axes position error.

The semi-major axis of the *principal* axis ellipse is rotated an angle (Θ) counterclockwise from the right hand orthogonal axis. Figure 3-1 shows this transformation. The angle (Θ) is computed from the expression

$$\Theta = \frac{1}{2} \arctan \left(\frac{2\rho\sigma_1\sigma_2}{\sigma_1^2 - \sigma_2^2} \right) \tag{3.11}$$

Where

$$\sigma_1 = \sqrt{\alpha} \tag{3.12}$$

$$\sigma_2 = \sqrt{\gamma} \tag{3.13}$$

and ρ is the correlation coefficient.

The two new variances, v_{p1} and v_{p2} in principal axes, can be calculated using the following two expressions:

$$v_{p1} = \frac{1}{2} \left(\sqrt{V} - \sqrt{Q} \right) \tag{3.14}$$

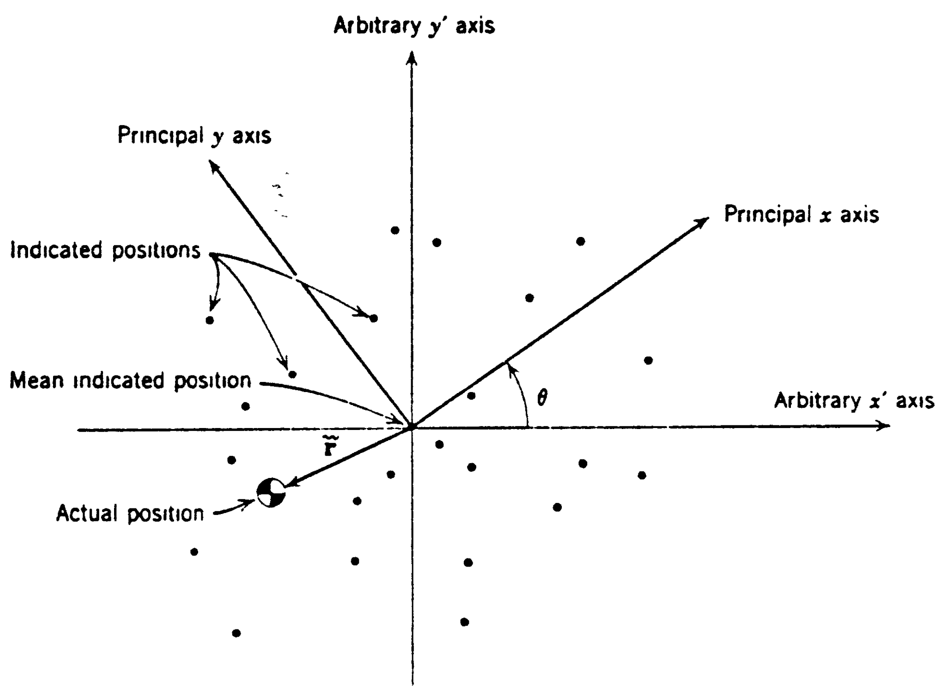

Figure 3.1: Rotation From Arbitrary Axes to Principal Axes

$$v_{p2} = \sqrt{V} - v_{p1} \tag{3.15}$$

where

$$V = \sigma_1^2 + \sigma_2^2 + 2\sigma_1\sigma_2\sqrt{1-\rho^2} \tag{3.16}$$

$$Q = \sigma_1^2 + \sigma_2^2 - 2\sigma_1\sigma_2\sqrt{1-\rho^2} \tag{3.17}$$

The gradient for each master-secondary pair is calculated from equation (3.18), and the arbitrary axis components, r_n and p_n are computed from equations (3.19) and (3.20).

$$\nabla = \frac{2\nu}{c} \sin\left(\frac{\psi_s - \psi_m}{2}\right) \tag{3.18}$$

$$r = -\nabla \sin\left(\frac{\psi_s + \psi_m}{2} - \varsigma\right) \tag{3.19}$$

$$p = \nabla \cos\left(\frac{\psi_s + \psi_m}{2} - \varsigma\right) \tag{3.20}$$

where (ψ_s) and (ψ_m) are the angles from North to the slave and master respectively, at the receiver, and (ς) is the runway heading.

The square roots of the new principal axes variances are the standard deviations used to plot the error ellipse. The ellipse is a bivariate normal ellipse of constant probability. If the semi-diameters are of length equal to three standard deviations, the probability of falling within the corresponding ellipse is approximately 98%. All ellipses genterated in this report are 3σ ellipses.

A FORTRAN program has been written that does all of the transformations and rotations to produce a principal axis, bivariate normal ellipse. It is contained in Appendix A along with its supporting programs and subroutines.

3.2 DETERMINATION OF TD STANDARD DEVIATIONS

Two sets of TD standard deviations must be computed for use in the original TD covariance matrix. Since two TD update scenarios are being examined in this work, one set must be computed for each scenario. TD standard deviations for the approach plate scenario will be computed from the USCG HMS quarterly reports, as the relavent time frame is on the order of two months. TD STDs for the real time approach update scenario will be computed from data gathered during the flight tests. The analytical results chapter gives a more detailed description on actual TD STD calculation.

Chapter 4

FLIGHT TEST ORGANIZATION

This chapter outlines the organization of the flight tests conducted to examine the validity of the mathematical model presented earlier. Both the data taking scheme and the flight plans are presented.

4.1 DATA TAKING METHOD

The flight tests were performed in a Grumman (Tiger) AA5B. During these tests, the information of interest was recorded from a LORAN-C receiver and a VOR/ILS transceiver. Figure 4-1 lists the equipment used and illustrates the flow of information and power between them.

During a data taking session, information is recorded from the two receivers. The LORAN-C receiver used is a Micrologic ML-3000 marine receiver outfitted with airborne type filters to make it essentially an airborne unit. The unit is equipped with a serial data output port which is connected

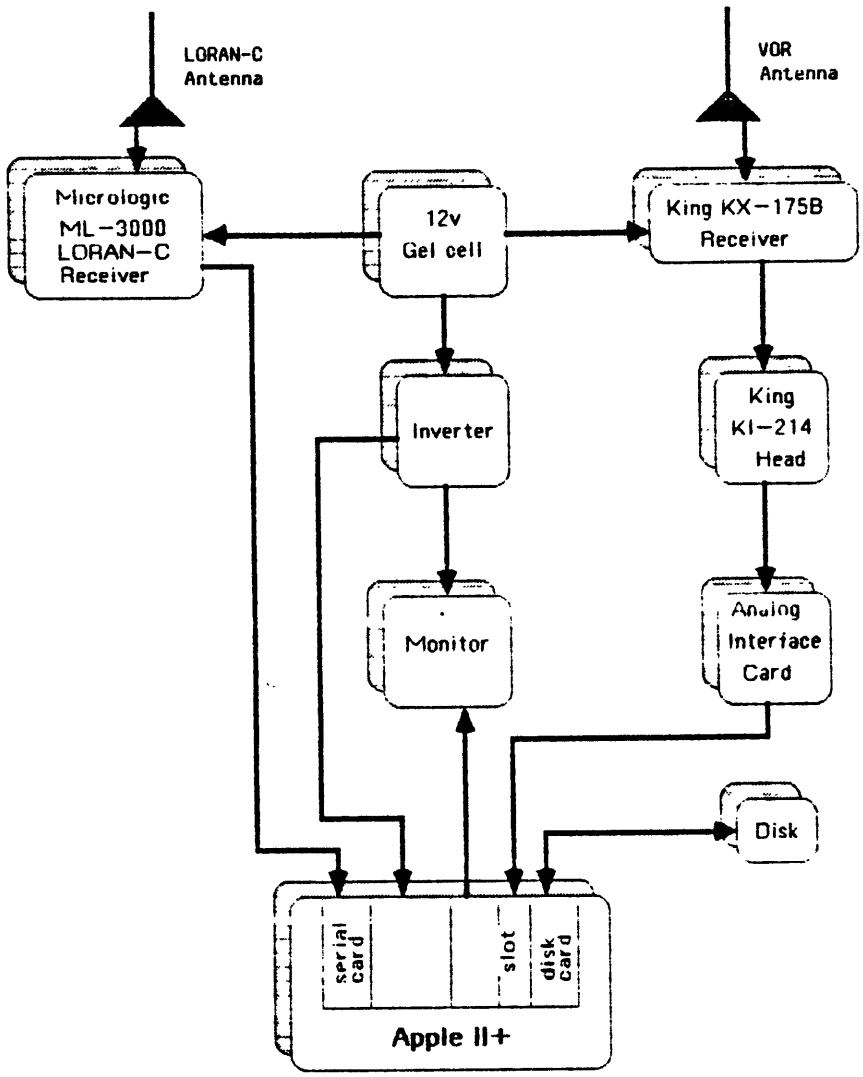

Figure 4.1: Data Taking Equipment

to a serial card in an Apple II+. The information collected by the Apple is the TDs of the two secondaries selected, their SNRs and the master's SNR.

The VOR transceiver used is a King KX-175B in conjunction with a KI-214 head. The ILS autopilot output from the head has been tapped, and the left/right error is sent to an analog interface card and in turn to the Apple. The output of the head will be 200 millivolts (floating) full scale deflection. The A/D card compares the analog voltage input with a comparison voltage on the card. This comparison voltage is divided into 256 step voltages. A clock steps the comparison voltage by one increment and compares the two. If there is no match, the process repeats until there is one. When there is a match, the now digital information is sent to the Apple. For the purpose of this research, a comparison voltage of +5v DC was chosen. This choice was made because it is convienently on the board as an option, and because the resolution was fine enough for excellent accuracy.

The output of the ILS head is two 30 Hz signals with a DC bias. Because the amplitude of these signals is so large, the DC information is masked. Consequently a 2 stage lowpass filter with a measured cutoff frequency of approximately 0.7 Hz was constructed. The analog input can take on negative values, consequently a difference amplifier was added to the system. A bias of +2.28 volts was added to shift the origin of the input, and the signal from the head was given a gain of +10 to make full scale deflection 2.0

volts. This gives a peak to peak swing of 4.0 volts. All of this gives better than 1.5% resolution. Figure 4.2 shows a schematic of the analog interface board, figure 4.3 shows a diagram of the filter and amplifier added to the board, and figure 4.4 is a photograph if the analog board and modification board. The maker of the board is Computer Continuum of Daly City, CA.

The information is called to the computer by a basic program that interrogates the two receivers every twelve GRI, which for the 9960 chain is about 1.2 seconds. This program was written by Professor Antonio Elias of MIT for related research and was modified by Lyman R. Hazleton, Jr. to interrogate the ILS receiver at the same time as it did the LORAN-C receiver. The program is contained in Appendix C. On board the plane, the information is stored on flexible disks.

The LORAN-C uses an antenna mounted on the rear of the plane. The ILS transceiver uses the antenna of an extra radio in the plane's avionics stack. Figure 4.5 is a photograph of the LORAN antenna location.

The equipment is powered by two 12v DC gel cells. The Apple and its monitor receive power from an inverter that converts 12v DC to 120v AC. The Apple system and the LORAN receiver receive power from one battery and the ILS transceiver receives power from the other one. This isolation of the ILS transceiver eliminated AC noise encountered from the inverter when all pieces of equipment were powered by one battery.

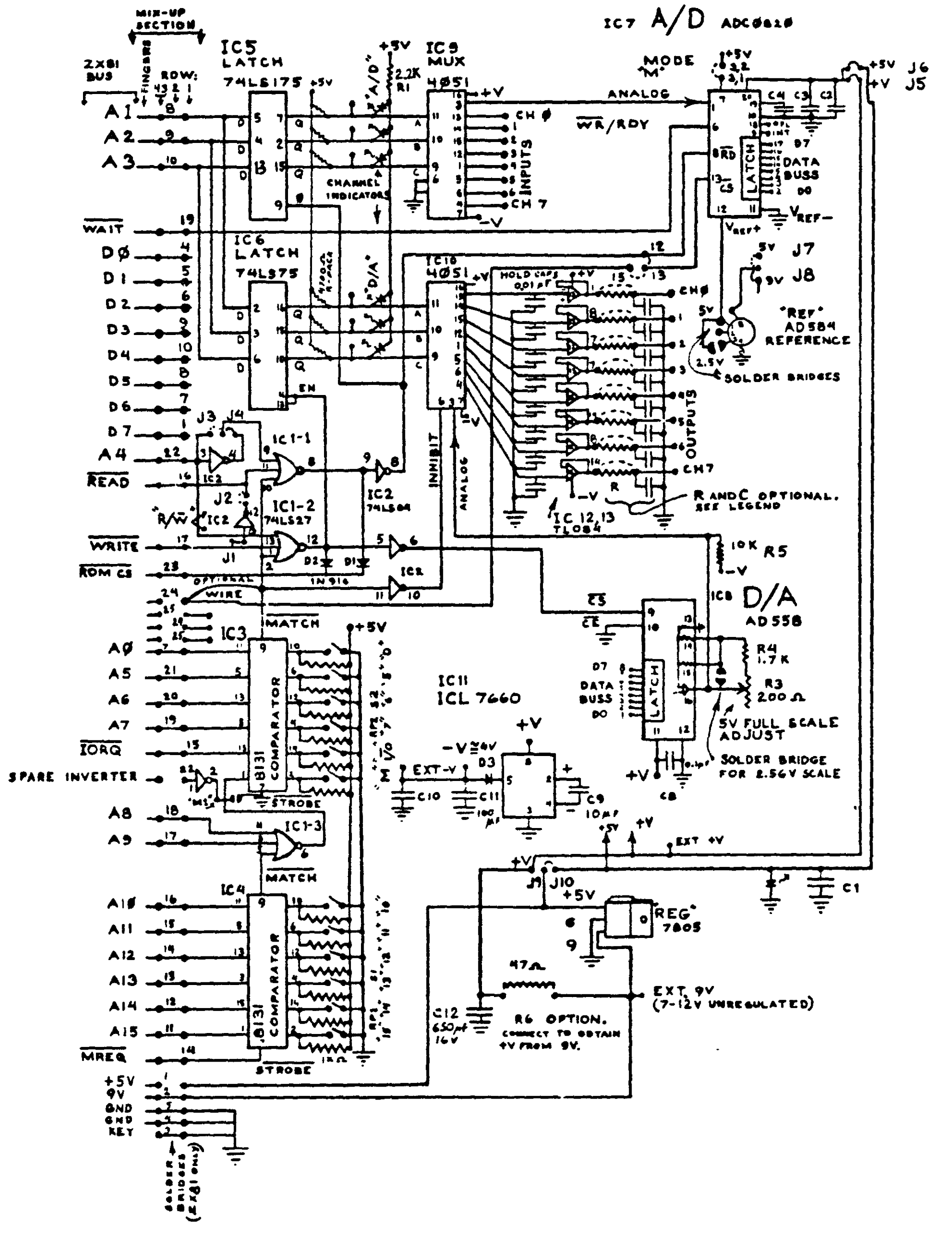

Figure 4.2: Analog Interface Board Schematic

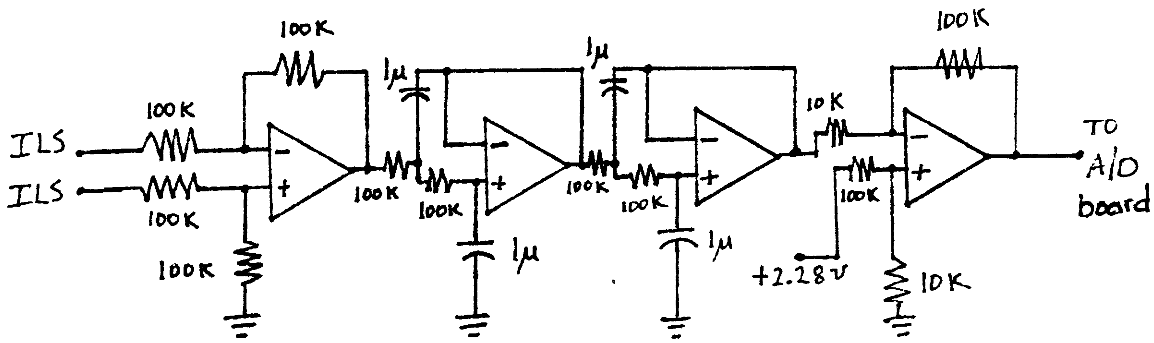

Figure 4.3: Low Pass Filter and Difference Amplifier

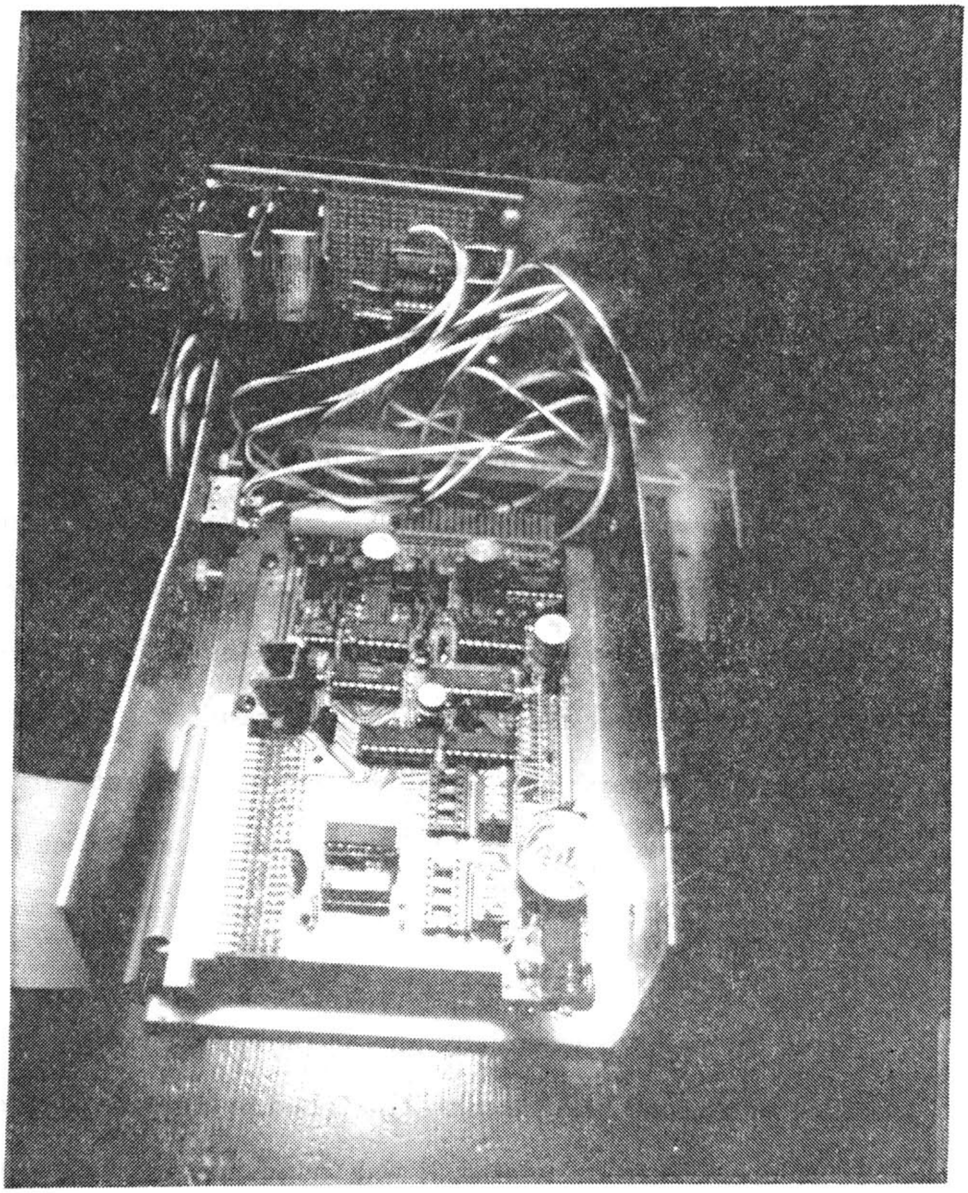

Figure 4.4: Analog Interface and Modification Boards

Each cell is rated at 20 amp-hours. The total system draws 8.7 amps nominal current, and bench tests show that each cell can support this load for 3 hours 45 minutes before permanent damage to the cell begins.

All of the equipment is contained in an aluminum pallet which is itself placed in the rear passenger seat behind the pilot. With the exception of the antennas, the pallet and equipment is completely autonomous from the airplane's navigation and electrical systems. The autonomous pallet was used so the aircraft would not have to be put into experimental category. Figure 4.6 shows the pallet and equipment configuration. Figures 4.7 and 4.8 are photographs of the pallet after installation in the airplane.

Due to the weight, size, and location of the pallet, a special airworthiness certificate was necessary. The end result was the obtaining of a supplimentary airworthiness certificate for restricted category. This gives the plane two airworthiness certificates, a standard one which is valid when the pallet is NOT in the plane, and a restricted one which is valid then the pallet is installed.

Since the pallet is essentially part of the airframe when it is installed, detailed weight and balance calculations had to be made for the pallet and the airplane. When completed, it was found that the weight and balance were within the normal category for the plane.

Appendix C contains very detailed information on the pallet construction, copies of the form 337 and airworthiness certificate, and the airplane

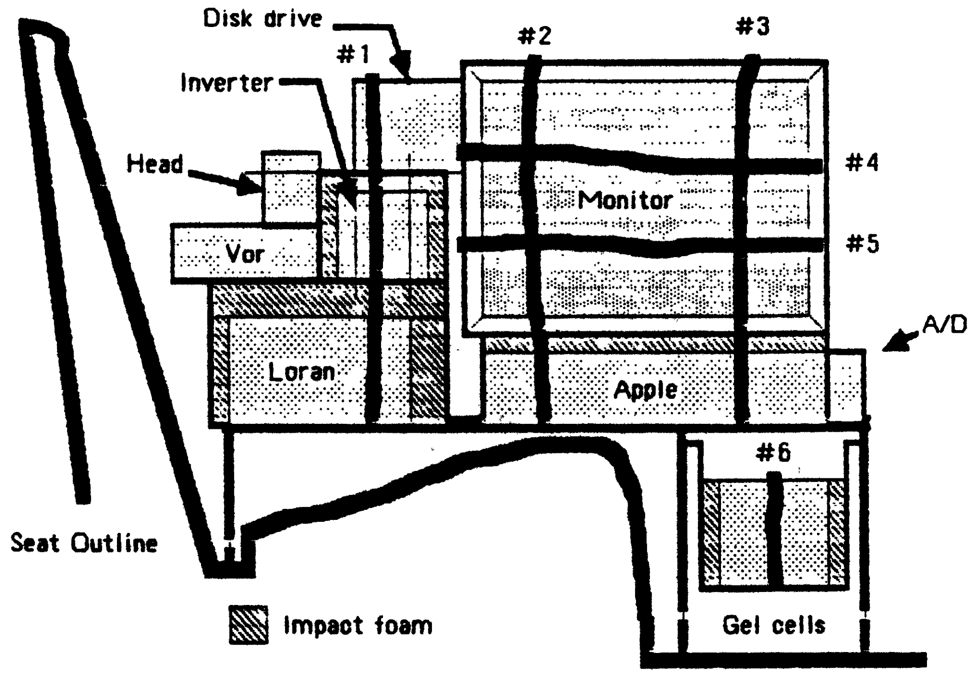

Figure 4.5: Pallet and Equipment Configuration

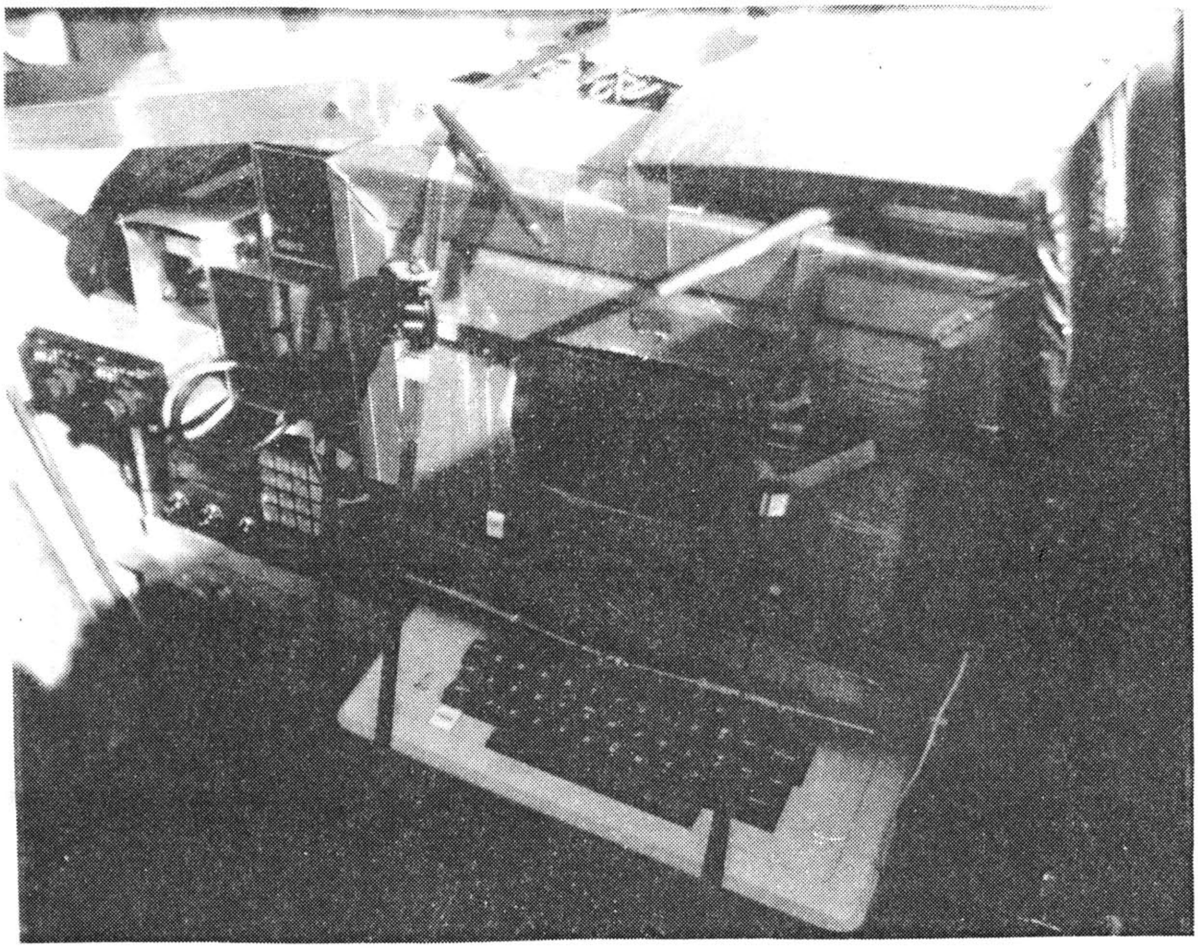

Figure 4.6: Installed Pallet, Side View

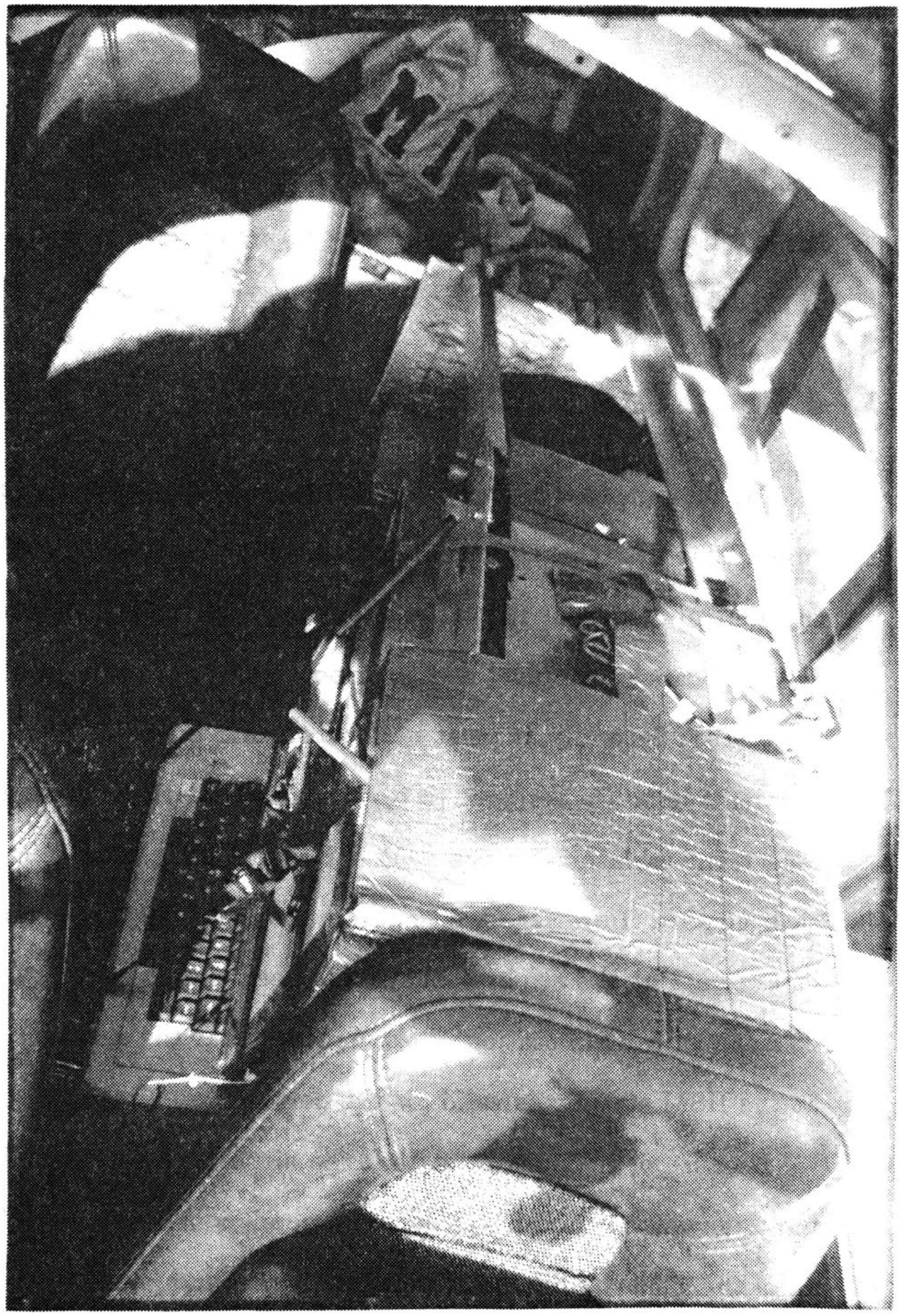

Figure 4.7: Installed Pallet, Top View

weight and balance for several different scenarios. It should be noted that the detailed work on the pallet construction was necessary due to the nature of the testing.

4.2 AIRPORT CHOICE

For the purposes of this research, the pool of qualified airports is rather small. The first constraint is related to the data taking method. Because the control device, or the system that the LORAN is being compared to is an ILS localizer, we must test at airports with at least a localizer if not the whole ILS. Secondly, it must be located near a USCG HMS site. Because the flight tests are designed to test the mathematical model which includes long term variations in the LORAN signal, long term data is needed at each airport. However, due to several constraints, this is not possible. In lieu of data at the airports, they have been chosen so that they are within 20 miles of a HMS station. It is assumed that the seasonal data gathered at the HSM stations is valid for the neighboring airports.

Because of the constraint that the airport be near a HMS station, the first step was to choose stations with good, consistant data. Table 4-1 lists all of the 9960 chain HMS stations both past and present with their startup and shutdown dates and secondaries tracked.

After examining in detail all of the HMS quarterlies that contain the actual data it bacame clear that technical problems with some of the stations

STATION NAME	STARTUP	SHUTDOWN	SECONDARIES
Cape Elizabeth NJ	01AUG82	CURRENT	W,X,Y
Sandy Hook NJ	01AUG82	CURRENT	W,X,Y
Plumbrook OH	01SEP80	15MAY84	Z
Point Allerton PA	23SEP81	03DEC81	W,X,Y
Avery Point CT	01AUG82	CURRENT	W,X,Y
Glouchester City PA	07OCT81	20MAR84	X,Y,Z
Yorktown VA	20SEP81	12AUG84	X,Y,Z
Lewes DE	01AUG82	CURRENT	X,Y,Z
Nahant MA	25SEP81	27MAR84	W,X,Y
Massena NY	01AUG82	CURRENT	W,X,Z
Cape Vincent NY	02FEB82	16SEP83	W,X,Z
Buffalo NY	20OCT82	20AUG84	W,Y,Z
Bass Harbor ME	14OCT82	30MAR84	W,X
Alexandria Bay NY	14SEP82	23AUG84	W,X,Z
Iroquois Lock ONT	11SEP82	03OCT83	W,X
Bequharnois QUE	14SEP82	03OCT83	W,X
Brossard QUE	12SEP82	03OCT83	W,X
Bristol RI	01OCT82	CURRENT	X,Y
Dunbar Forrest MI	14MAR83	15MAY84	Z
Pittsfield MA	01SEP84	CURRENT	W,X,Y,Z
Jackman ME	01OCT84	CURRENT	W,X
Newport VT	01AUG84	CURRENT	W,X,Y
Rutland VT	01AUG84	CURRENT	W,X,Y,Z
Burlington VT	01AUG84	CURRENT	W,X,Y,Z

Table 4.1: HMS Station Locations and Collection Dates

made their data sparse despite being on air for a long time. The HMS stations chosen as having good, consistent data over a significant period were: Nahant, MA; Bristol, RI; Avery Pt., CT; Bass Harbor, ME; Massena, NY; Glouchester City, NJ; Lewes, DE; and Alexandria Bay, NY. Due to time constraints and the need to take a reasonable amount of data, four of these sites were chosen as test sites. They were chosen on the basis of the size of the long term ellipses plotted for the sites, and the fact that four of five secondaries for the 9960 chain are covered.

In terms of the size of the long term ellipses, the sites were chosen so as to represent both good and bad airports. That is to say that some airports have a large expected error and some have a small expected error. The second criterion of covering all secondaries in the 9960 chain was not met, but proximity to MIT or more specifically, Hanscom AFB was also a factor in the choices.

The final selection of HMS sites fell on Avery Pt., CT; Bass Harbor, ME; Bristol, RI; and Nahant, MA. Once these sites were chosen, the airport selection was a matter of finding airports as close to the HMS sites as possible that had an ILS. Using this criterion, four airports were chosen, three with a complete ILS and one with the localizer portion. Table 4-2 lists these airports and their corresponding HMS sites.

HMS SITE	AIRPORT	TYPE
Avery Point CT	Groton/New London	ILS
Bristol RI	Newport, Newport State	LOC
Bass Harbor ME	Bar Harbor, Hancock County	ILS
Nahant MA	Bedford, Hanscom AFB	ILS

Table 4.2: Candidate Airports

4.3 FLIGHT PLANS

This section describes the flight plans and overall data taking scheme during the flights.

4.3.1 Flight Data Taking Scheme

Each flight test involves gathering two forms of information: static and dynamic. The static testing involves gathering the short term TD standard deviations at the touchdown points. This allows the plotting of ellipses that correspond to the transmitted update to the pilot scenario. To do this, the plane will sit as close to the runway touchdown point as is allowed by the various towers. Ideally, the plane should be on the runway threshold. The Apple will collect TD data from the LORAN for five minutes. From this information, the mean and standard deviation of the signal over that time period will be calculated. If it is not possible to actually sit on the threshold, the plane must make a very short stop on the threshold before taking off to get the TDs for that point.

AIRPORT	RUNWAY	STATIC TRIADS	FLIGHT TEST TRIADS
New London CT	5	WY XY	WY XY
Newport RI	22	XY	XY
Bar Harbor ME	22	WX	WX
Bedford MA	11	WX XY	WX XY

Table 4.3: Candidate Runways and Triads

The dynamic testing involves making ILS approaches to the runway using each LORAN-C triad being tested. Two approaches will be made for each triad. For the airports with full ILS, data taking will commence upon passing over the outer marker. This will be signaled by the flipping of the NDB display in the cockpit. Data taking will cease when the plane passes over the runway threshold.

For airports without the glide slope portion of the ILS, data taking will commence upon passing over a specified radial of a local VOR. Again, this will be signaled by the flipping of the NDB display in the cockpit.

The data collected will be stored on floppies after each approach or static test. This allows quick and virtually unlimited storage space, and the data can be recalled to verify its existance before leaving the test site.

Table 4-3 lists the runways and triads to be statically and dynamically tested for each airport.

Chapter 5

STATIC TEST RESULTS

This chapter presents the results obtained from running the programs that produce a position error ellipse, and from the static tests performed while the airplane was stationary on the runway centerlines.

5.1 LONG TERM RESULTS

The goal of this part of the research was to plot position error ellipses that would correspond to an update scenario that included publishing TD corrections in the bi-monthly approach plates. Just as a pilot would look in the plates to obtain relavent VOR frequencies, for example, he would find the TDs for the touchdown point on the desired runway and enter them into his LORAN receiver.

5.1.1 USCG Data

As mentioned earlier, the USCG has many Harbor Monitor Stations

Avery Point HMS ($3\frac{1}{4}$ years of data)				
	1 Jan 31 Mar	1Apr 30 Jun	1 Jul 30 Sep	1 Oct 31 Dec
$\overline{\sigma_w}$	.085	.053	.029	.087
σ_{wmax}	.096	.064	.030	.091
$\sigma_{\overline{w}}$	.043	.022	.039	.034
$\overline{\sigma_x}$	.044	.030	.030	.038
σ_{xmax}	.053	.037	.033	.047
$\sigma_{\overline{x}}$	.016	.018	.021	.018

Table 5.1: Avery Point HMS Long Term Data

that have collected LORAN-C data over a period of two to four years. That was the data base used to compute the long term σs for the approach plate scenario. The source of the data was the Harbor Monitor System quarterly reports, published every three months. This data is summarized in tables 5.1-5.4. The three parameters presented are 1) $\overline{\sigma_s}$, the average standard deviation of the TDs from year to year over the specified period, 2) σ_{smax}, the maximum standard deviation from year to year of the TDs over the period, and 3) $\sigma_{\overline{s}}$, the standard deviation of the *mean* TD values recorded from year to year over the specified period. When the entry for one of these paremeters is *N/A*, meaning that only one year of data was available, and no σ could be calculated.

One year of HMS data is contained in four sections, each section being three months in length. The approach plates are published six times a year in eight week intervals. Since the approach plates are to carry the

Bass Harbor HMS ($1\frac{1}{4}$ years of data)				
	1 Jan 31 Mar	1 Apr 30 Jun	1Jul 30 Sep	1 Oct 31 Dec
$\overline{\sigma_w}$	.071	.031	.048	.079
σ_{wmax}	.072	.031	.048	.079
$\sigma_{\overline{w}}$	.004	N/A	N/A	N/A
$\overline{\sigma_x}$	.052	.033	.032	.054
σ_{xmax}	.052	.033	.032	.054
$\sigma_{\overline{x}}$	.047	N/A	N/A	N/A

Table 5.2: Bass Harbor HMS Long Term Data

Bristol HMS (2 years of data)				
	1 Jan 31 Mar	1 Apr 30 Jun	1 Jul 30 Sep	1 Oct 31 Dec
$\overline{\sigma_x}$	.035	.029	.024	.028
σ_{xmax}	.036	.031	.026	.028
$\sigma_{\overline{x}}$	.019	.025	.023	.006
$\overline{\sigma_y}$	.106	.061	.041	.099
σ_{ymax}	.125	.064	.045	.122
$\sigma_{\overline{y}}$	.012	.011	.002	.003

Table 5.3: Bristol HMS Long Term Data

Nahant HMS ($2\frac{1}{2}$ years of data)				
	1 Jan 31 Mar	1 Apr 30 Jun	1 Jul 30 Sep	1 Oct 31 Dec
$\overline{\sigma_w}$	.058	.030	.022	.032
σ_{wmax}	.099	.036	.025	.037
$\sigma_{\overline{w}}$	.022	.014	.003	.013
$\overline{\sigma_x}$	.065	.044	.032	.068
σ_{xmax}	.091	.045	.039	.086
$\sigma_{\overline{x}}$	.011	.042	.060	.014
$\overline{\sigma_y}$	.089	.053	.033	.083
σ_{ymax}	.109	.061	.039	.086
$\sigma_{\overline{y}}$	.026	.039	.058	.018

Table 5.4: Nahant HMS Long Term Data

TD corrections, the $\sigma's$ must be rearranged so as to correspond to the six approach plate segments. For 1985, the approach plate publication intervals are 17 Jan-14 Mar, 14 Mar-9 May, 9 May-4 July, 4 July-29 Aug, 29 Aug-24 Oct, 24 Oct-19 Dec. The HMS data segments are 1 Jan-31 Mar, 1 Apr-30 Jun, 1 Jul-30 Sep, 1 Oct-31 Dec. In most cases, as would be expected, there is some overlap between the two schedules. The approach plate dates cross over and cover some fraction of more than one HMS segment.

As can be seen from tables 5.1-5.4, the σs vary with the season, the winter months generally being worse than the summer. If an assumption is made that the eight week publication segments can effectively be increased to twelve weeks, a linear relationship between the plate and HMS segments can be found. Twelve weeks is chosen primarily because it is the segment

Plate #	Segment Dates	Formula
1	17 Jan-14 Mar	$\sigma_{a1} = \sigma_{h1}$
2	14 Mar-9 May	$\sigma_{a2} = \frac{1}{3}\sigma_{h1} + \frac{2}{3}\sigma_{h2}$
3	9 May-4 Jul	$\sigma_{a3} = \frac{5}{6}\sigma_{h2} + \frac{1}{6}\sigma_{h3}$
4	4 Jul-29 Aug	$\sigma_{a4} = \frac{1}{6}\sigma_{h2} + \frac{5}{6}\sigma_{h3}$
5	29 Aug-24 Oct	$\sigma_{a5} = \frac{1}{2}\sigma_{h3} + \frac{1}{2}\sigma_{h4}$

Table 5.5: HMS σ to Approach Plate σ formulae

length of the HMS data. This also allows one week lead time for actual printing and distribution and three weeks lag time for pilots using old approach plates. This simplifying assumption will tend to increase the σs over the plate segments because the segments are now twelve instead of eight weeks. Overestimation of the errors is preferable to underestimation, so this assumption is acceptable.

The approach plate $\sigma's$ are then the HMS quarterly $\sigma's$ times the fraction of the plate segment covered by the quarterly segment. Table 5.5 lists the conversion equations used for this transformation. σ_{an} is the standard deviation for approach plate n, and σ_{hn} is the standard deviation for HMS quarter n.

As mentioned earlier, it is more desirable to overestimate than to underestimate the errors. Consequently, the standard deviation used in the equations in table 5.5 will be the σ_{hmax}, the maximum standard deviation for each HMS segment. Table 5.6 lists the $\sigma_{an}s$ as a function of secondary transmitter. The top row lists the approach segments from table 5.5.

	(1)	(2)	(3)	(4)	(5)
Avery Point HMS					
σ_w	.096	.075	.058	.036	.061
σ_x	.053	.042	.036	.034	.040
σ_y	.147	.095	.065	.050	.081
Bass Harbor HMS					
σ_w	.072	.045	.034	.045	.064
σ_x	.052	.039	.033	.032	.043
Bristol HMS					
σ_x	.036	.033	.028	.027	.027
σ_y	.125	.084	.061	.048	.084
Nahant HMS					
σ_w	.099	.057	.034	.027	.031
σ_x	.091	.060	.044	.040	.063
σ_y	.109	.077	.057	.043	.063

Table 5.6: Approach Plate Segment Standard Deviations

5.1.2 Long Term Error Ellipses

The standard deviations listed in table 5.6 were used in conjunction with the FORTRAN programs listed in appendix A to generate the long term position error ellipses. The program follows the mathematical model outlined in chapter three. Table 5.7 lists the important parameters calculated by the program. S_1 and S_2 are secondaries one and two, CA is the crossing angle of the two gradients, RWY is the runway number, ∇_1 and ∇_2 are the magnitude of the gradients in feet/μs , and SD_{max} and SD_{min} are the 3σ semi-major and semi-minor diameters in feet.

Site	Rwy	S_1	S_2	∇_1	∇_2	CA	SD_{max}	SD_{min}
BED	11	W	X	591.8	532.9	124	147.5	79.0
BED	11	X	Y	532.8	962.7	143	395.6	90.3
BAR	22	W	X	599.9	1042.5	97	123.5	80.5
NEW	22	X	Y	491.9	850.4	124	261.1	48.3
GRO	5	W	Y	671.2	778.2	94	222.7	150.7
GRO	5	X	Y	499.8	778.2	119	255.9	62.4

Table 5.7: Position Error Ellipse Parameters

These parameters which define the position error ellipse can be run through a simple plotting program with the result being a plotted ellipse. This was done for all of the situations listed in table 5.7. The short term errors and corresponding ellipses are contained in the next section.

Figures 5.1-5.6 contain the ellipses listed in Table 5.7. For the airports, the top of the figure is the runway direction, and right is orthogonal to the runway.

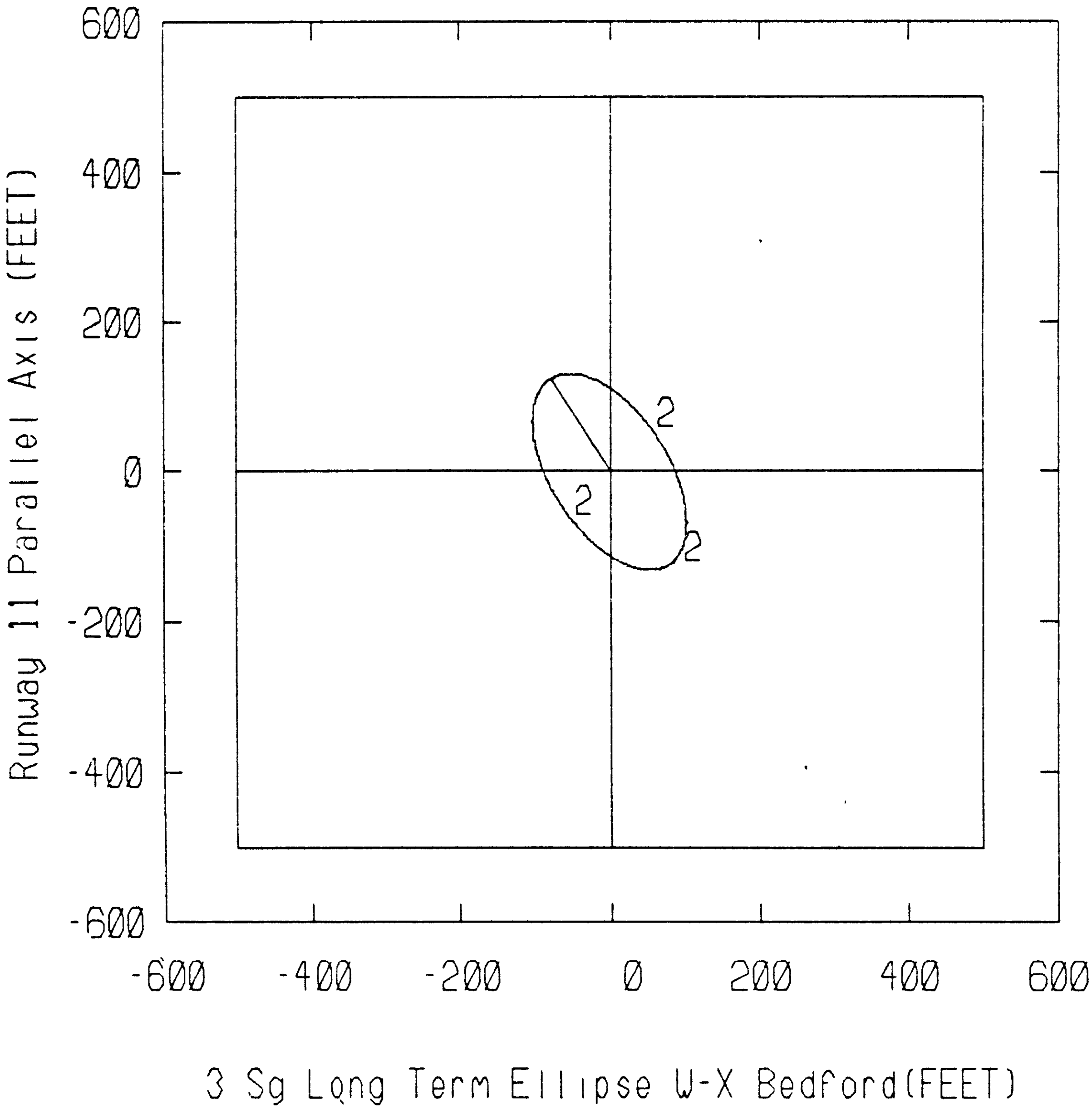

Figure 5.1: Long Term W,X Error Ellipse for Bedford

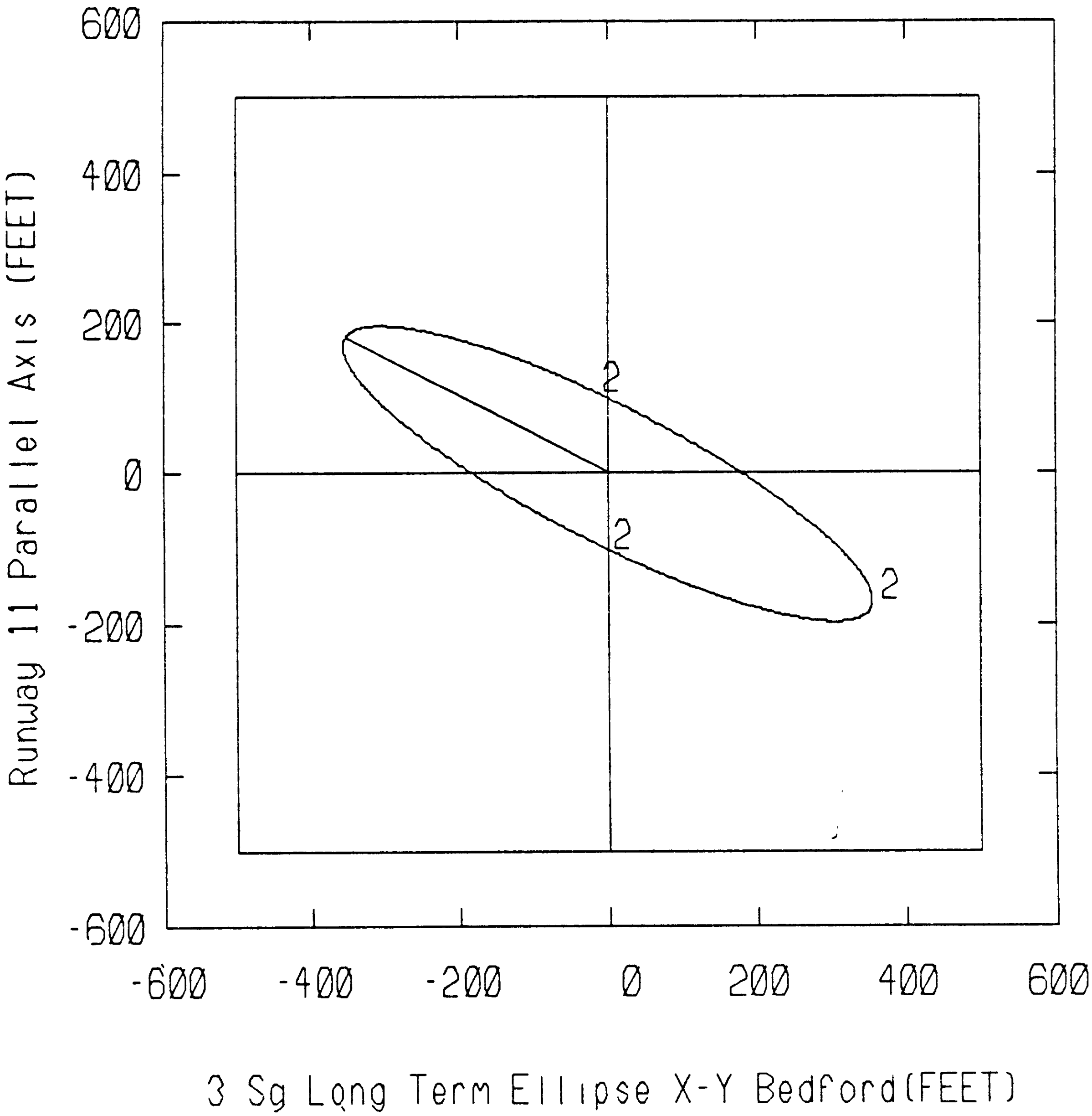

Figure 5.2: Long Term X,Y Error Ellipse for Bedford

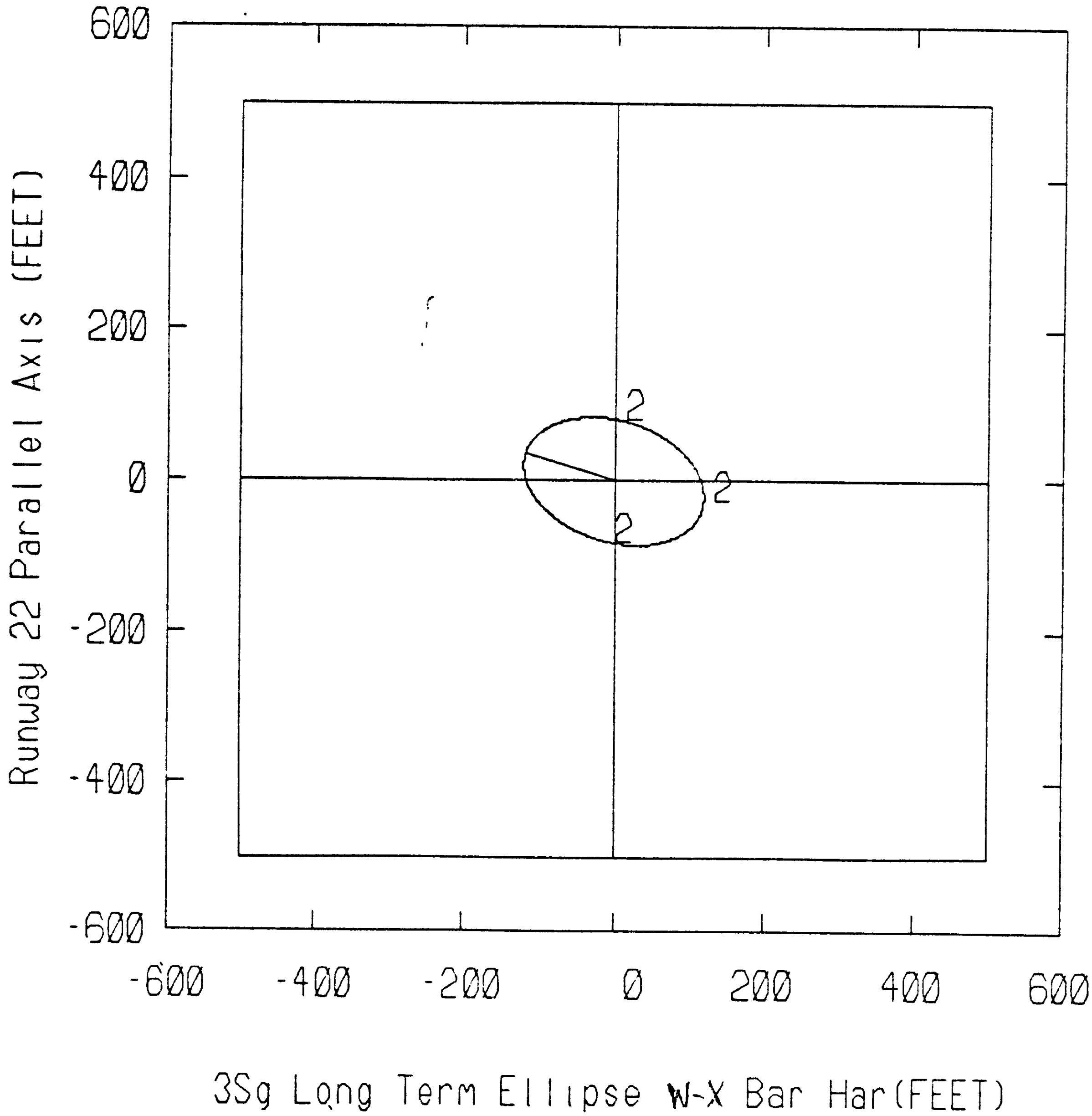

Figure 5.3: Long Term W,X Error Ellipse for Bar Harbor

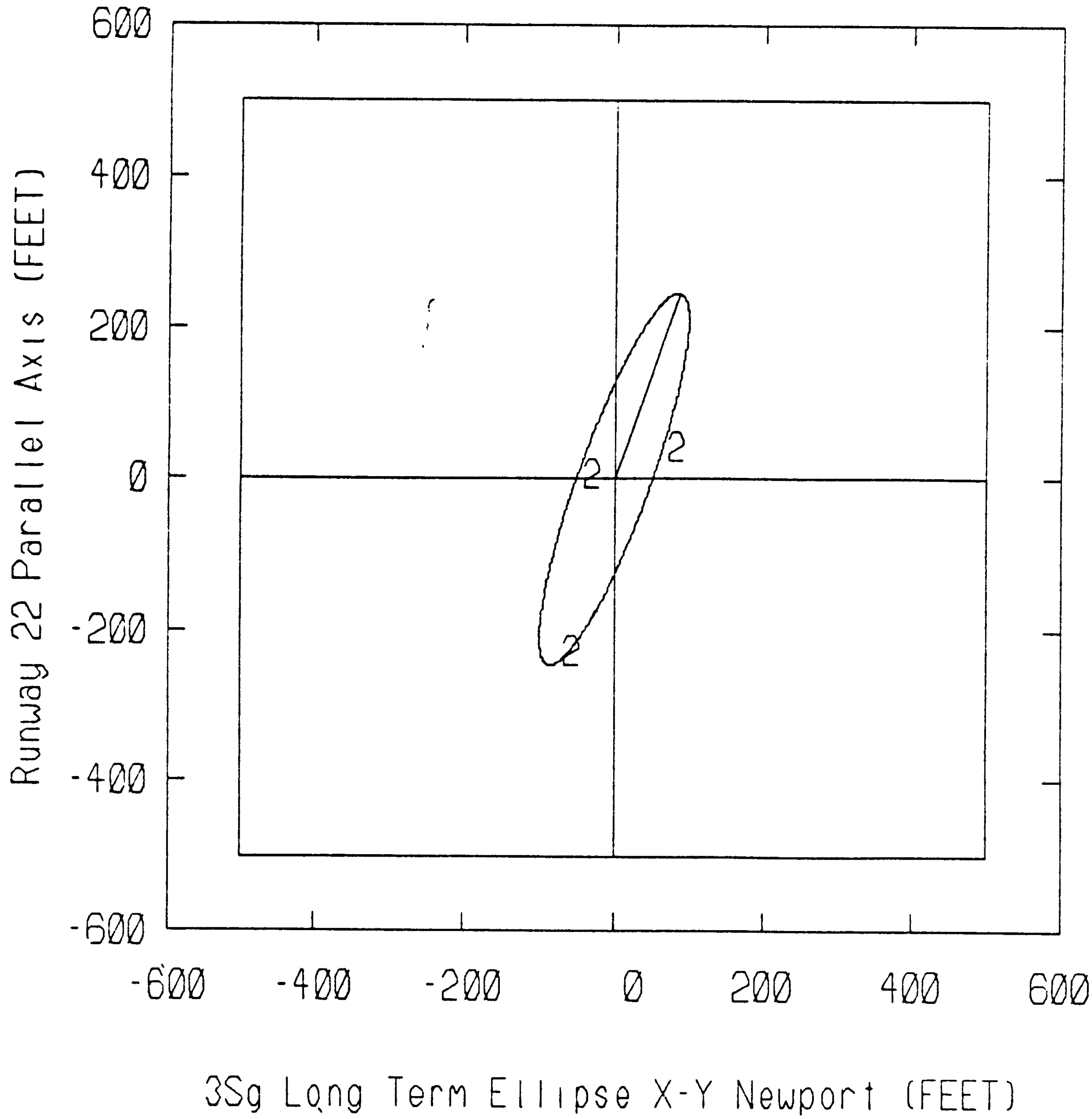

Figure 5.4: Long Term X,Y Error Ellipse for Newport

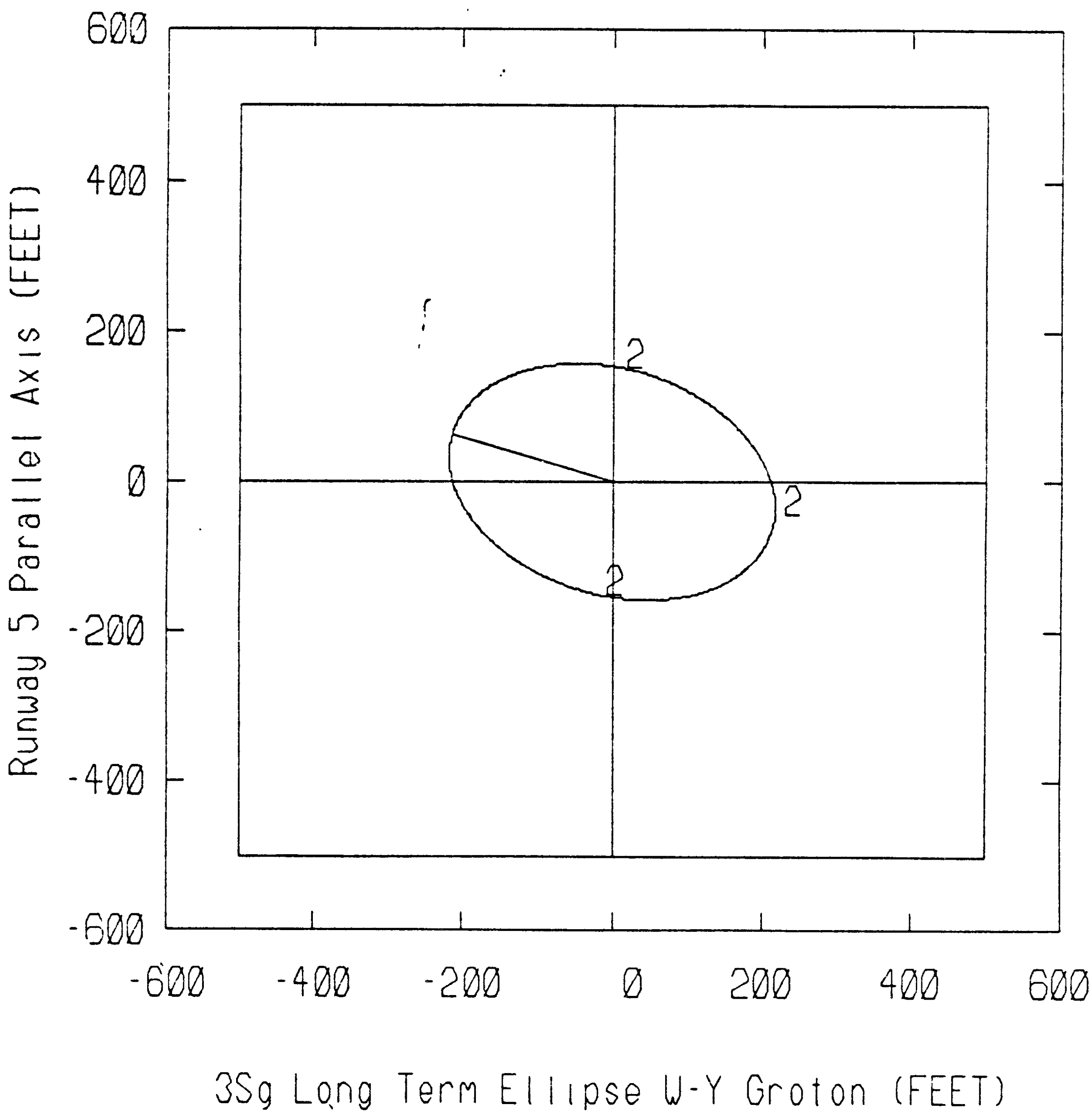

Figure 5.5: Long Term W,Y Error Ellipse for Groton

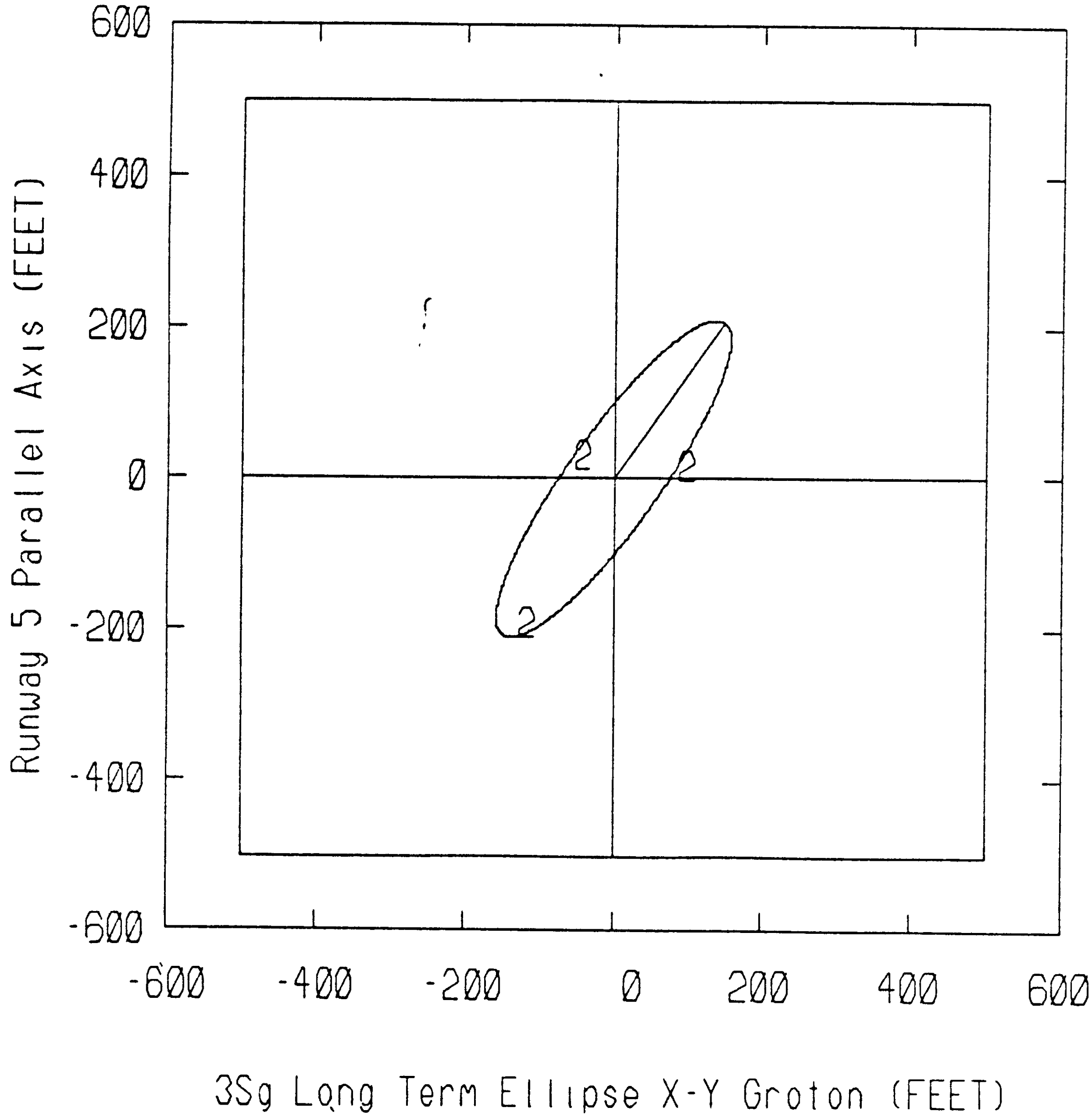

Figure 5.6: Long Term X,Y Error Ellipse for Groton

The box drawn around the ellipses at a distance of 500 ft is there to provide a better reference for the ellipse. The one semi-major axis is drawn to give a better view of the angle that the ellipse is rotated from the horizontal. After the short term results are presented in the next section, these long term ellipses will be compared to the corresonding short term ellipses.

5.2 SHORT TERM RESULTS

This section presents short term results in two categories. First, data was taken on the various runways while the airplane was stationary. The results of these experiments will be presented, and using these results, short term position error ellipses will be generated.

The goal of this section of the research was to plot error ellipses corresponding to the scenario of radioing TD corrections to the pilot as he nears the airport.

5.2.1 Airplane Ground Test Results

Data was collected by the system described in chapter four while on the centerline of the various runways. The plane was taxied to the centerline and was positioned between the first set of VASI lights, 500 to 700 feet from the runway threshold, depending on the airport. This point between the VASI lights served as the reference point for both the static and the flight tests.

The program FR2, contained in Appendix B collected the time differences, SNRs of the master and secondaries, and the cross track error of the ILS. The ILS data was taken to help identify the center point of the localizer in terms of the output of the program. This will be explained in detail in chapter six. The program recorded 250 data points at 1.19 second intervals (for a total of 5 minutes). A second program PLOTFILE, also contained in Appendix B was run to calculate averages and standard deviations. The results of this are presented in table 5.8.

The same PLOTFILE program can also plot the TD points. Figures 5.7 through 5.12 are the scatter plots of the same tests listed in table 5.8. Just as with the long term ellipses, the top of the figure is the direction of the runway.

Hanscom AFB				
	Test 1	Test 1	Test 2	Test 2
	Caribou(W)	Nantucket(X)	Nantucket(X)	Carolina Beach(Y)
$\overline{TD}$	14119.1829	26032.0798	26032.083	44367.8865
σ	.02453	.02141	.02311	.02600
$\overline{SNR}$	216	236	236	204
$\overline{SNRM}$	236		234	
Bar Harbor				
	Test 1	Test 1		
	Caribou(W)	Nantucket(X)		
$\overline{TD}$	12304.3961	25861.9411		
σ	.02303	.02657		
$\overline{SNR}$	229	232		
$\overline{SNRM}$	202			
Newport				
	Test 1	Test 1		
	Nantucket(X)	Carolina Beach(Y)		
$\overline{TD}$	25753.1447	44011.0707		
σ	.02109	.03524		
$\overline{SNR}$	237	220		
$\overline{SNRM}$	233			
Groton				
	Test 1	Test 1	Test 2	Test 2
	Caribou(W)	Carolina Beach(Y)	Nantucket(X)	Carolina Beach
$\overline{TD}$	14692.2282	43997.4371	26128.3875	43997.4386
σ	.02654	.01480	.03880	.02223
$\overline{SNR}$	198	227	236	228
$\overline{SNRM}$	236		236	
$\overline{SNRM}$ is the average SNR for Seneca (master)				

Table 5.8: Ground Test Data

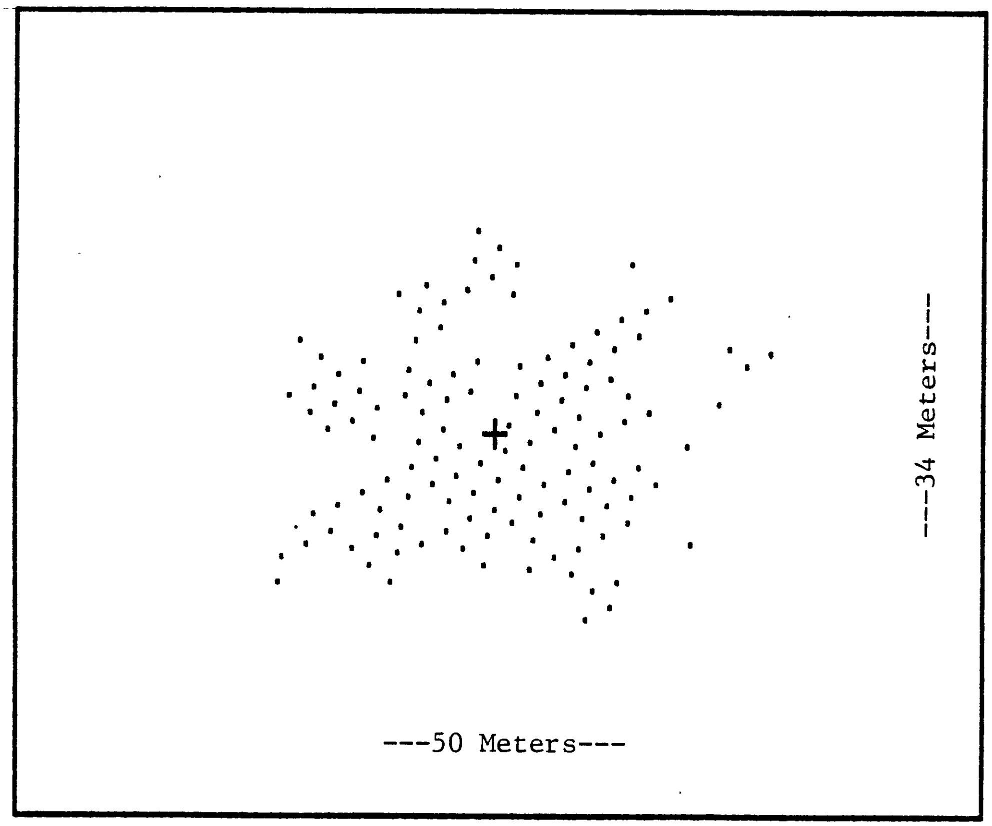

Figure 5.7: Scatter Plot of Bedford W,X Short Term Data

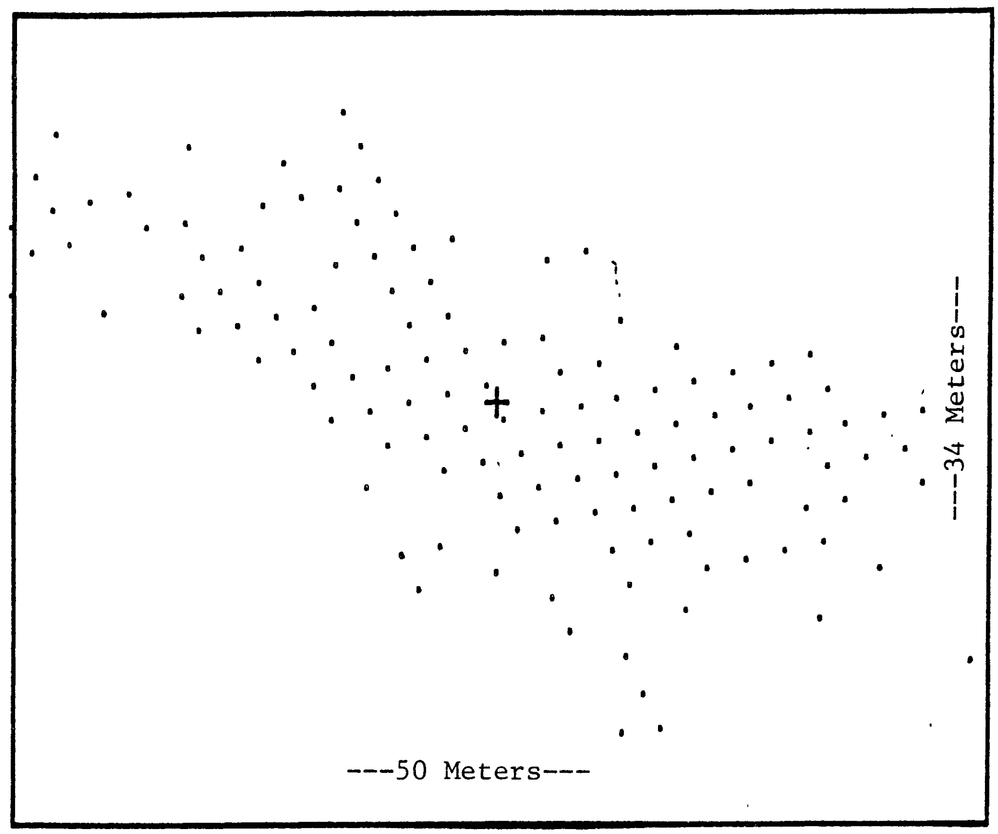

Figure 5.8: Scatter Plot of Bedford X,Y Short Term Data

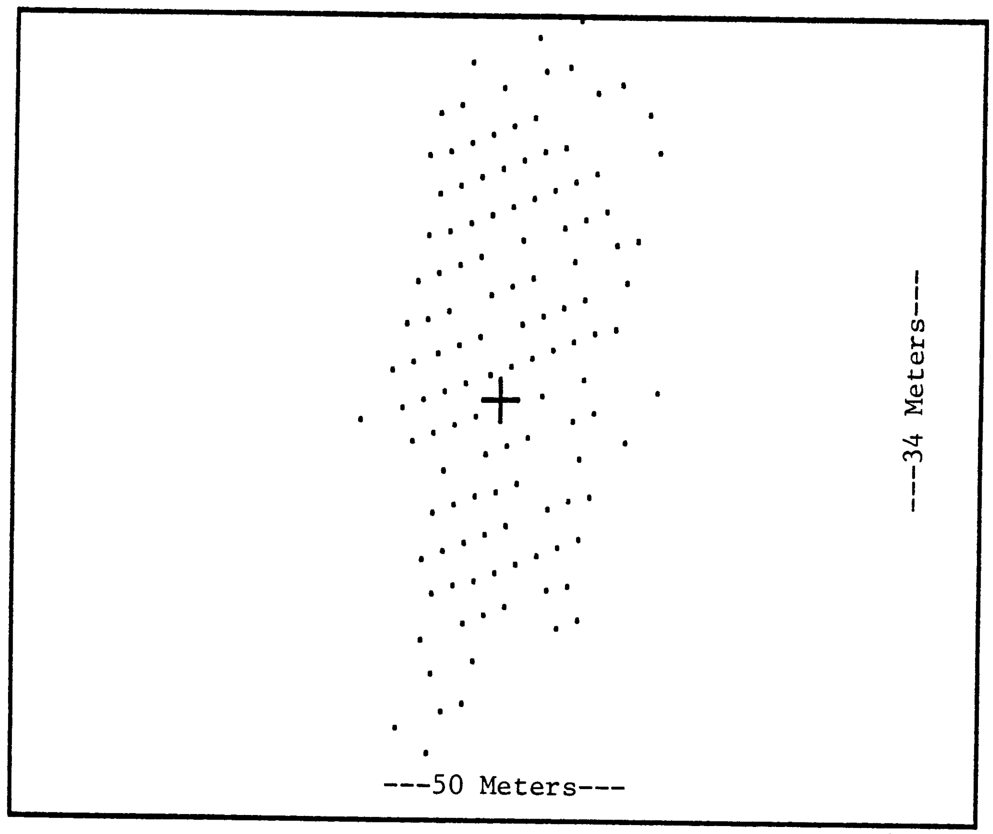

Figure 5.9: Scatter Plot of Newport X,Y Short Term Data

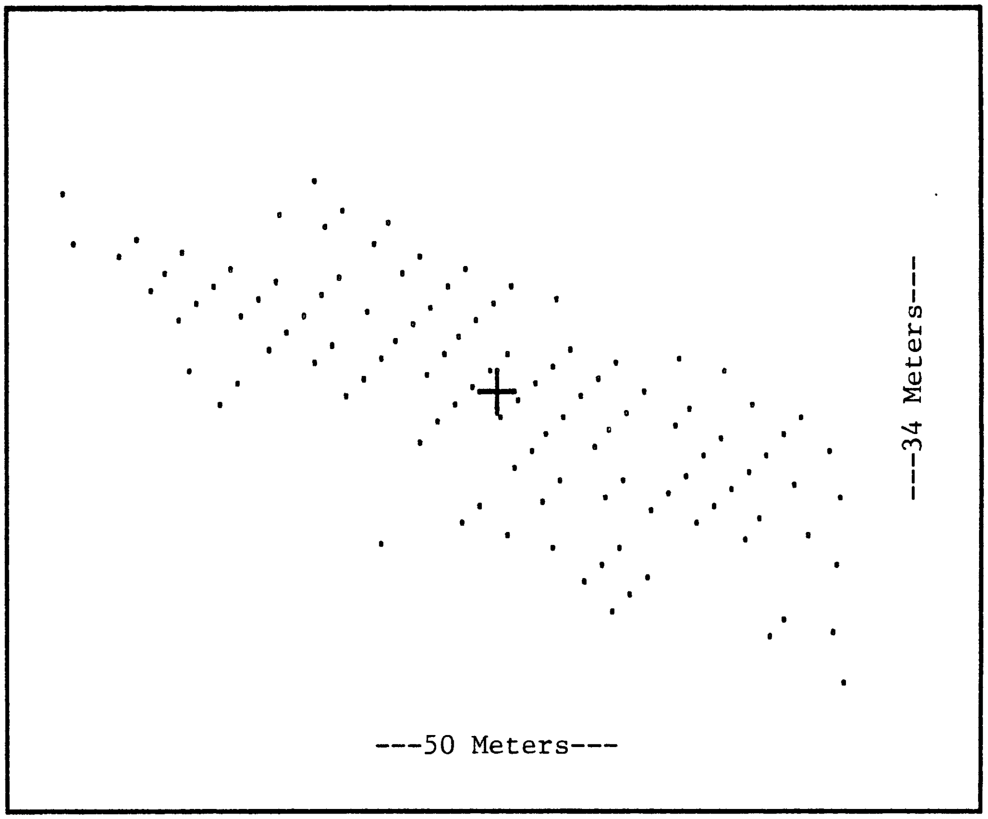

Figure 5.10: Scatter Plot of Bar Harbor W,X Short Term Data

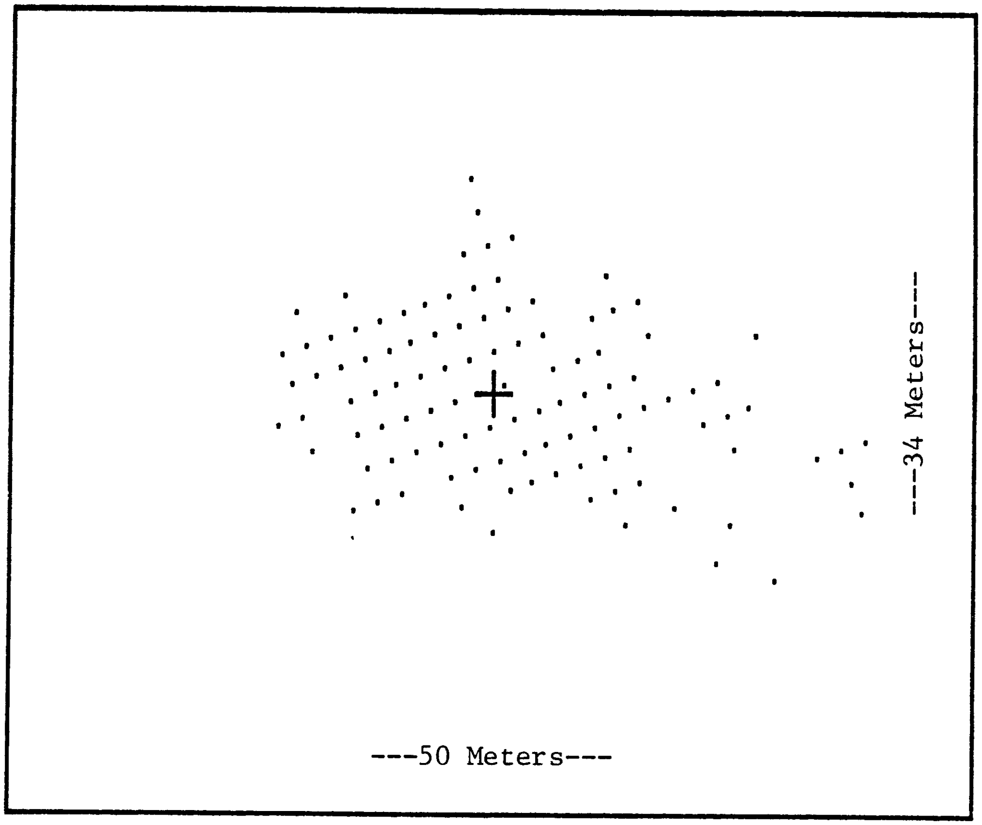

Figure 5.11: Scatter Plot of Groton W,Y Short Term Data

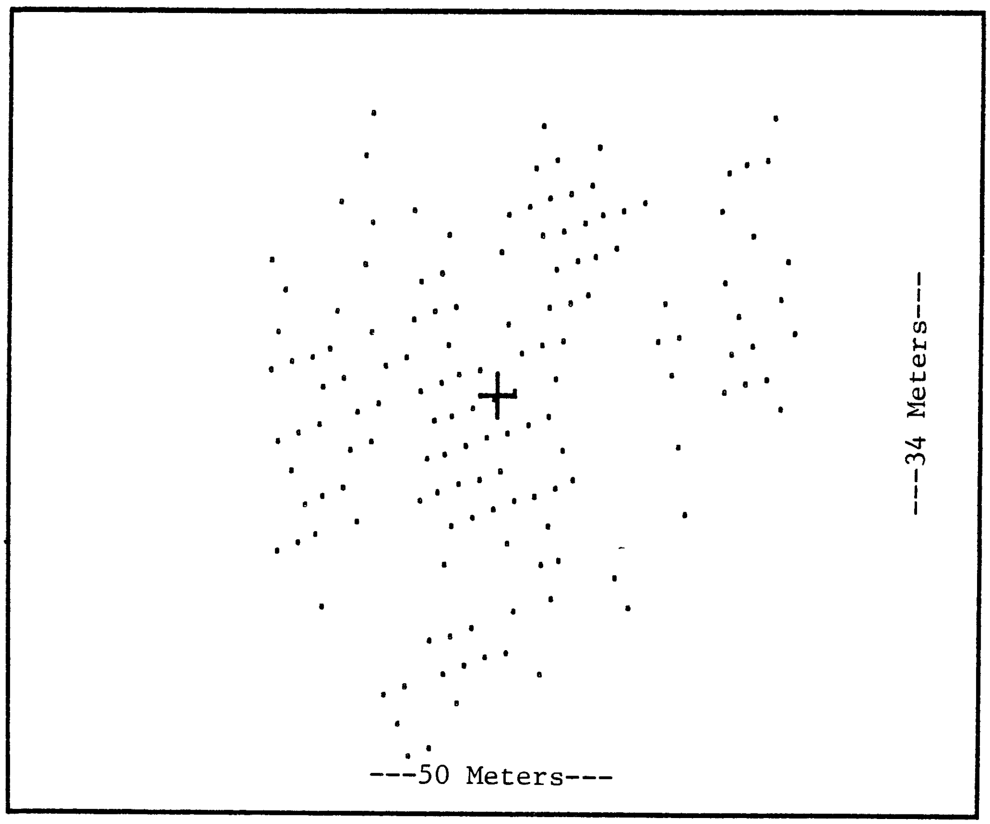

Figure 5.12: Scatter Plot of Groton X,Y Short Term Data

Site	Rwy	S_1	S_2	∇_1	∇_2	CA	SD_{max}	SD_{min}
BED	11	W	X	591.8	532.9	124	62.0	33.0
BED	11	X	Y	532.9	962.7	143	123.3	33.5
BAR	22	W	X	599.9	1042.5	97	72.7	41.3
NEW	22	X	Y	491.9	850.4	124	69.2	29.3
GRO	05	W	Y	671.2	778.2	94	62.4	53.1
GRO	05	X	Y	499.8	778.2	119	110.2	54.6

Table 5.9: Position Error Ellipse Parameters

5.2.2 Short Term Error Ellipses

Using the standard deviations computed in the last section, short term position error ellipses can be generated using the same method as presented in section 5.1.2. The ellipse parameters calculated are presented in table 5.9.

Again, using the same method as presented in secion 5.1.2, the short term position error ellipses can be plotted. These ellipses are contained in figures 5.13 through 5.18.

5.3 COMBINED RESULTS

This section presents the preceding results in perspective with each other. Section 5.2.1 compares the short term error ellipses with the LORAN scatter plots. Section 5.2.2 compares the long term ellipses with the short term ellipses.

5.3.1 Short Term Ellipses vs. Scatter Plots

The short term ellipses generated in section 5.2.2 are predictions of the error in position with the given standard deviations used in their formulation. On the other hand, the scatter plots from which the standard deviations were computed are *real* errors in position. By superimposing the two plots, it is possible to see how well the ellipses predict the scatter plots. Figures 5.19 through 5.24 contain these superimposed plots. It should be kept in mind that only 250 data points were taken and this may not be enough to get the whole picture as far as the *real* error. Another important point to keep in mind is that the simplifying assumption was made that the correlation coefficient between the two TD standard deviations was zero.

Discussion and analysis of these plots as well as the plots in section 5.3.2 appears in chapter seven ANALYSIS OF RESULTS.

5.3.2 Long Term vs. Short term Ellipses

Two update scenarios have been presented and position error ellipses have been generated for each. A good method of comparing the two scenarios against each other is to superimpose the long term and short term plots and compare the errors. Figures 5.25 through 5.30 contain the superimposed plots. Again, discussion and analysis of these plots is reserved for chapter seven.

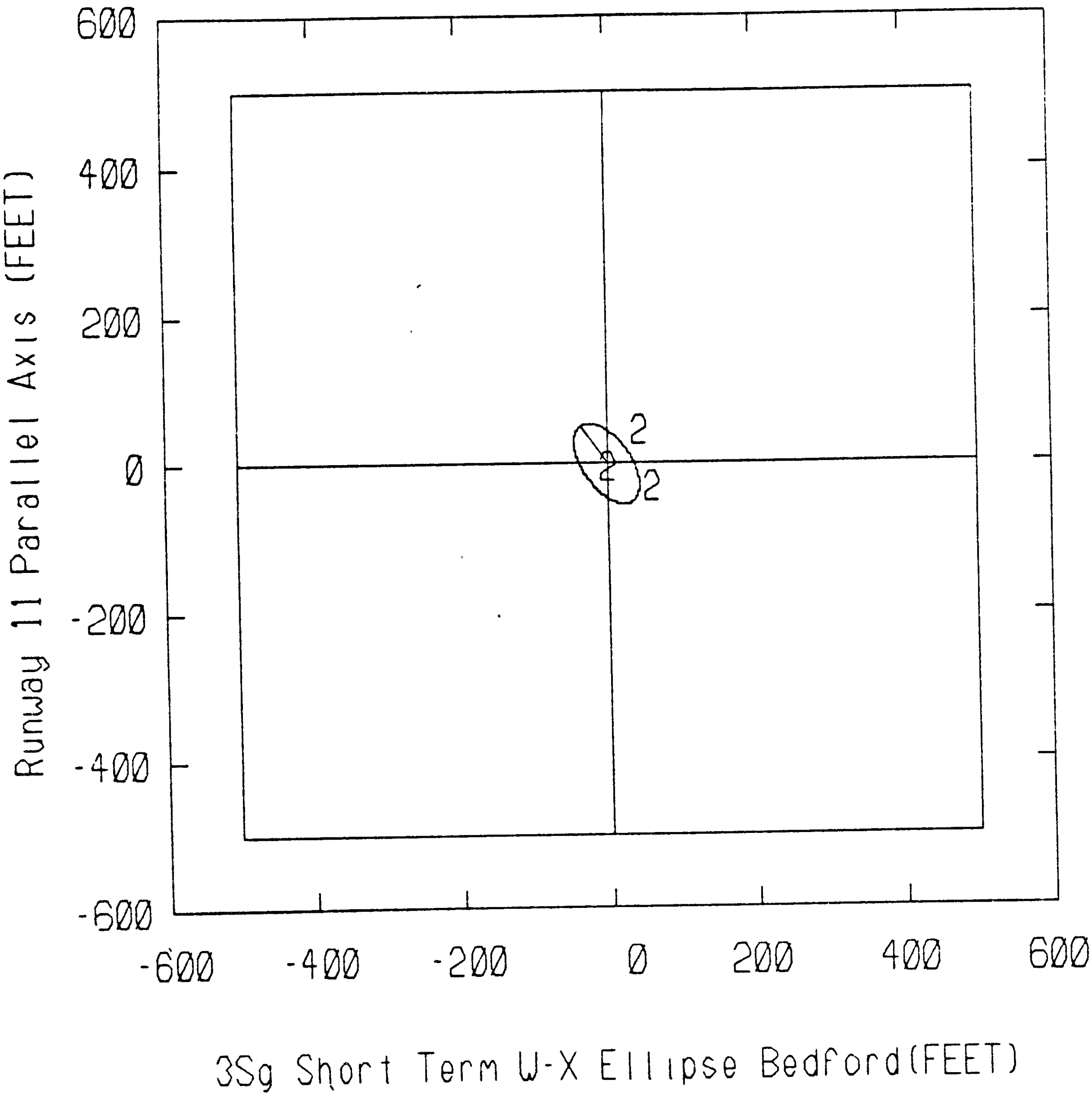

Figure 5.13: Short Term W,X Error Ellipse for Bedford

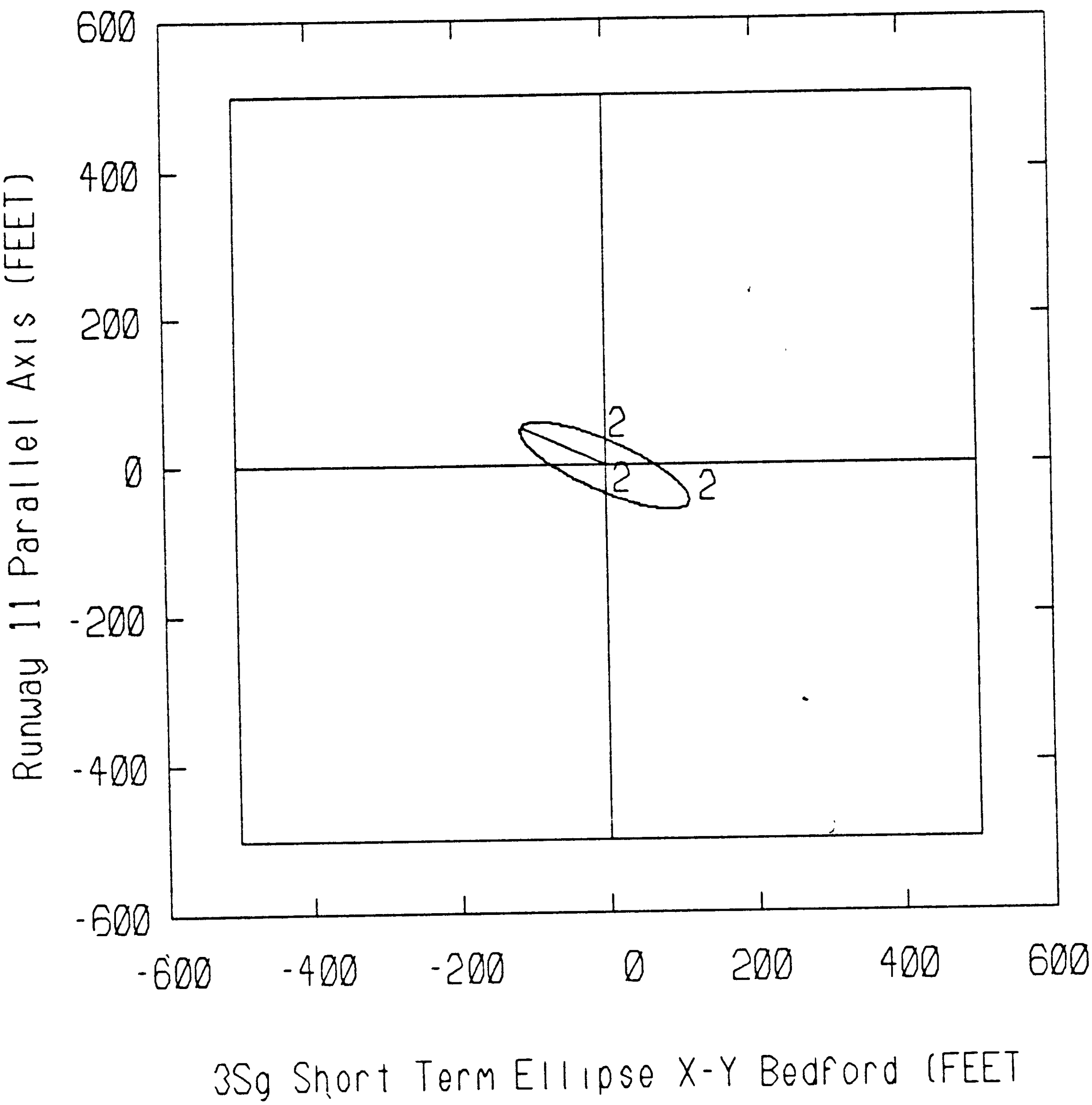

Figure 5.14: Short Term X,Y Error Ellipse for Bedford

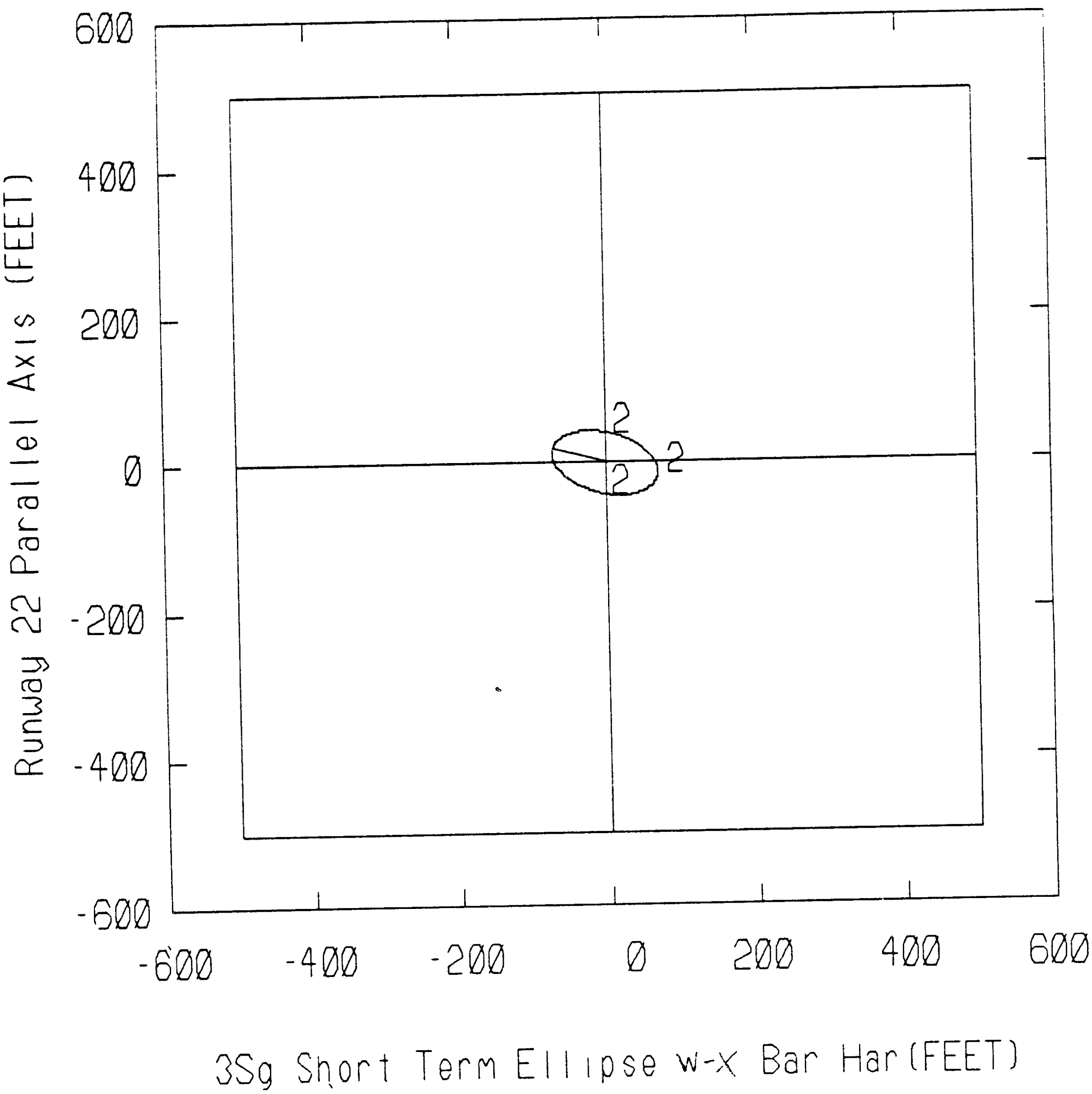

Figure 5.15: Short Term W,X Error Ellipse for Bar Harbor

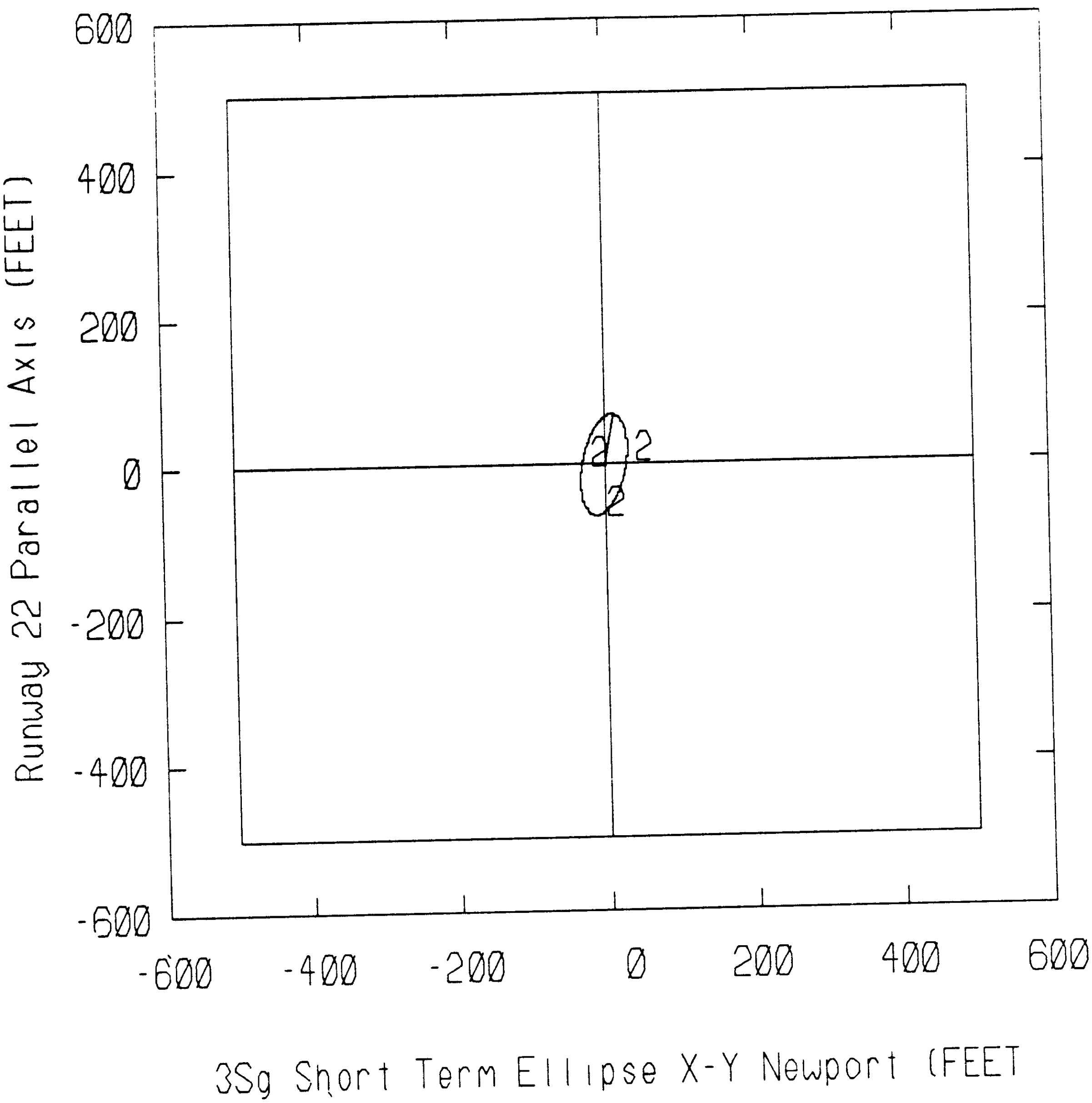

Figure 5.16: Short Term X,Y Error Ellipse for Newport

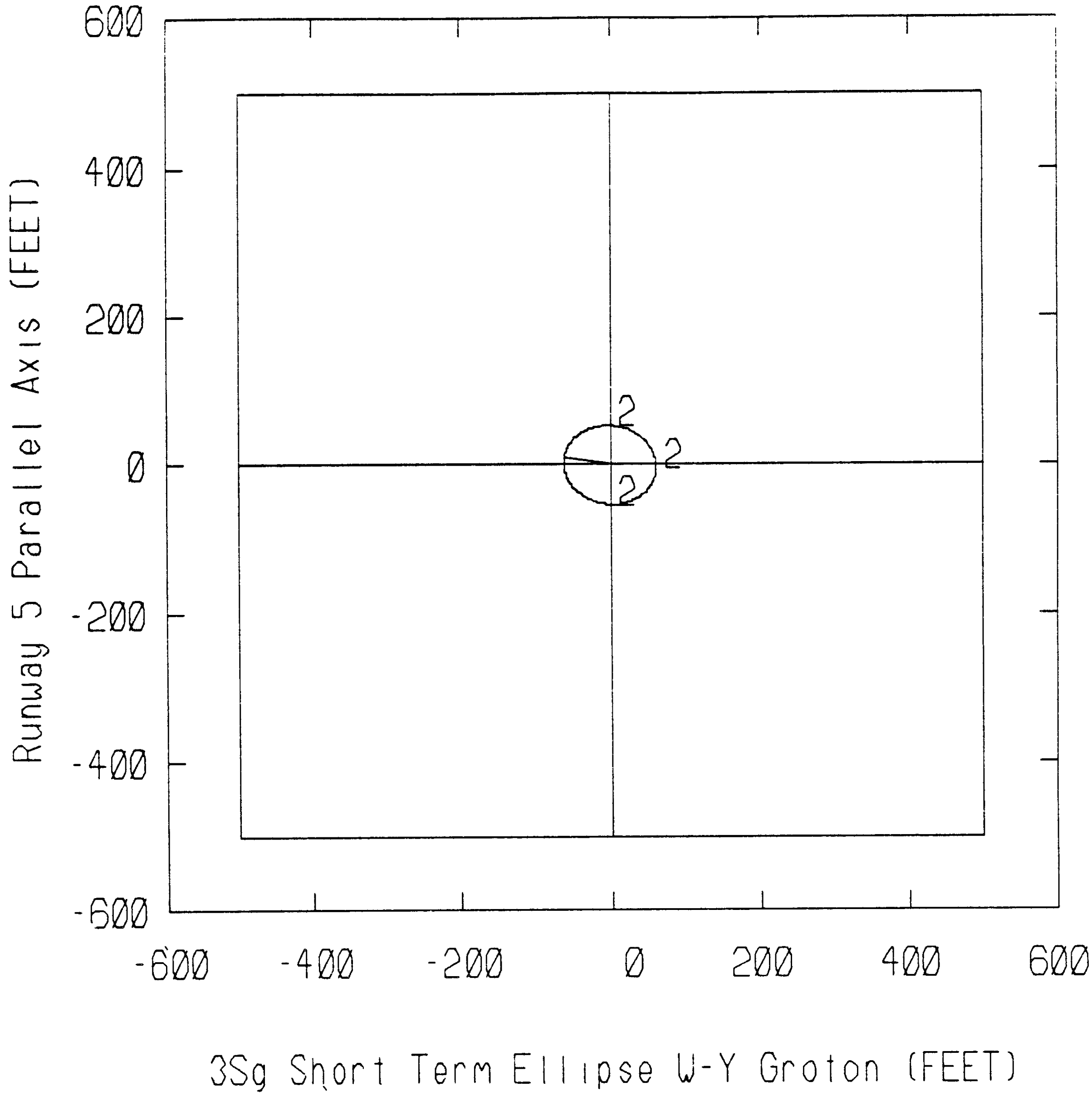

Figure 5.17: Short Term W,Y Error Ellipse for Groton

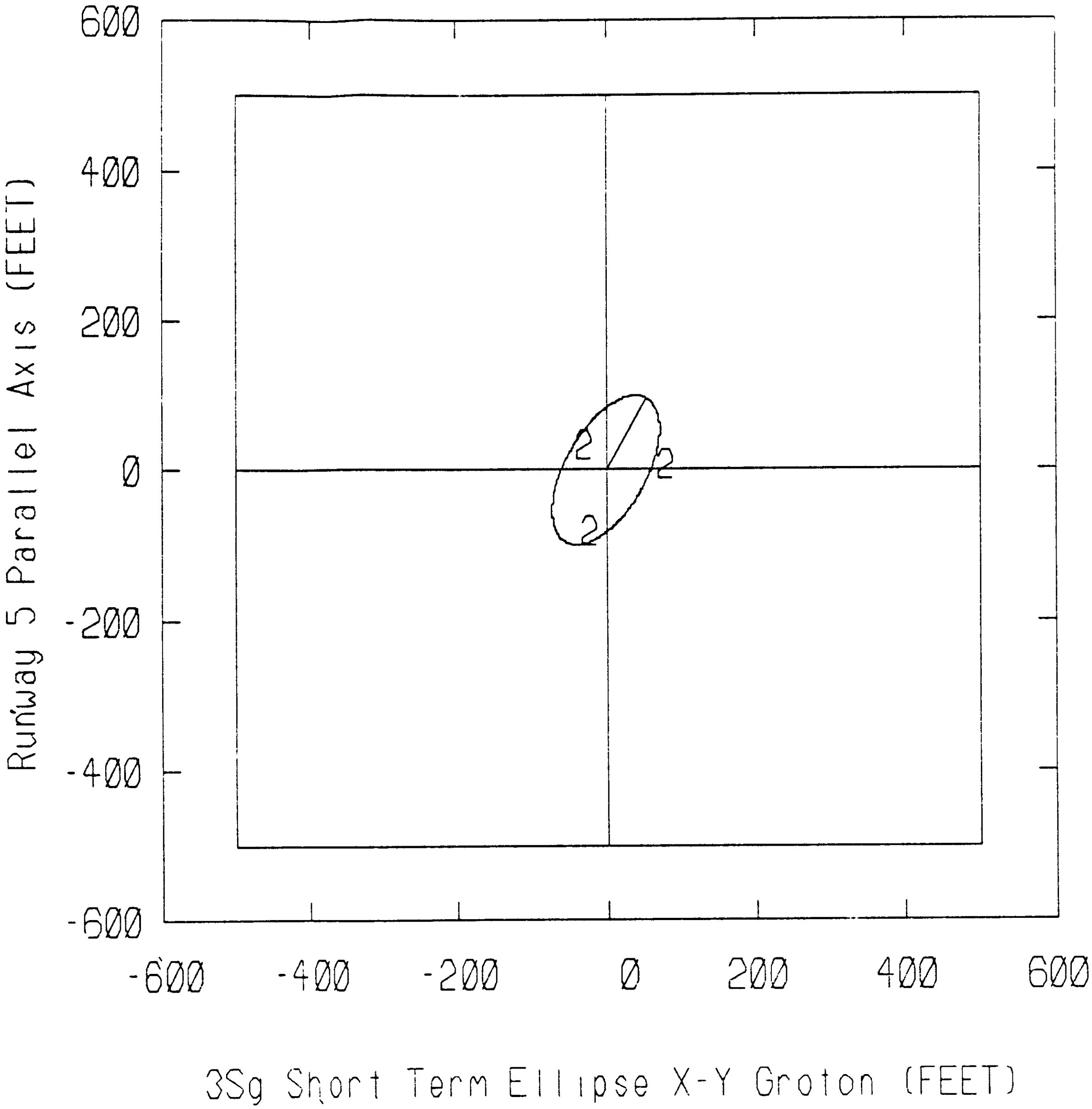

Figure 5.18: Short Term X,Y Error Ellipse for Groton

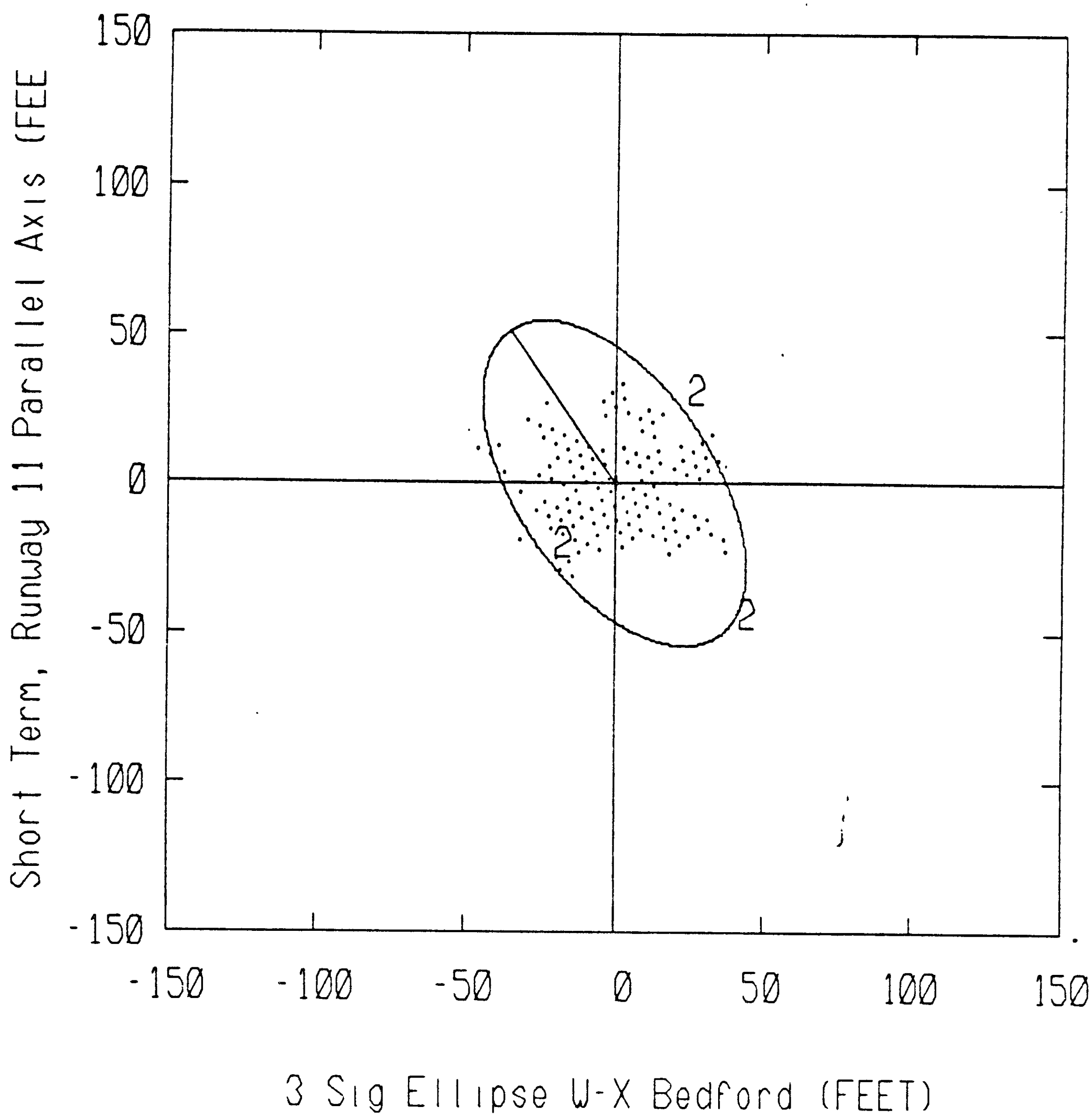

Figure 5.19: Scatter Plot and Short Term Ellipse, W,X Bedford

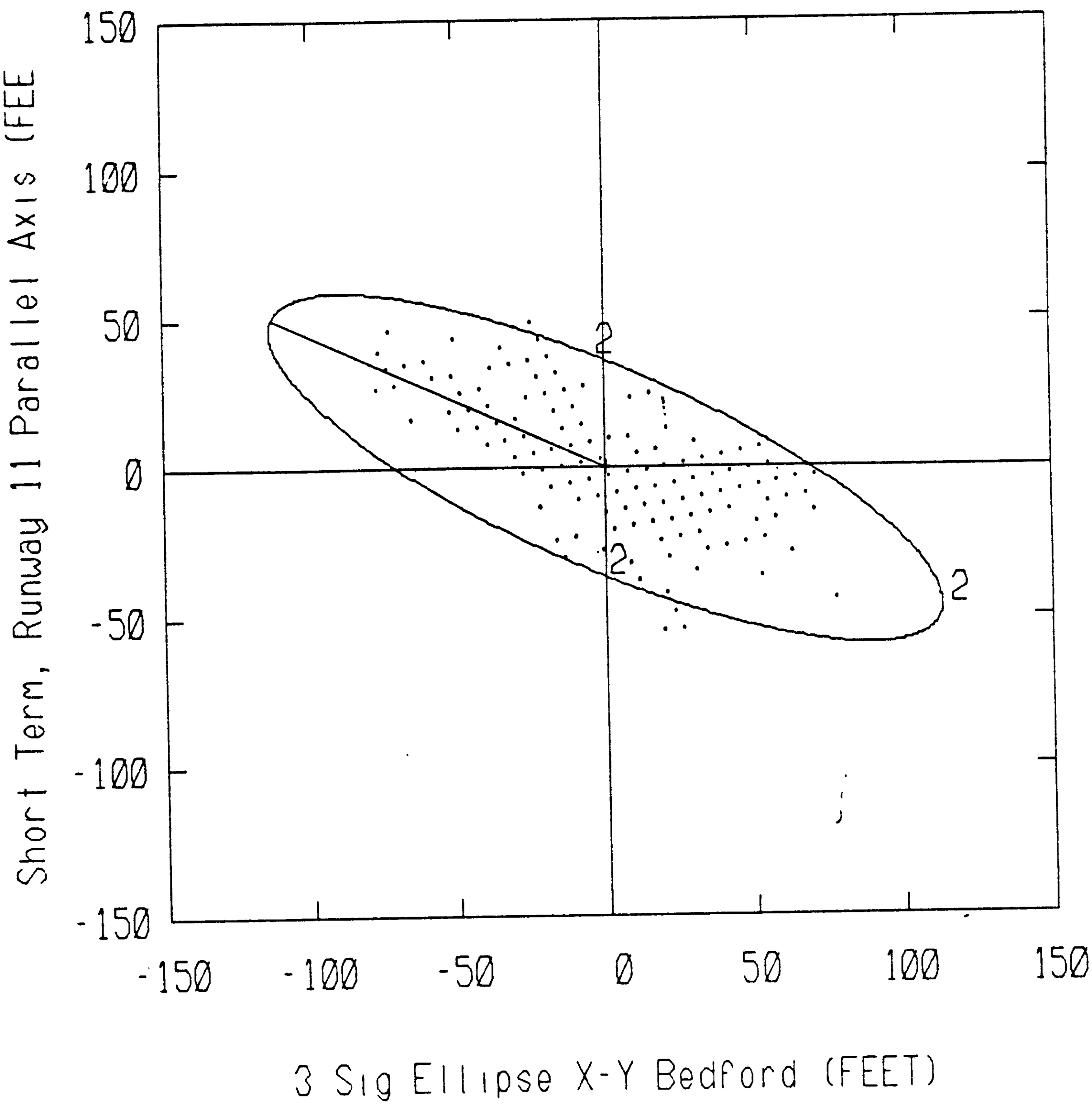

Figure 5.20: Scatter Plot and Short Term Ellipse, X,Y Bedford

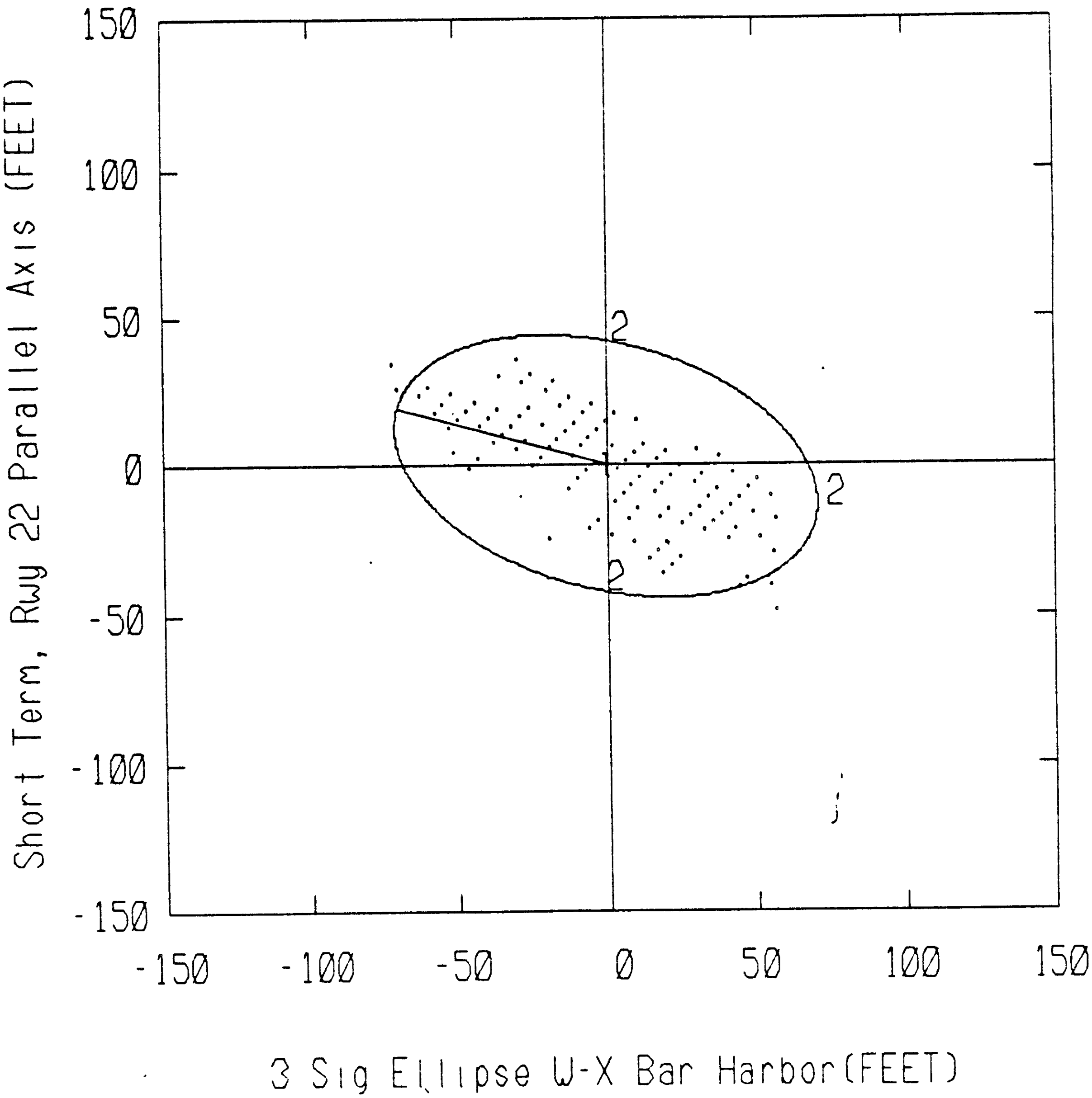

Figure 5.21: Scatter Plot and Short Term Ellipse, W,X Bar Harbor

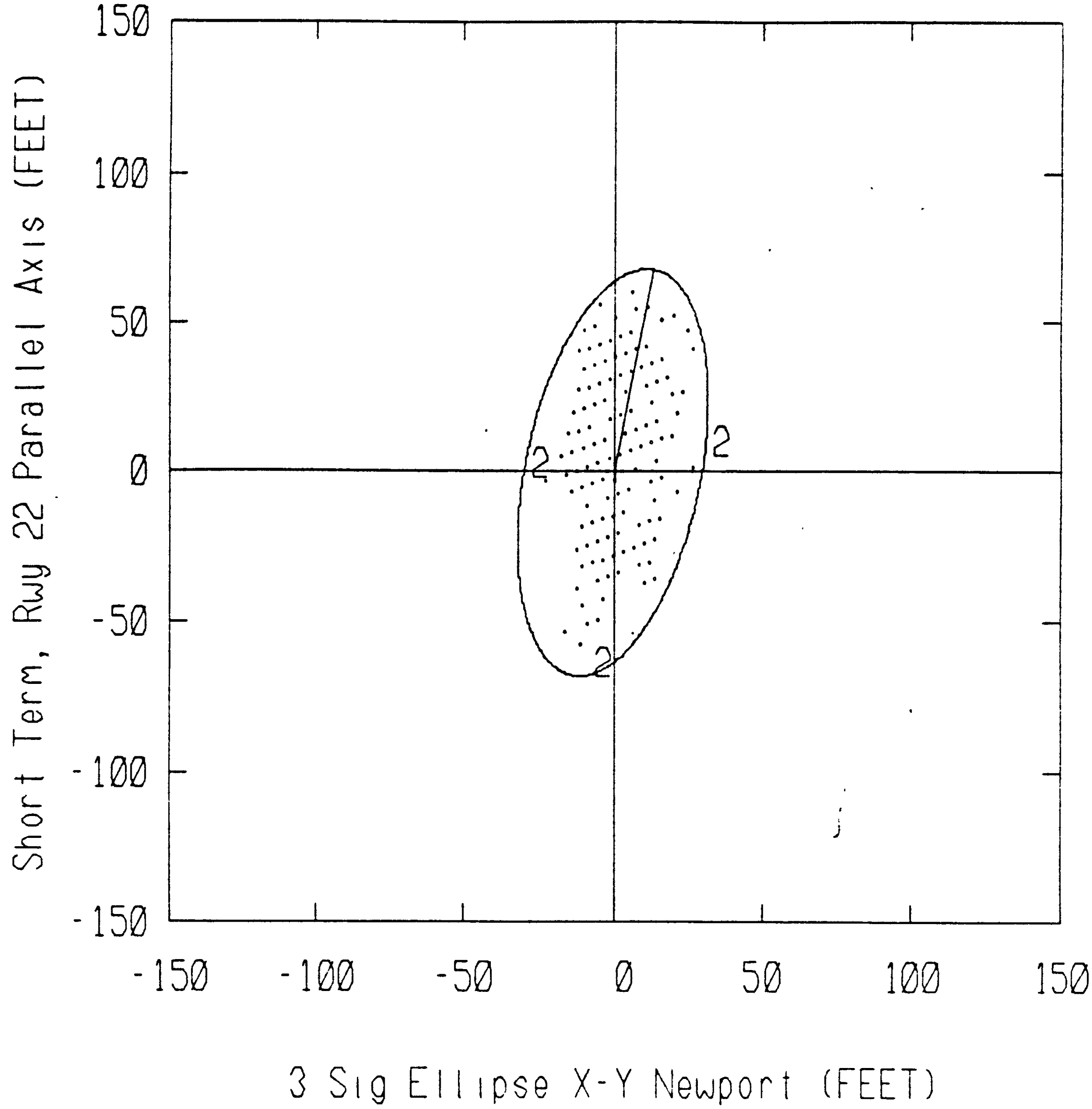

Figure 5.22: Scatter Plot and Short Term Ellipse, X,Y Newport

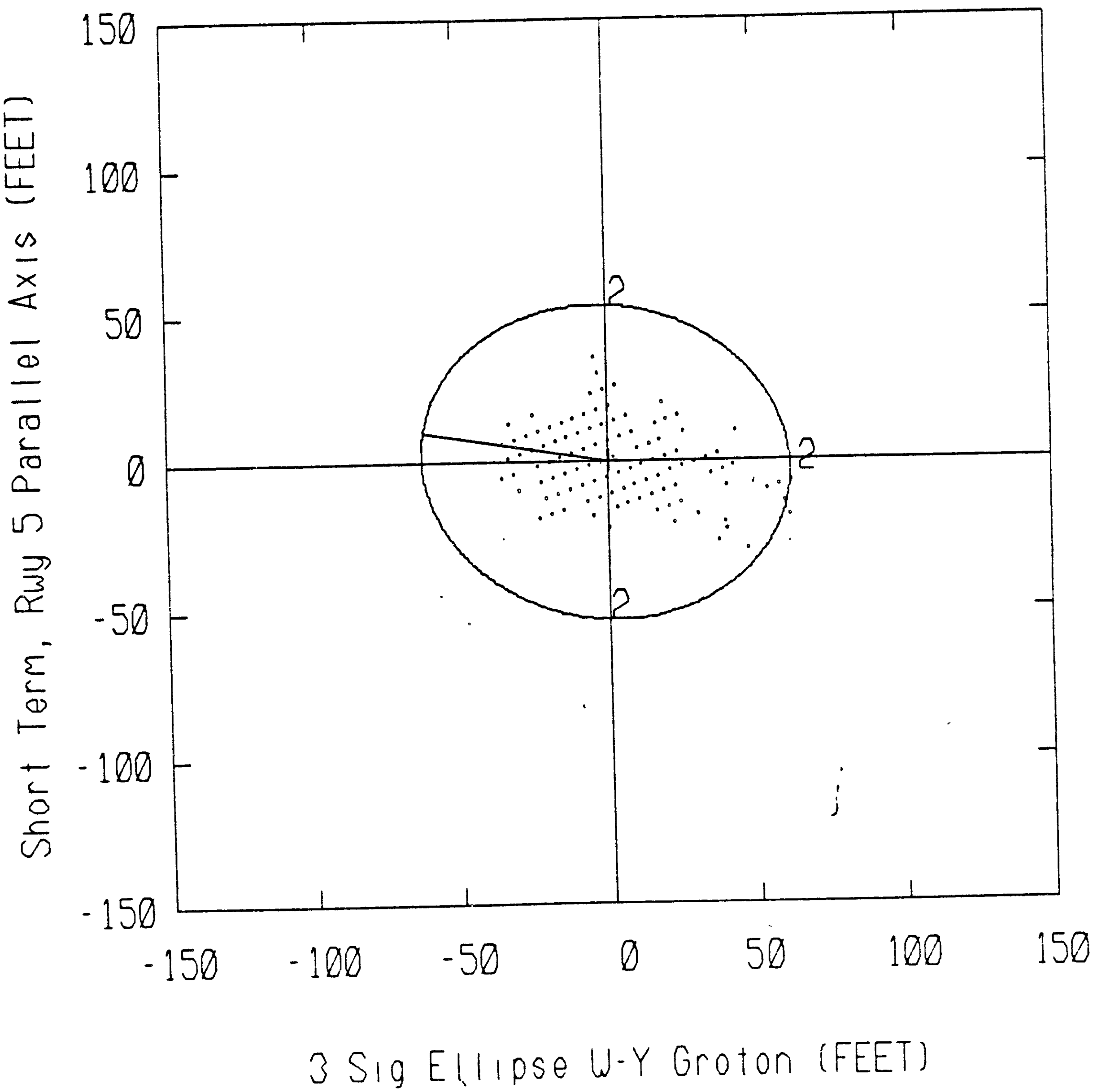

Figure 5.23: Scatter Plot and Short Term Ellipse, W,Y Groton

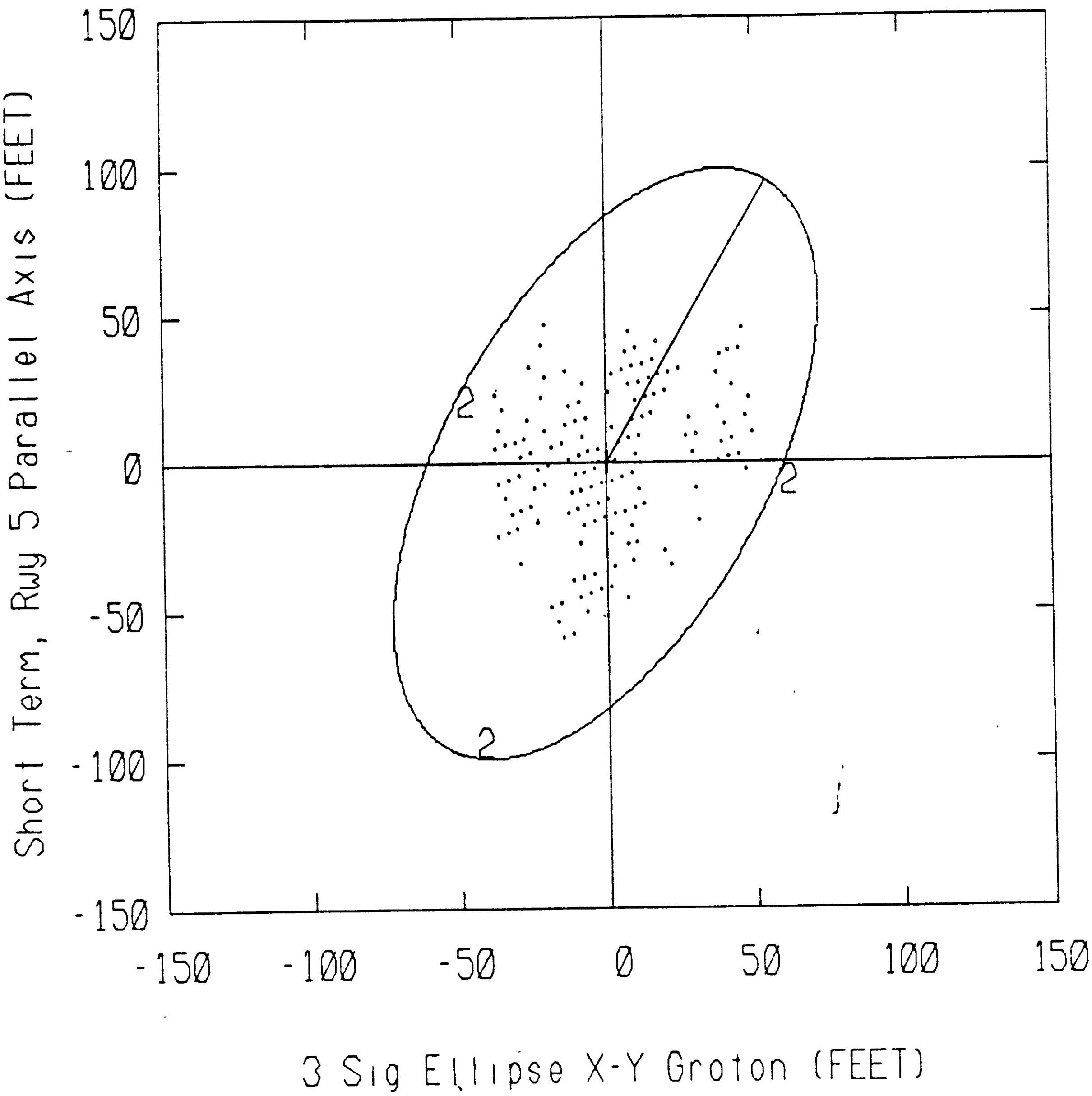

Figure 5.24: Scatter Plot and Short Term Ellipse, X,Y Groton

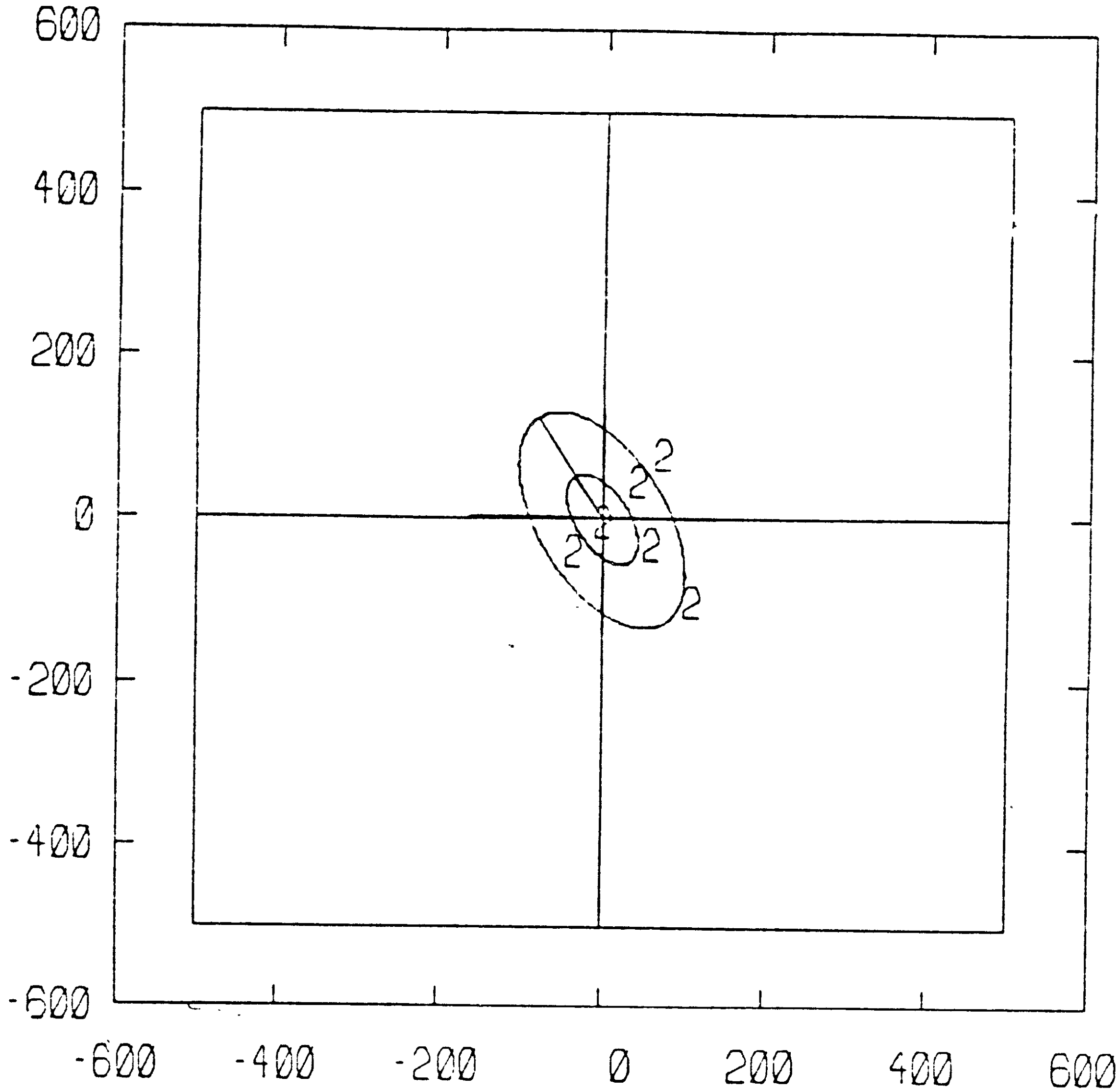

Figure 5.25: Long and Short Term Ellipses, W,X Bedford

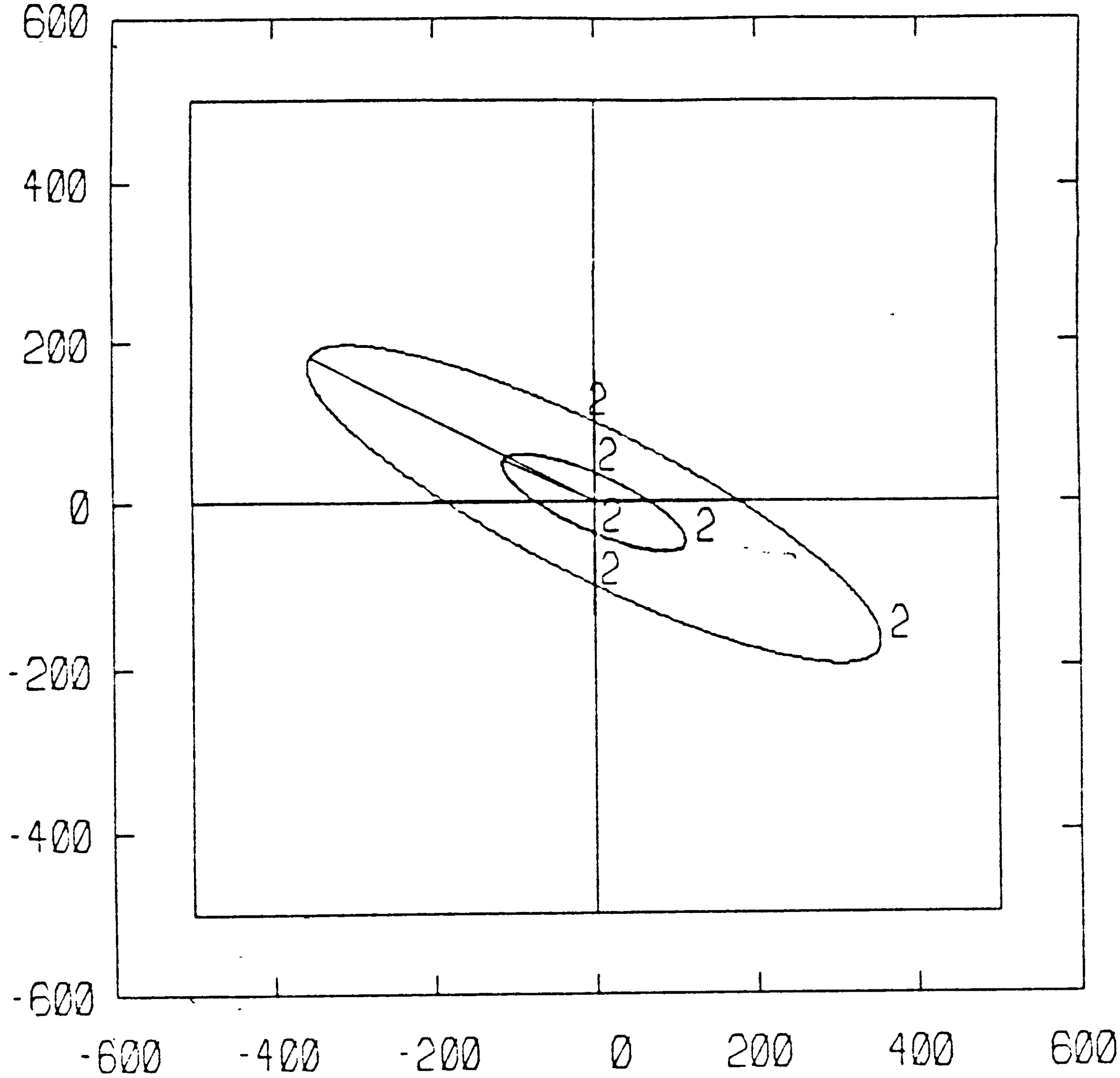

Figure 5.26: Long and Short Term Ellipses, X,Y Bedford

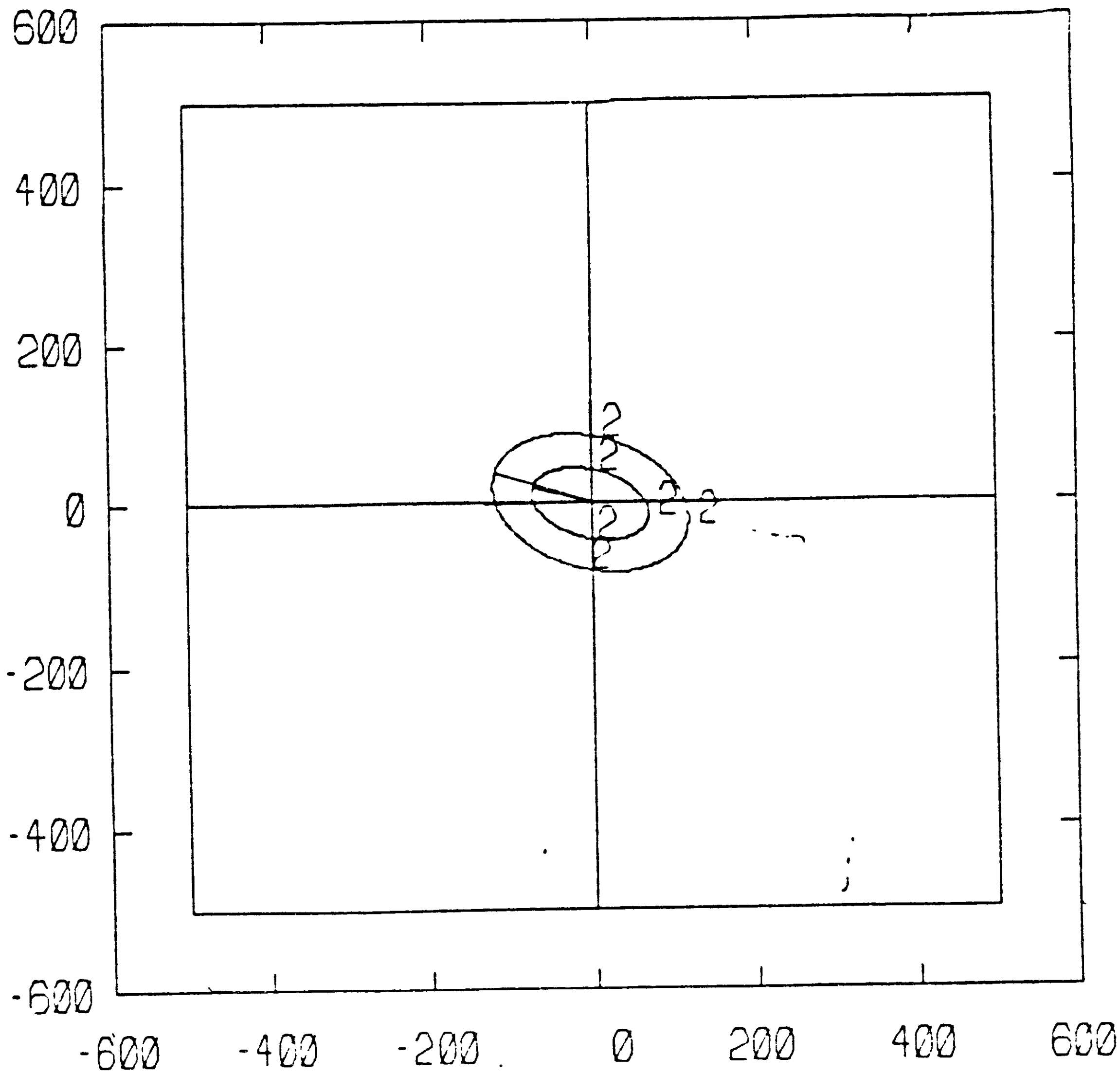

Figure 5.27: Long and Short Term Ellipses, W,X Bar Harbor

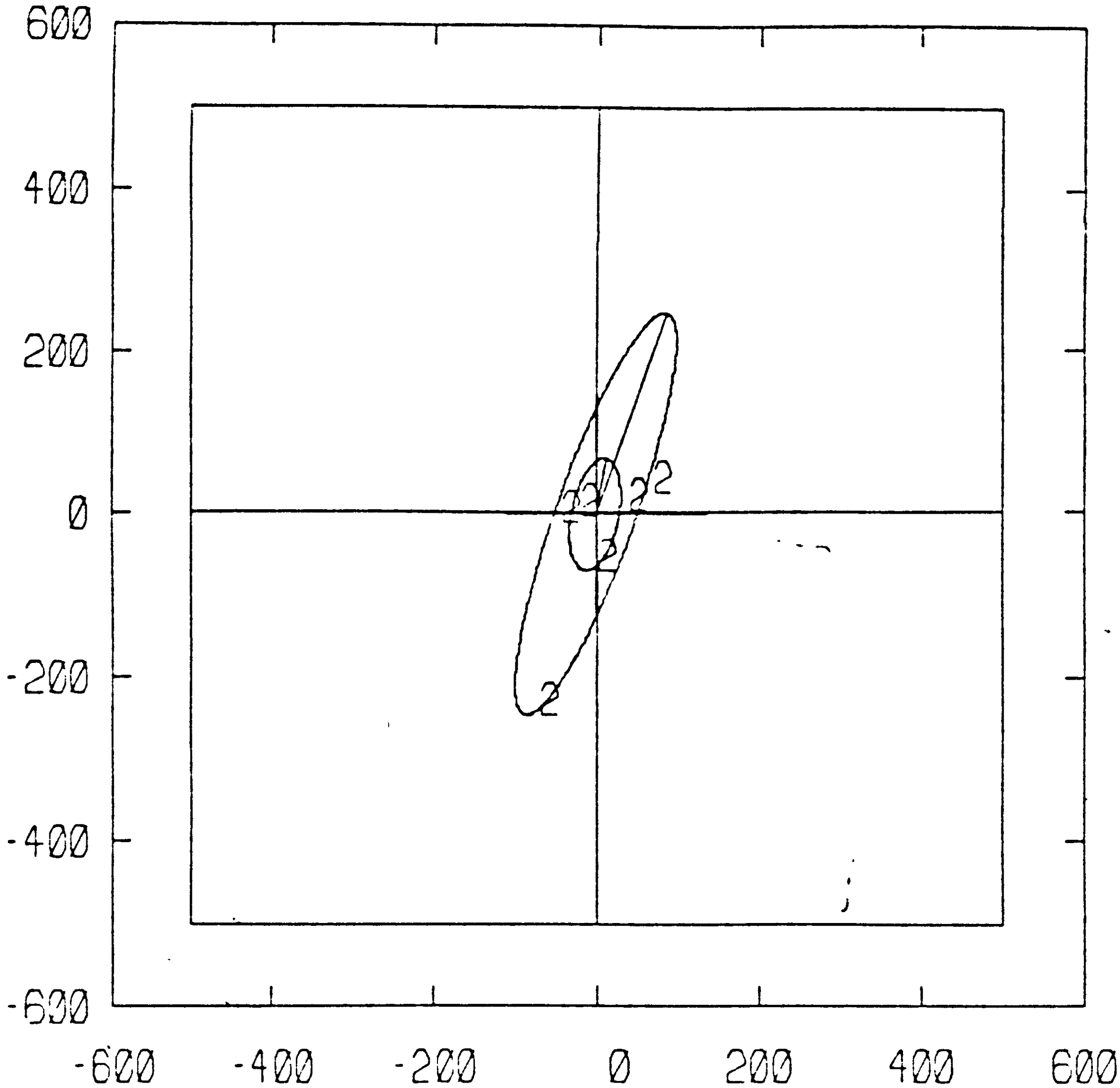

Figure 5.28: Long and Short Term Ellipses, X,Y Newport

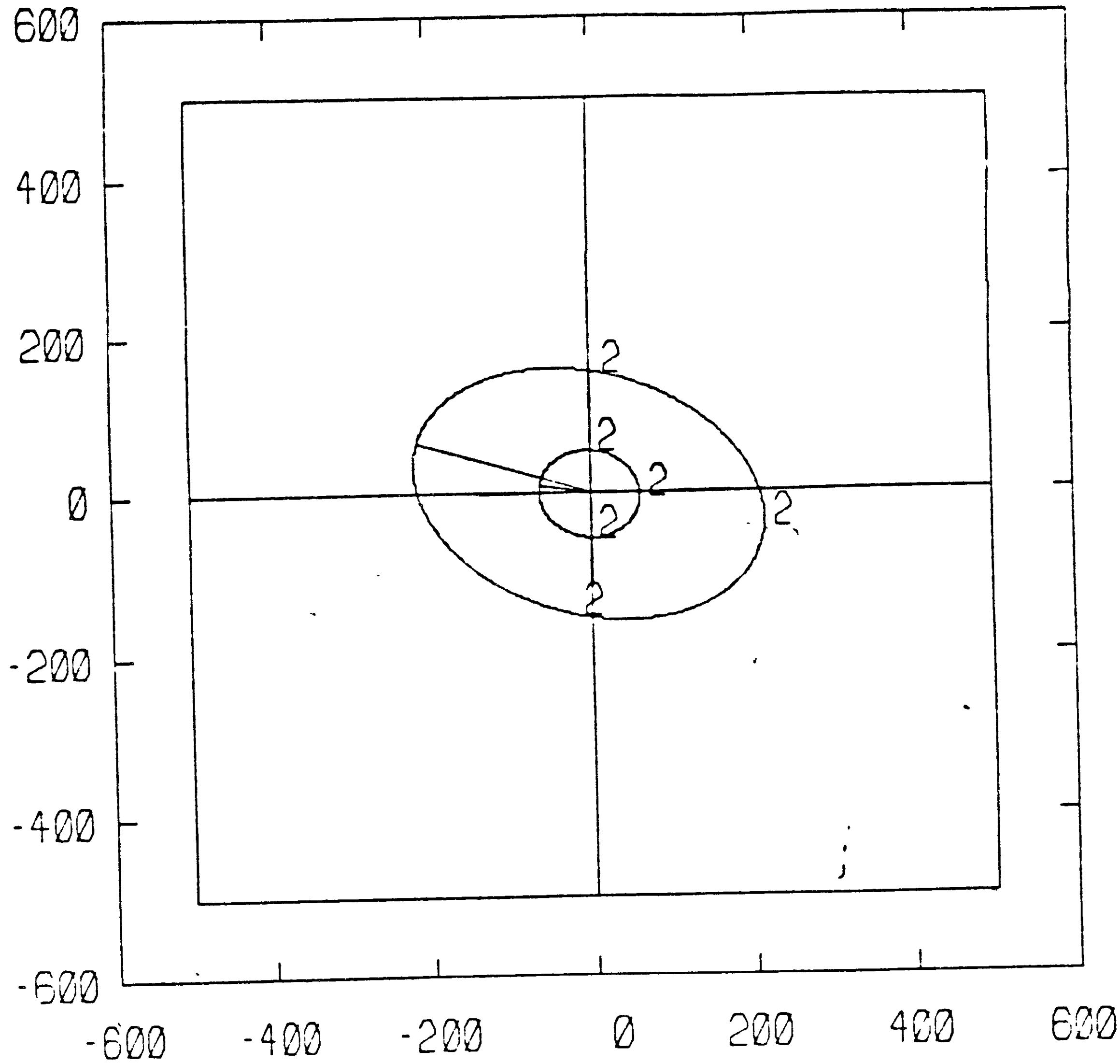

Figure 5.29: Long and Short Term Ellipses, W,Y Groton

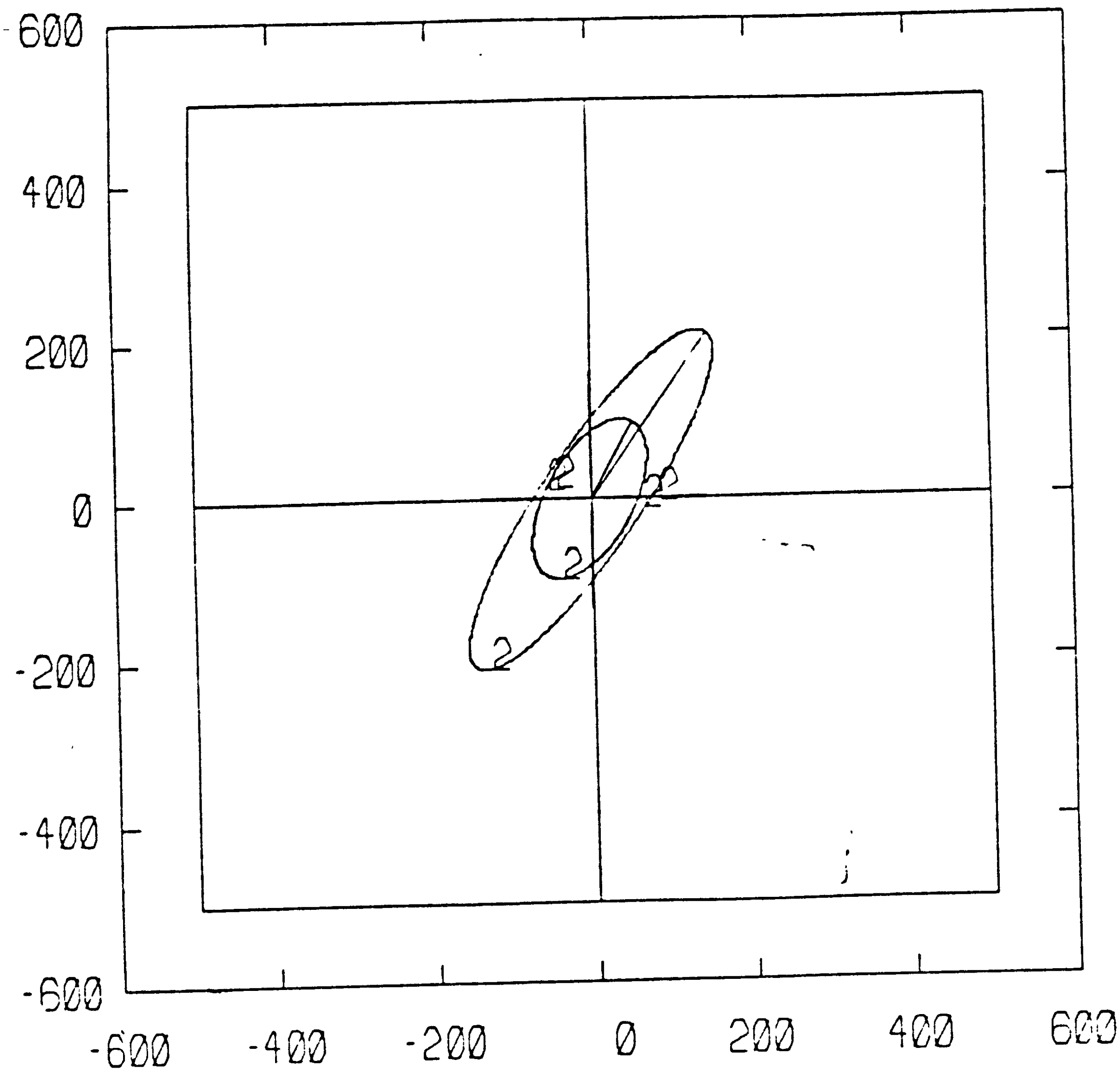

Figure 5.30: Long and Short Term Ellipses, X,Y Groton

Chapter 6

FLIGHT TEST RESULTS

A total of fourteen approaches were made at the four target airports. This chapter presents the data taken and problems encountered. These flight tests were performed a fair amount of time behind schedule. This is a tribute to the difficulty involved in performing flight tests. For a successful flight test, the data taking equipment had to be functioning perfectly, the airplane had to be in working order, the weather had to be VFR, and the winds had to be out of such direction that we could fly the ILS runways. The biggest problem encountered was that of the data taking equipment functioning. Two missions had to be scrubbed due to equipment failures that were caused by the vibration and sometimes quite violent movement of the airplane.

6.1 LOCALIZER CALIBRATION

As mentioned in chapter four, the localizer data was left and right cross track error taken from the autopilot output of the ILS head. Once filtered, this was in the form of a DC voltage sent through an analog to digital converter and recorded by the Apple. The actual values recorded were interger numbers between 0 and 255. To assure that the relationship between needle deflection and number output was not only known, but linear as well, a VOR/ILS test set from Lincoln Laboratories in Bedford was used in conjunction with an Apple to measure the values.

The set output was adjusted to give a known needle deflection, and the output of the A/D board was recorded. The needle deflection was adjusted in one dot localizer increments, and was set by eye. The accuracy therefore of this adjustment is assumed to be $+/-\frac{1}{5}$ of a dot. Table 6.1 lists the deflection in dots right or dots left, the corresponding angle in degrees, and the hex and decimal outputs. The localizer width is set so as to give full deflection with 700 feet cross track error at the runway theshold. This gives 0.46 degrees per dot for Hanscom, 0.71 degrees per dot at Groton, 1.11 degrees per dot at Newport, and 0.68 degrees per dot at Bar Harbor. The program used during the flight tests records decimal numbers, however the program used to test the localizer on the test bench records hex numbers. Consequently the hex numbers had to be converted to their decimal equivalent. The *centered* column lists the output if the zero point, 107, is subtracted from the output. This gives a directionality to the data not easily seen otherwise. The centering of the data was employed

Dots	Angle	Hex	Decimal	Centered
5R	2.30°	BA	186	79
4R	1.84°	A7	167	60
3R	1.38°	98	152	45
2R	0.92°	87	135	28
1R	0.46°	79	121	14
0	0	6B	107	0
1L	0.46°	5D	93	-14
2L	0.92°	4E	78	-29
3L	1.38°	3D	61	-46
4L	1.84°	2B	43	-64
5L	2.30°	16	22	-86

Table 6.1: Localizer Calibration Values

before plotting the results as well.

Figure 6.1 shows a plot of this information, dots versus decimal output with a $+/-\frac{1}{5}$ dot error envelope. The plot clearly shows the linearity of the relationship between dots and decimal output. There is some non-linearity present as 4 dots and greater are reached, but the assumption of linearity is still made. The vast majority of the flying was done within 3 dots or better of center, within which this is an excellent assumption.

The program PLOTFILE that eventually transforms the decimal output back to angles uses these ranges. For example, .46° corresponds to 121 and .92° corresponds to 135. If the output is 130 then the corresponding angle (ϕ) is

$$\phi = .46^\circ + .46\frac{130 - 121}{14} = .76^\circ \qquad (6.1)$$

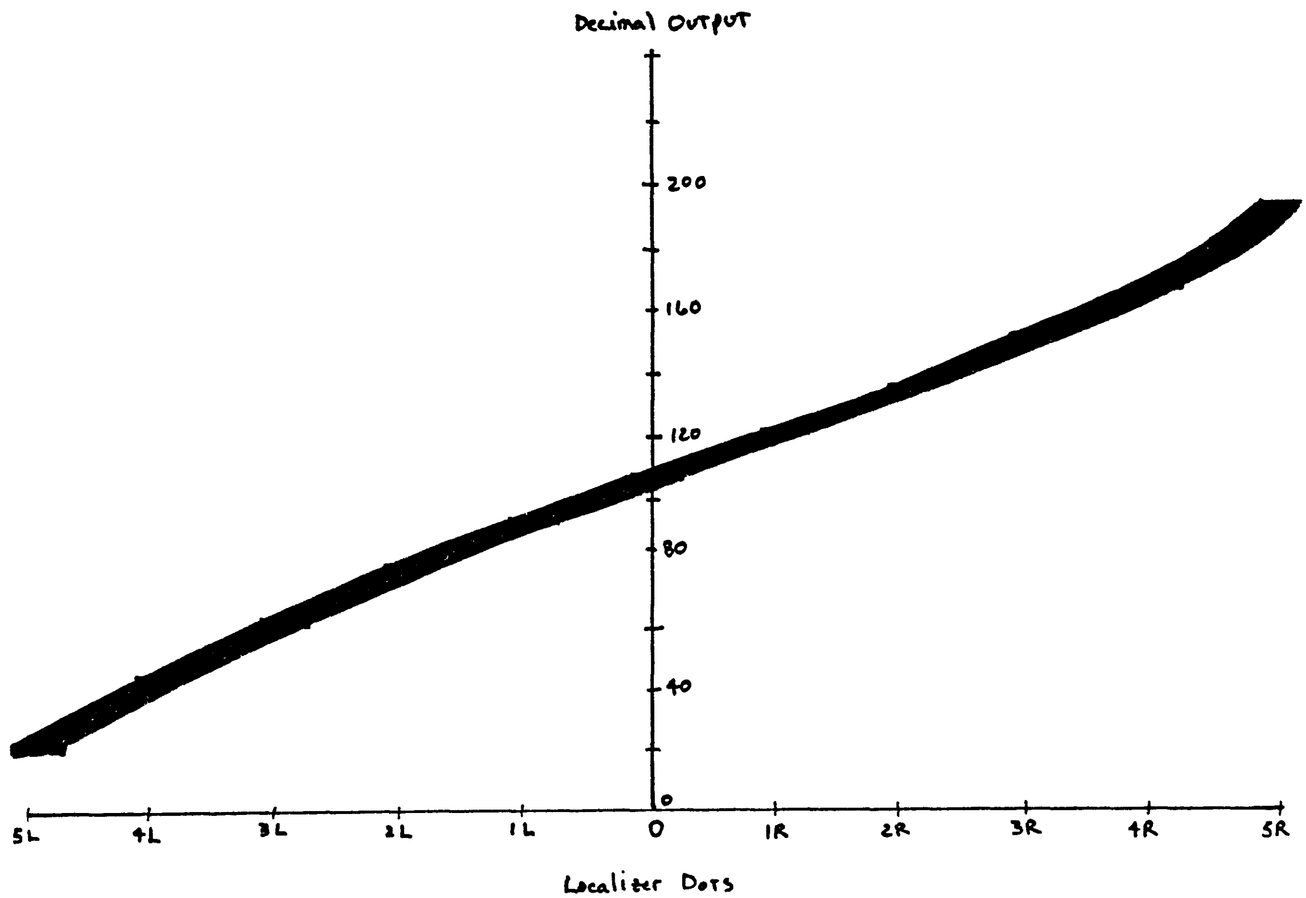

Figure 6.1: Needle Deflection versus Decimal Output

6.2 FIGHT TEST DETAILS

The airplane was flown well past the outer marker of the runway to give the pilot ample time to lock onto the localizer signal and to give the operator sufficient time to ready the data taking program. As the pilot flew the plane toward the outer marker, the copilot watched the NDB needle for swing. As the plane passed over the outer marker and the NDB needle passed either 270 or 90, the copilot yelled *mark*. At this time, the operator started the data taking program by pressing any key on the Apple keyboard, and started a stopwatch.

As the plane flew over the centerline of the runway and passed the first set of VASI lights, the copilot again yelled *mark*. This was the operator's que to stop the program and the stopwatch. Because the program has a cycle time of 1.19 seconds, *ie* writes a line of data every 1.19 seconds, the along track portion of the LORAN data can have an error of up to 1.19 seconds times the speed of the airplane. Since the target speed of the aircraft was 90 knots, any along track measurements could have an error of $+/-178$ feet. As the goal of this portion of the work is to obtain cross track error, this is not a catestrophic problem.

The time measurements from outer marker to VASI lights were used to compute the ground speed of the plane. Although the plane was oscillating about the localizer center, and thus travelling faster than would be indicated by multiplying the elapsed time and the distance from outer marker to VASI light, what is important is the effective ground speed along the beam. That *is* calculated by multiplying the elapsed time and the distance traveled along the beam.

It was mentioned in chapter five that ILS data was recorded during the static portions of testing. This was to determine the local ILS center. The center measured on the test bench was 107, however it was observed that the center on the runway was different for different days. On the first flying day, 10 May, the center was 100, and on the second day, 12 May, the center was 118. There were equipment problems between days and several IC chips were replaced. It is very possible that they had different operating characteristics.

A second reason for recording the localizer data during the static testing was to see how much noise was present. With the airplane completely stationary, the localizer output varied by a maximum of 2 bits. In other words, the localizer center might be 100 and the recording would see some 102*s* and 98*s*. At the runway threshold at Hanscom, 2 bits corresponds to 9.1 feet and at the outer marker (4 nautical miles from the threshold) 2 bits corresponds to 36.6 feet. For the Grumman Tiger, that is well under one wing span. The localizer data is quite clean.

One area that was not investigated was the correctness of the localizer beam itself. No analysis was performed to see if bends in the beam or scalloping were present. The key factor is that the beam is certified.

Even if the beam bends or is scalloped it is nontheless a certified *precision* approach aid.

6.3 FLIGHT TESTING RESULTS

This section presents the actual results of the flight tests. The information is not presented in the exact same form as recorded because lists of TD values and decimal numbers would not be very meaningful. It is, however displayed in a format that makes the errors easy to visualize.

Table 6.2 lists the flight test numbers, date flown, LORAN-C triads used, elapsed time of approach, speed along localizer beam, localizer center point, gives a pilot number (the approaches were flown by three pilots), the number of hours of flying each pilot has.

The LORAN data recorded is in the form of TDs, collected once every 1.19 seconds. Given a reference time difference, it is possible to transform the TDs into position information in the form of North and East distances from the reference point. This is accomplished by multiplying each time difference minus the reference point by a coefficient that is either the North or East component of the gradient. The result of this transformation then is a North and an East distance for each TD point. These points can then be plotted with respect to the reference point.

The program PLOTFILE does such a transformation. For these tests, the reference point was chosen as the point on the runway centerline be-

Test	Date	Triad	Time(min)	Speed(kts)	Center	Pilot	Hours
Hanscom AFB							
1	10 May	W,X	2:18	104.4	100	1	100
2	10 May	W,X	2:06	114.4	100	1	100
3	12 May	X,Y	2:44	87.9	118	2	850
4	12 May	X,Y	2:25	99.4	118	3	55
5	12 May	W,X	3:00	80.1	118	2	850
Newport							
6	24 May	X,Y	3:45	97.6	123	1	850
7	24 May	X,Y	4:08	88.6	123	1	850
Groton							
8	24 May	W,Y	4:24	75.1	118	1	850
9	24 May	W,Y	3:54	84.7	118	1	850
10	24 May	X,Y	4:15	77.7	118	1	850
Bar Harbor							
11	29 May	W,X	3:31	92.0	118	1	850
12	29 May	W,X	3:26	94.5	118	1	850
13	29 May	W,X	3:32	91.8	118	1	850

Table 6.2: Flight Test Parameters

tween the first set of VASI lights. The TDs used for this reference point were the average TDs calculated from the static tests. It is possible then to plot the path that the LORAN says the plane took during each approach. The program PLOTFILE also plots the paths after doing the coordinate transformation. Plots of the LORAN paths appear later in this section. The program PLOTFILE appears in Appendix C.

The localizer data recorded is in the form of cross track angles. It is also possible to plot the localizer path in terms of distance from runway and cross track error in feet. Each data point is recorded every 1.19 seconds. The velocity of the plane down the localizer beam has already been computed. If the assumption is made that the last data point of each run was recorded as the reference point was passed, it is possible to backtrack along the data and compute the distance from the runway. The second to last data point would then be recorded 1.19 seconds prior to passing the reference point. Given, for example the speed of approach number one, 104.4 kts, 1.19 seconds traveling at 104.4 kts is 207 feet. Therefore the second to last data point was taken 207 feet from the reference point. The third to last data point was taken 414 feet from the reference point, and so on. The localizer angle of error is referenced to the localizer array, which is located between 3000 and 8000 feet from our reference point, depending on the airport and runway in question. The distance from the array is now known, and the data point is the angle off of the centerline of the beam.

If y is the distance from the reference point in feet, and the distance from the reference point to the localizer array is 7950 feet as is the case with Hanscom, and α is the angle off of the beam, the cross track error in feet, x is computed by

$$x = (y + 7950)\tan(\alpha) \tag{6.2}$$

The along track (along the runway centerline) distance is known and from that the cross track distance is computed. It is now possible to plot the localizer path in the same coordinate system as the LORAN paths. Plots of the localizer paths also appear later in this section with the corresponding LORAN paths.

Examining superimposed plots of the LORAN and localizer paths give a good qualitative and somewhat quantitative feel for the differences between the two. The idea is that the localizer is a certified precision approach system, and if the LORAN can closely track the localizer path, that makes a strong statement about the accuracy of the LORAN system.

One method of comparing the two paths is to subtract the localizer cross track error from the LORAN cross track error leaving only LORAN error. Once the localizer error has been subtracted out, the residual error would be pure LORAN error. This would simulate the airplane flying exactly down the center of the localizer beam.

The difficult part of this type of analysis is computing the localizer cross track error. The cross track error is a direct function of distance from the localizer array, as shown in equation 6.1. The method used earlier to compute the localizer distance out assumes a constant velocity during the entire approach. This assumption is fine for plotting the path, but introduces undesirable errors when doing numerical calculations.

A second method is to use the LORAN distance out as the localizer distance out. Since the two sets of data are perfectly correlated time-wise, the true distance out is the same for both. This method has one major flaw. The goal of this research is to test the accuracy of LORAN. The ILS has been chosen as the system to test the LORAN against. Using the LORAN distance out would be like using the LORAN to test the accuracy of LORAN. The two sets of data would be strongly correlated, which is of course undesirable.

The chosen method of comparing the two sets of data is to look at angle error only. This is accomplished in the following manner. The localizer data is already an angle error. The LORAN data can be easily converted to along track and cross track distances. This is what is done in order to plot the path. These distances are referenced to the VASI-runway centerline point already mentioned. By adding on the 7950 feet from this reference point to the localizer array, the LORAN data is now referenced to the array, as is the localizer data. Once again, if we let y be the distance out from the VASI reference point, let x be the cross track error in feet, and letα be the error angle,

$$\alpha = \arctan(\frac{x}{y}) \tag{6.3}$$

The LORAN error is now expressed as an error angle referenced to the same point as the localizer error angle. By simply subtracting the localizer angle from the LORAN angle, the angle that the LORAN differes from the localizer is computed. This can be done for each point in the data sets. This needs no simplifying assumptions, introduces no correlation, and is simply 'clean' error. It is also possible to do statistical analysis on the error such as calculating the mean and standard deviation. The program PLOTFILE does this. It transforms the LORAN data into angle error, subtracts the localizer angle from the loran angle, and then computes the mean difference angle and the standard deviation of the difference angle.

The following pages contain the localizer path plots, LORAN path plots, superimposed LORAN and localizer path plots, and a listing of the LORAN error angle, localizer error angle, difference between the two, and the standard deviation and mean of this difference.

One point to be noted on approach number two at Hanscom. Initially, the LORAN differs from the localizer by more than a degree. This is attributed to a momentary power outage which caused the LORAN to lose track of the stations. It takes the LORAN roughly two to five minutes to lock on to a triad. This momentary outage was one of the vibration induced problems mentioned earlier. During the flight, the outage went unnoticed.

However, it does explain the rapid rate at which the LORAN catches up to the localizer. Similar reasoning is applied to approach two at Newport.

It should also be noted that the first two data points in each set are ignored. The program is selecting the location of the information during these two interrogations of the receivers.

Approach three at Bar Harbor was done keeping the ILS indicator at three dots to the right. Approach two at Bar Harbor was flown using the magnetic heading of the runway instead of the localizer beam in an effort to find any scalloping or bending of the beam. Approach four at Groton was flown in an oscillàtory manner using a 15 degree intercept angle to examine the LORAN's performance under large acceleration.

Finally, when viewing the combined LORAN-localizer plots from the runway, so that the plane is coming toward you, a positive differential angle means that the LORAN is to the left of the localizer.

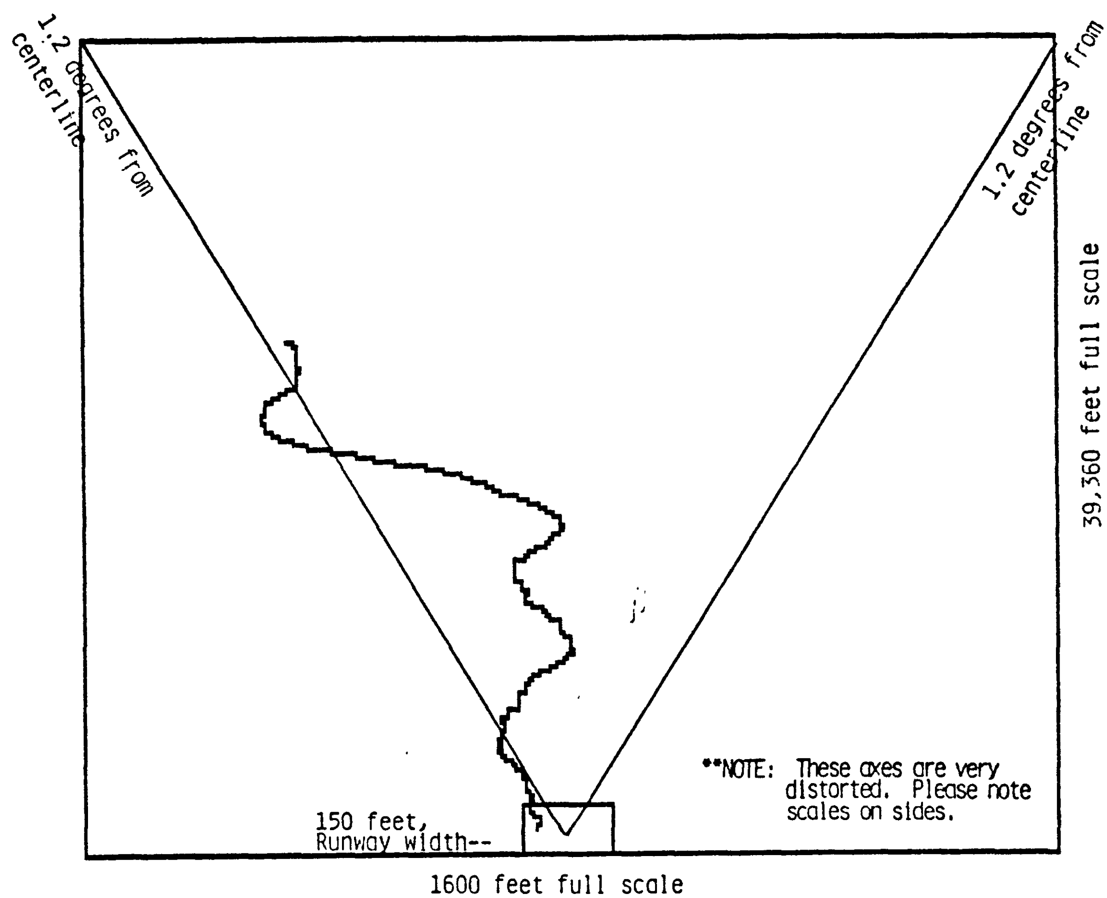

Figure 6.2: Hanscom Approach 1, WX LORAN Path

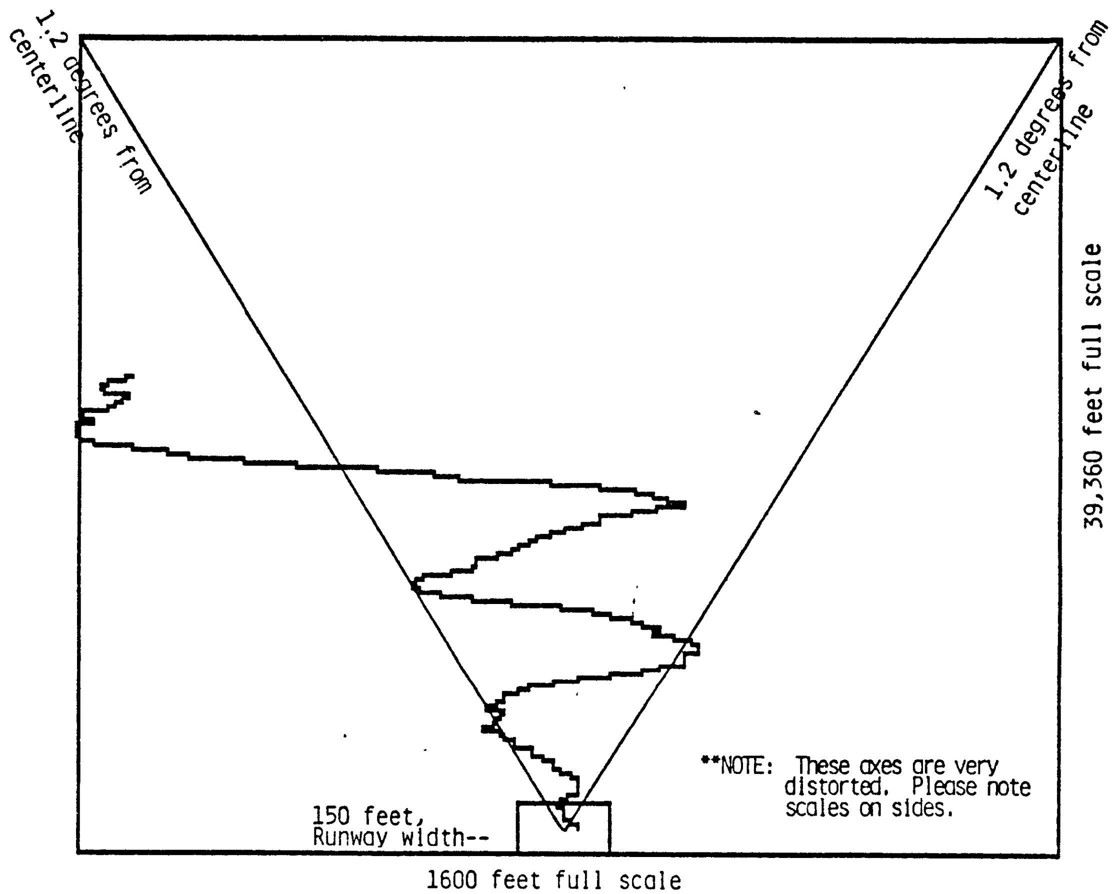

Figure 6.3: Hanscom Approach 1, WX Localizer Path

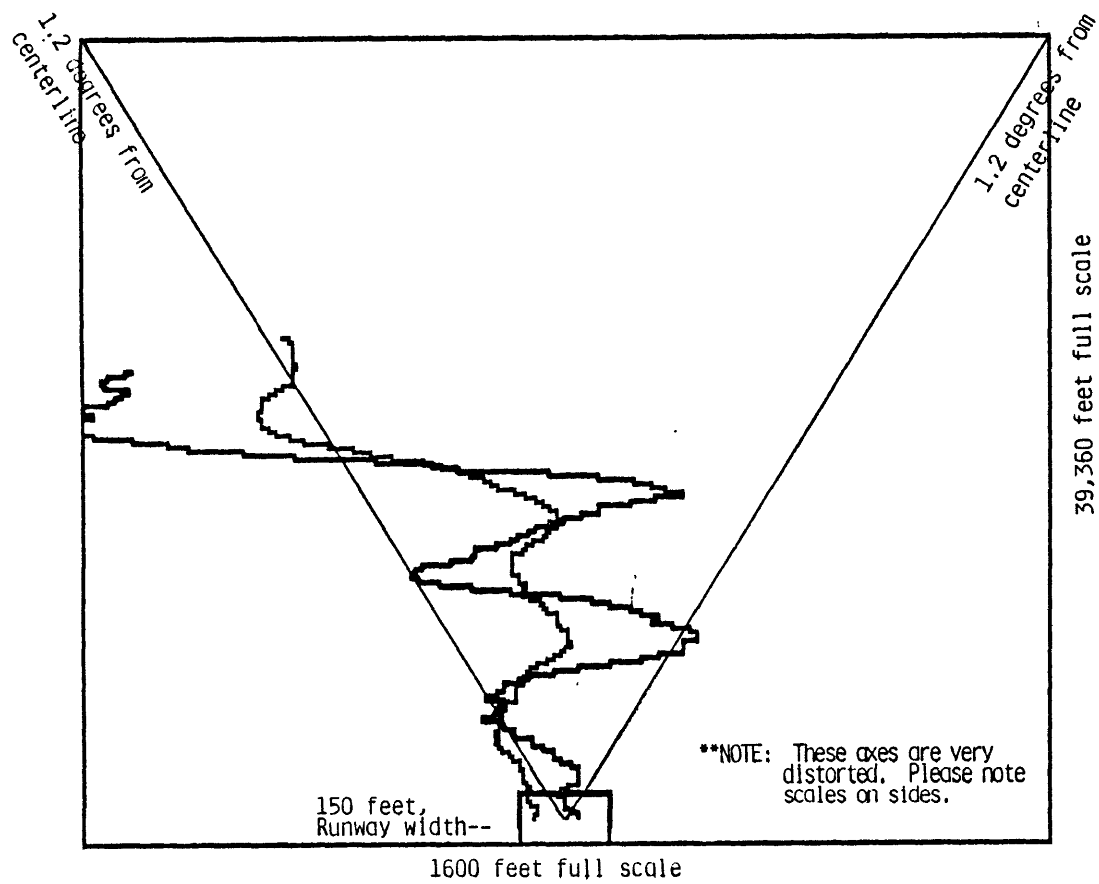

Figure 6.4: Hanscom Approach 1, WX Combined Paths

# PNT	LOCALIZER ANGLE	LORAN ANGLE	DIFFERENCE LORAN-LOC
1	.8871	.8356	-.051
2	4.048	.8189	-3.22
3	1.352	.8138	-.539
4	1.38	.8241	-.555
5	1.441	.8208	-.620
6	1.472	.8295	-.642
7	1.472	.8287	-.643
8	1.410	.8420	-.568
9	1.441	.8519	-.589
10	1.472	.8583	-.613
11	1.502	.8684	-.634
12	1.594	.9060	-.688
13	1.625	.9396	-.685
14	1.594	.9597	-.634
15	1.656	.9885	-.667
16	1.686	1.006	-.679
17	1.717	1.006	-.711
18	1.686	1.027	-.659
19	1.656	1.028	-.627
20	1.533	1.033	-.500
21	1.410	1.021	-.388
22	1.352	.9968	-.356
23	1.163	.9583	-.205
24	.9741	.9123	-.061
25	.69	.8424	.1524
26	.4928	.7622	.2694
27	.3942	.7022	.3079
28	.0657	.6248	.5591
29	-.131	.5211	.6526
30	-.262	.4598	.7227
31	-.328	.4016	.7302
32	-.394	.3648	.7591
33	-.46	.3124	.7724
34	-.361	.2819	.6433
35	-.262	.2606	.5235
36	-.131	.2037	.3352
37	-.131	.1637	.2951

Begin approach (margin note beside row 6)

Table 6.3: Hanscom Approach 1, WX Error Angles

38	-.065	.1193	.1850
39	0	.0879	.0879
40	.0657	.0581	-7.51
41	.1314	.0322	-.099
42	.1642	.0409	-.123
43	.1971	.0287	-.168
44	.23	.0375	-.192
45	.2957	.0618	-.233
46	.3942	.0757	-.318
47	.3942	.1009	-.293
48	.4271	.1441	-.283
49	.5257	.1808	-.344
50	.6571	.2006	-.456
51	.69	.2362	-.453
52	.7228	.2389	-.483
53	.69	.2507	-.439
54	.5914	.2459	-.345
55	.46	.2529	-.207
56	.2628	.2197	-.043
57	.0328	.2292	.1964
58	-.131	.1994	.3308
59	-.23	.2186	.4486
60	-.328	.2104	.5390
61	-.394	.1822	.5764
62	-.490	.1404	.6311
63	-.46	.1237	.5837
64	-.582	.0963	.6790
65	-.674	.0521	.7268
66	-.736	.0443	.7803
67	-.736	.0499	.7859
68	-.674	.0252	.6999
69	-.674	-5.94	.6687
70	-.674	-.014	.6598
71	-.552	-9.67	.5423
72	-.46	-.024	.4350
73	-.262	1.009	.2638
74	-.065	.0213	.0870
75	.0657	.0689	3.281
76	.23	.1059	-.124
77	.2957	.1748	-.120

Table 6.4: Hanscom Approach 1, WX Error Angles Continued

78	.3942	.2265	-.167
79	.3942	.2479	-.146
80	.46	.2770	-.182
81	.5257	.2905	-.235
82	.4271	.3283	-.098
83	.46	.3299	-.130
84	.4928	.3428	-.150
85	.5257	.4141	-.111
86	.5914	.4249	-.166
87	.4928	.4720	-.020
88	.46	.4699	9.951
89	.3942	.4822	.0879
90	.3942	.5075	.1132
91	.2628	.5188	.2559
92	.2628	.5457	.2829
93	.1971	.5248	.3276
94	.0985	.5643	.4657
95	.0985	.5151	.4165
96	.0328	.4898	.4569
97	-.032	.4512	.4841
98	-.098	.4234	.5219
99	-.098	.4070	.5056
100	-.131	.3848	.5162
101	-.131	.4062	.5376
102	-.032	.3936	.4264
103	.0657	.3609	.2952
104	.0985	.3976	.2990
105	.0328	.4043	.3714
106	0	.4172	.4172
107	0	.3877	.3877
108	-.065	.3218	.3875
109	-.131	.3855	.5170

AVERAGE ERROR ANGLE = .0588592559
STANDARD DEVIATION = .455759259

Table 6.5: Hanscom Approach 1, WX Error Angles Continued

End approach

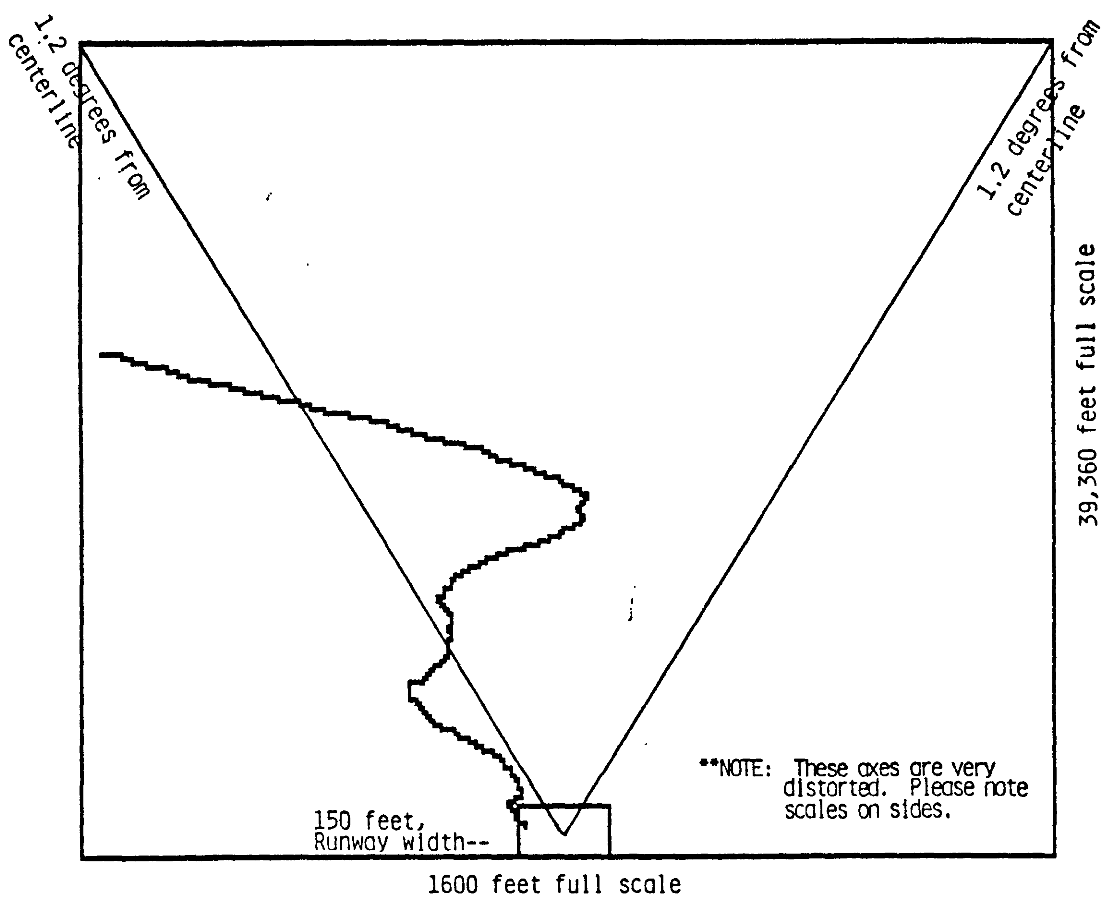

Figure 6.5: Hanscom Approach 2, WX LORAN Path

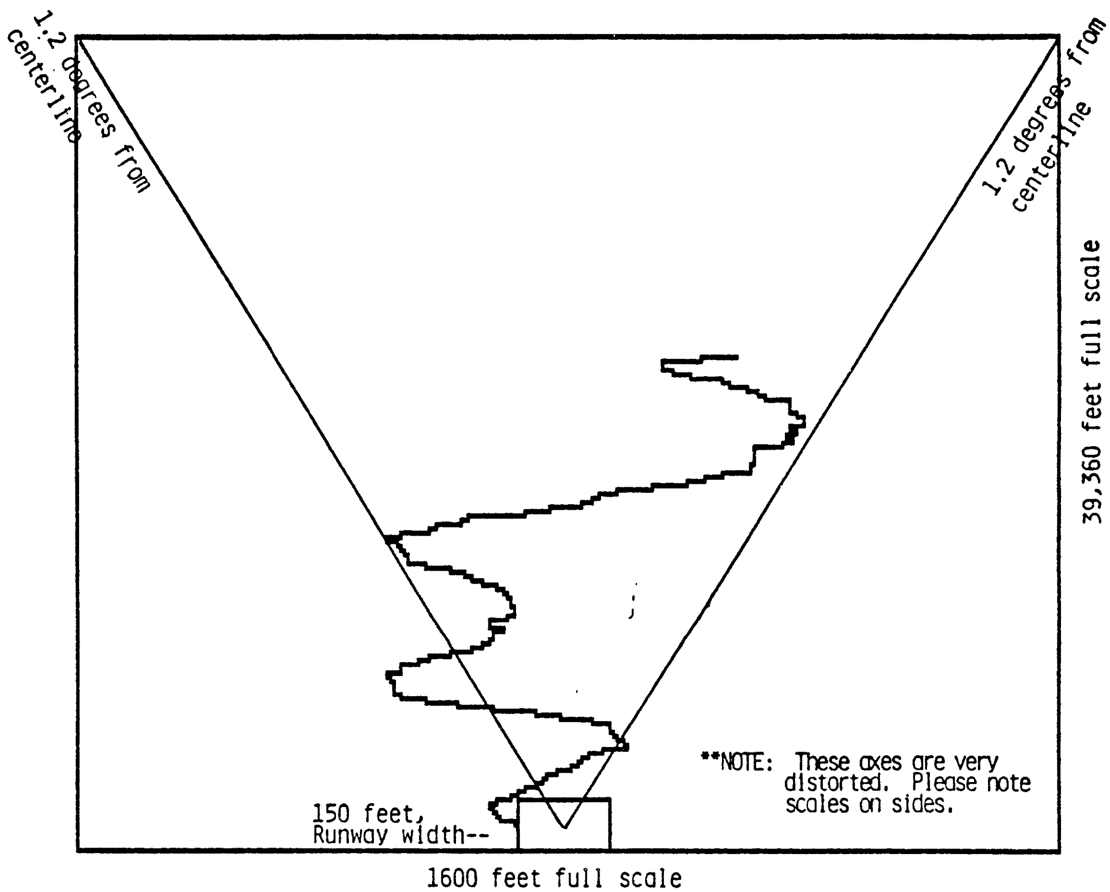

Figure 6.6: Hanscom Approach 2, WX Localizer Path

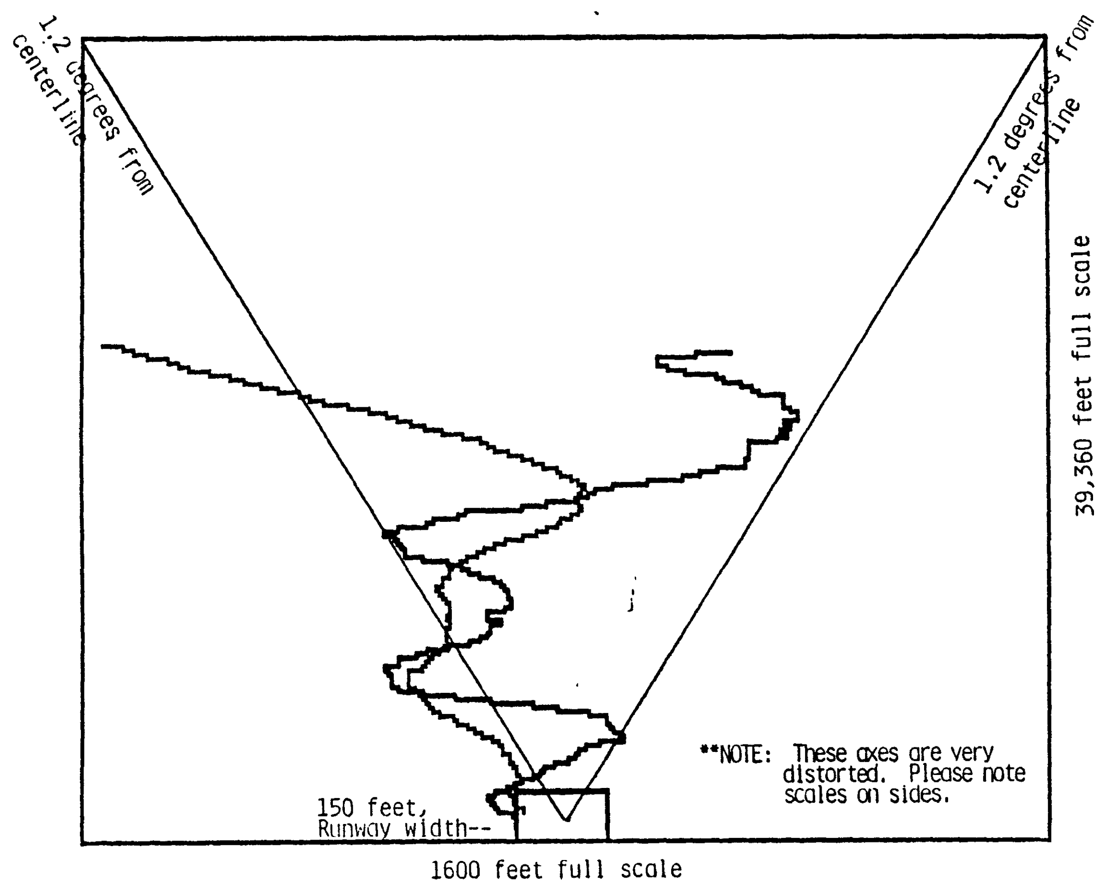

Figure 6.7: Hanscom Approach 2, WX Combined Paths

This is the data for BED AP2 WX2

# PNT	LOCALIZER ANGLE	LORAN ANGLE	DIFFERENCE LORAN-LOC
1	.5914	1.389	.7980
2	4.048	1.336	-2.71
3	-.521	1.280	1.801
4	-.295	1.218	1.514
5	-.295	1.166	1.462
6	-.328	1.111	1.440
7	-.394	1.053	1.447
8	-.490	.9718	1.462
9	-.521	.9178	1.439
10	-.582	.8627	1.445
11	-.613	.7944	1.407
12	-.644	.7163	1.360
13	-.736	.6500	1.386
14	-.736	.5958	1.331
15	-.766	.5232	1.289
16	-.797	.4825	1.279
17	-.797	.4164	1.213
18	-.766	.3470	1.113
19	-.797	.2935	1.090
20	-.766	.2423	1.009
21	-.797	.2014	.9987
22	-.766	.1412	.9078
23	-.674	.1152	.7899
24	-.674	.0659	.7406
25	-.674	.0252	.6999
26	-.674	9.917	.6756
27	-.674	-.035	.6392
28	-.582	-.055	.5275
29	-.521	-.082	.4384
30	-.46	-.075	.3843
31	-.328	-.066	.2623
32	-.197	-.048	.1485
33	-.131	-.062	.0686
34	-.065	-.077	-.012
35	.0657	-.068	-.133
36	.1642	8.586	-.155
37	.3942	.0232	-.371

Begin approach

Table 6.6: Hanscom Approach 2, WX Error Angles

38	.4271	.0725	-.354
39	.5257	.1119	-.413
40	.5585	.1717	-.386
41	.69	.2522	-.437
42	.7557	.3034	-.452
43	.7228	.3557	-.367
44	.69	.3837	-.306
45	.69	.4378	-.252
46	.69	.4673	-.222
47	.6242	.5025	-.121
48	.5257	.5292	3.541
49	.46	.5392	.0792
50	.4271	.5669	.1398
51	.3942	.5871	.1928
52	.3285	.6228	.2942
53	.2957	.6120	.3162
54	.2628	.6037	.3409
55	.2628	.5953	.3324
56	.2628	.5867	.3238
57	.2628	.5909	.3281
58	.2957	.5850	.2893
59	.3942	.6133	.2190
60	.3942	.6075	.2132
61	.3285	.6229	.2943
62	.3942	.6388	.2445
63	.3942	.6518	.2576
64	.46	.6621	.2021
65	.5257	.6725	.1468
66	.6571	.6898	.0327
67	.7885	.7224	-.066
68	.8542	.7641	-.090
69	.9741	.8104	-.163
70	.9741	.8355	-.138
71	1.082	.8754	-.206
72	1.082	.9766	-.105
73	1.082	.9801	-.102
74	1.082	1.003	-.078
75	1.055	1.015	-.039
76	.92	.9845	.0645
77	.7228	.9790	.2561

Table 6.7: Hanscom Approach 2, WX Error Angles Continued

78	.4928	.9734	.4805
79	.1971	.9580	.7608
80	.0328	.9241	.8912
81	-.197	.8850	1.082
82	-.328	.8015	1.130
83	-.328	.7778	1.106
84	-.394	.7236	1.117
85	-.46	.6718	1.131
86	-.490	.6534	1.144
87	-.295	.5781	.8738
88	-.197	.5320	.7291
89	-.131	.5144	.6458
90	-.098	.5128	.6114
91	-.032	.4674	.5003
92	.0657	.4871	.4214
93	.1642	.4670	.3027
94	.2628	.4279	.1650
95	.3942	.4056	.0113
96	.46	.4256	-.034
97	.5585	.4966	-.061
98	.69	.5654	-.124
99	.7885	.5646	-.223
100	.7885	.5370	-.251
101	.7557	.5509	-.204
102	.7228	.5152	-.207
103	.5914	.4777	-.113

AVERAGE ERROR ANGLE = .1649
STANDARD DEVIATION = .4281

Table 6.8: Hanscom Approach 2, WX Error Angles Continued

End approach

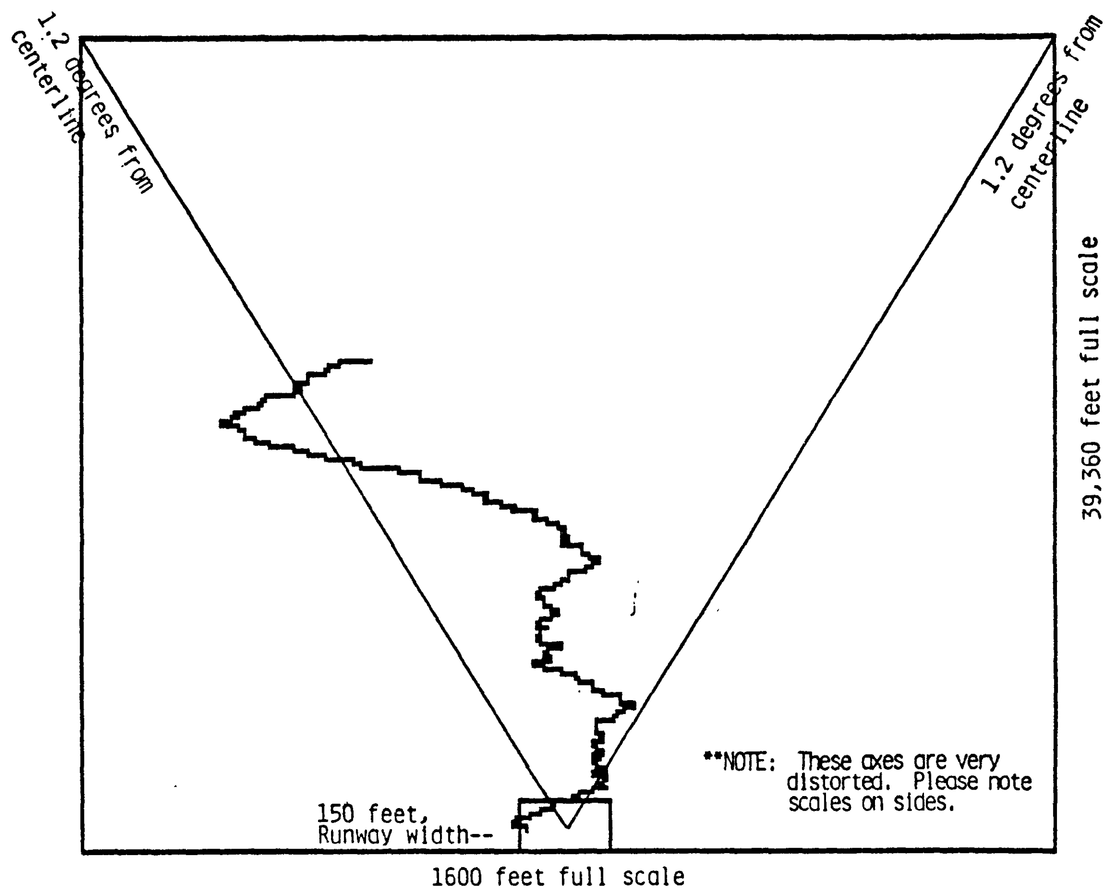

Figure 6.8: Hanscom Approach 3, XY LORAN Path

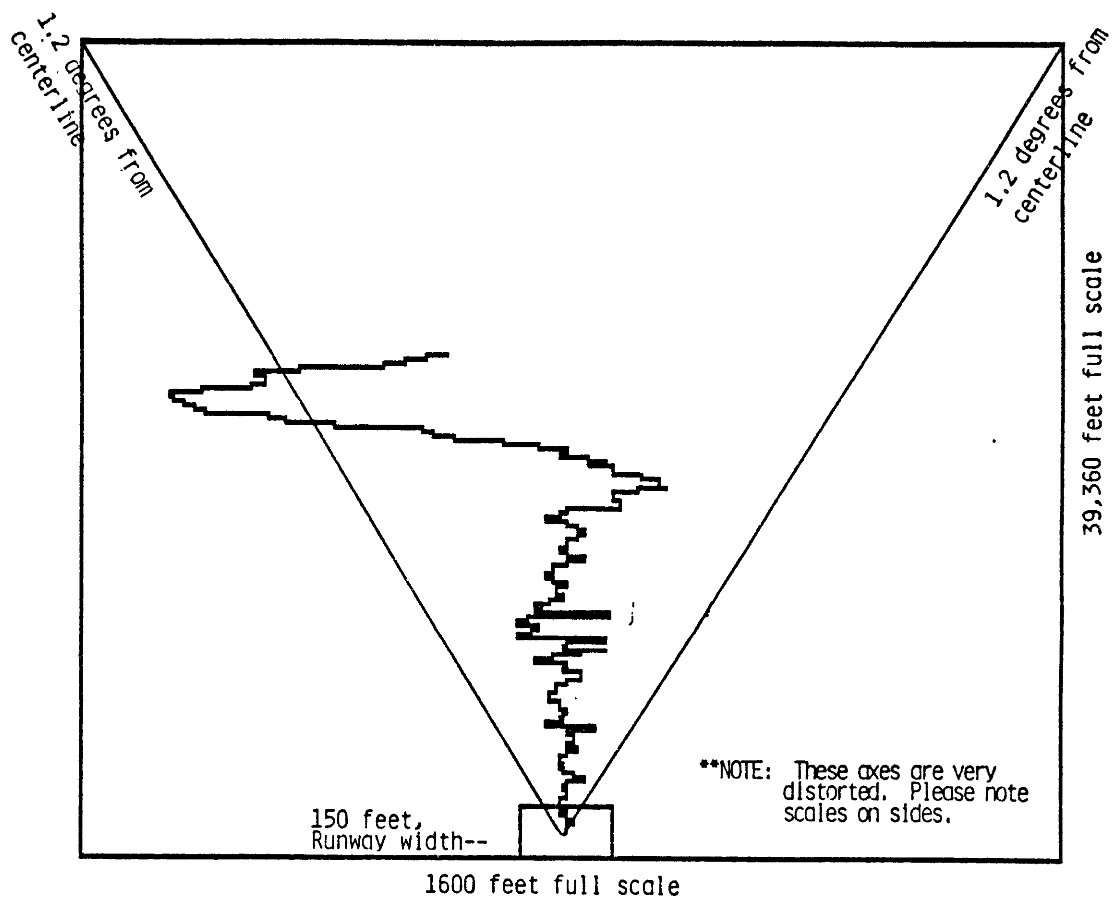

Figure 6.9: Hanscom Approach 3, XY Localizer Path

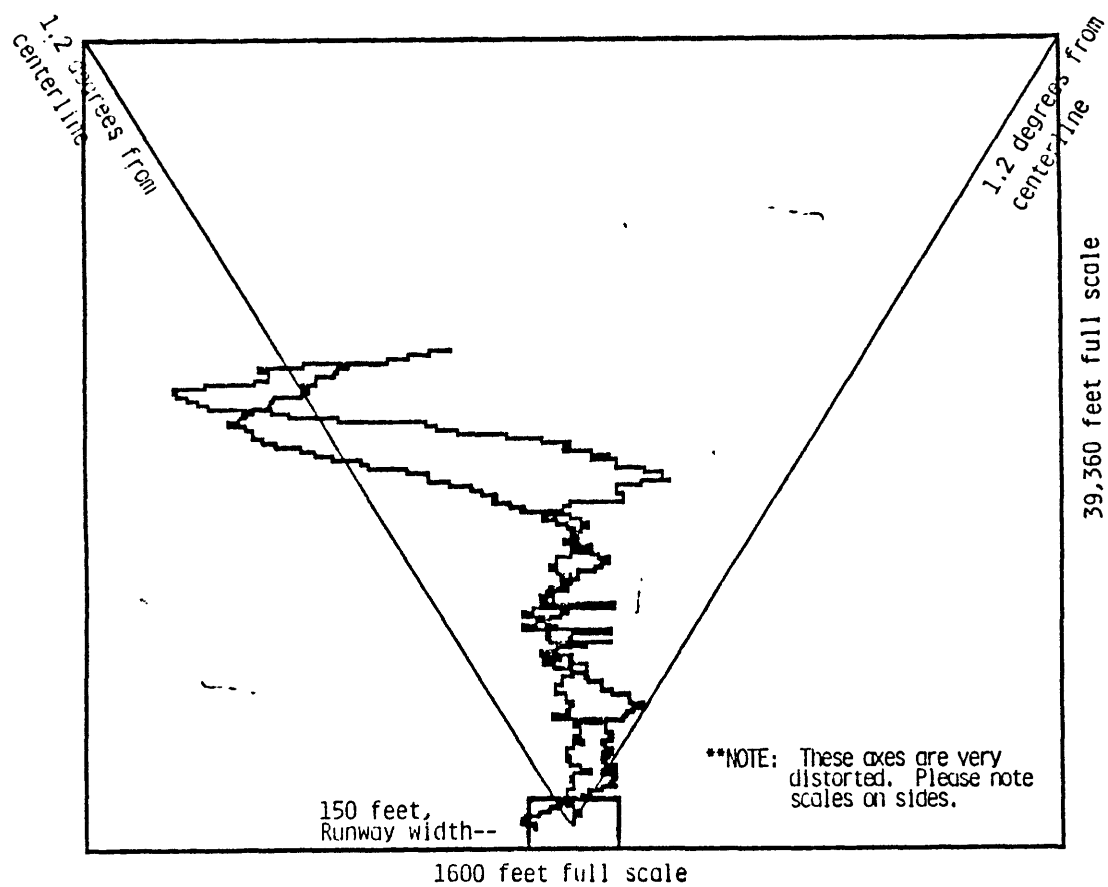

Figure 6.10: Hanscom Approach 3, XY Combined Paths

This is the data for BED AP3 XY1

# PNT	LOCALIZER ANGLE	LORAN ANGLE	DIFFERENCE LORAN-LOC
1	1.298	.5902	-.708
2	-2.55	.6255	3.176
3	.3614	.6912	.3297
4	.4271	.7340	.3069
5	.4928	.7529	.2600
6	.5585	.8084	.2498
7	.6571	.8097	.1525
8	.8214	.8603	.0388
9	.9741	.8500	-.124
10	.9470	.8768	-.070
11	.9470	.9665	.0195
12	1.001	.9945	-6.58
13	1.163	1.003	-.159
14	1.271	1.057	-.213
15	1.271	1.106	-.165
16	1.271	1.097	-.174
17	1.244	1.133	-.111
18	1.217	1.169	-.047
19	1.190	1.114	-.075
20	1.028	1.105	.0772
21	1.001	1.116	.1148
22	.9470	1.079	.1326
23	.7885	1.042	.2537
24	.4928	1.045	.5525
25	.46	.9659	.5059
26	.3942	.9276	.5333
27	.3285	.8673	.5387
28	.23	.7707	.5407
29	.0985	.7508	.6522
30	0	.7169	.7169
31	.0328	.6111	.5783
32	-.065	.5473	.6130
33	-.131	.5468	.6782
34	-.065	.4737	.5394
35	-.164	.3995	.5638
36	-.164	.3908	.5551
37	-.262	.3525	.6154

Begin approach

Table 6.9: Hanscom Approach 3, XY Error Angles

38	-.328	.3137	.6423
39	-.328	.3278	.6564
40	-.361	.2508	.6122
41	-.262	.2030	.4659
42	-.164	.2240	.3882
43	-.164	.1212	.2855
44	-.197	.1344	.3315
45	-.197	.0844	.2815
46	-.131	.0346	.1661
47	0	.0246	.0246
48	.0328	5.648	-.027
49	.0985	.0207	-.077
50	0	-6.34	-6.34
51	-.032	.0155	.0484
52	-.065	-.012	.0536
53	-.065	-.072	-7.27
54	-.032	-.067	-.034
55	0	-.095	-.095
56	0	-.142	-.142
57	.0328	-.120	-.153
58	0	-.113	-.113
59	-.065	-.081	-.016
60	-.065	-.013	.0524
61	0	-7.86	-7.86
62	.0657	-.010	-.076
63	.0657	.0316	-.034
64	.0985	.0562	-.042
65	.0657	.1277	.0620
66	.0657	.1447	.0790
67	0	.1429	.1429
68	.0657	.1125	.0468
69	.0657	.1208	.0551
70	.0328	.0792	.0463
71	.0985	.0383	-.060
72	.1642	.0461	-.118
73	.1314	.0837	-.047
74	.1642	.1314	-.032
75	-.197	.1498	.3470
76	.1971	.0981	-.099
77	.2628	.1458	-.116

Table 6.10: Hanscom Approach 3, XY Error Angles Continued

78	.2628	.1339	-.128
79	.1642	.1546	-9.65
80	.1971	.1425	-.054
81	.2628	.1418	-.121
82	-.197	.0311	.2282
83	0	.1048	.1048
84	.0328	.1366	.1038
85	-.197	.0905	.2876
86	-.065	.0877	.1534
87	.0985	.1882	.0897
88	.1971	.1303	-.066
89	0	.0367	.0367
90	.0328	-1.13	-.032
91	-.065	-.050	.0152
92	-.065	-.066	-5.68
93	-.065	-.154	-.088
94	0	-.160	-.160
95	.0657	-.191	-.257
96	.0657	-.246	-.312
97	.1314	-.354	-.486
98	.1314	-.351	-.482
99	.1314	-.357	-.489
100	.0657	-.456	-.522
101	.0657	-.387	-.453
102	0	-.357	-.357
103	.0328	-.336	-.369
104	.0657	-.263	-.328
105	.0328	-.203	-.236
106	.1642	-.211	-.375
107	-.197	-.218	-.021
108	0	-.283	-.283
109	-.032	-.262	-.229
110	-.032	-.270	-.237
111	-.032	-.217	-.185
112	0	-.240	-.240
113	-.065	-.295	-.229
114	0	-.211	-.211
115	.0657	-.267	-.332
116	.0657	-.228	-.294
117	.0328	-.268	-.301

Table 6.11: Hanscom Approach 3, XY Error Angles Continued

118	.0657	-.343	-.409
119	.0328	-.218	-.251
120	-.032	-.330	-.297
121	-.131	-.371	-.240
122	0	-.344	-.344
123	.0328	-.299	-.332
124	0	-.382	-.382
125	0	-.246	-.246
126	.0328	-.120	-.153
127	.0985	-.050	-.148
128	.0985	-.017	-.116
129	.0985	.1164	.0178
130	0	.1561	.1561
131	.0985	.2789	.1803
132	.0328	.3862	.3534
133	-.065	.4127	.4784
134	0	.5712	.5712
135	.0328	.6236	.5907
136	0	.4735	.4735

AVERAGE ERROR ANGLE = .0407962196
STANDARD DEVIATION = .304846632

Table 6.12: Hanscom Approach 3, XY Error Angles Continued

End approach

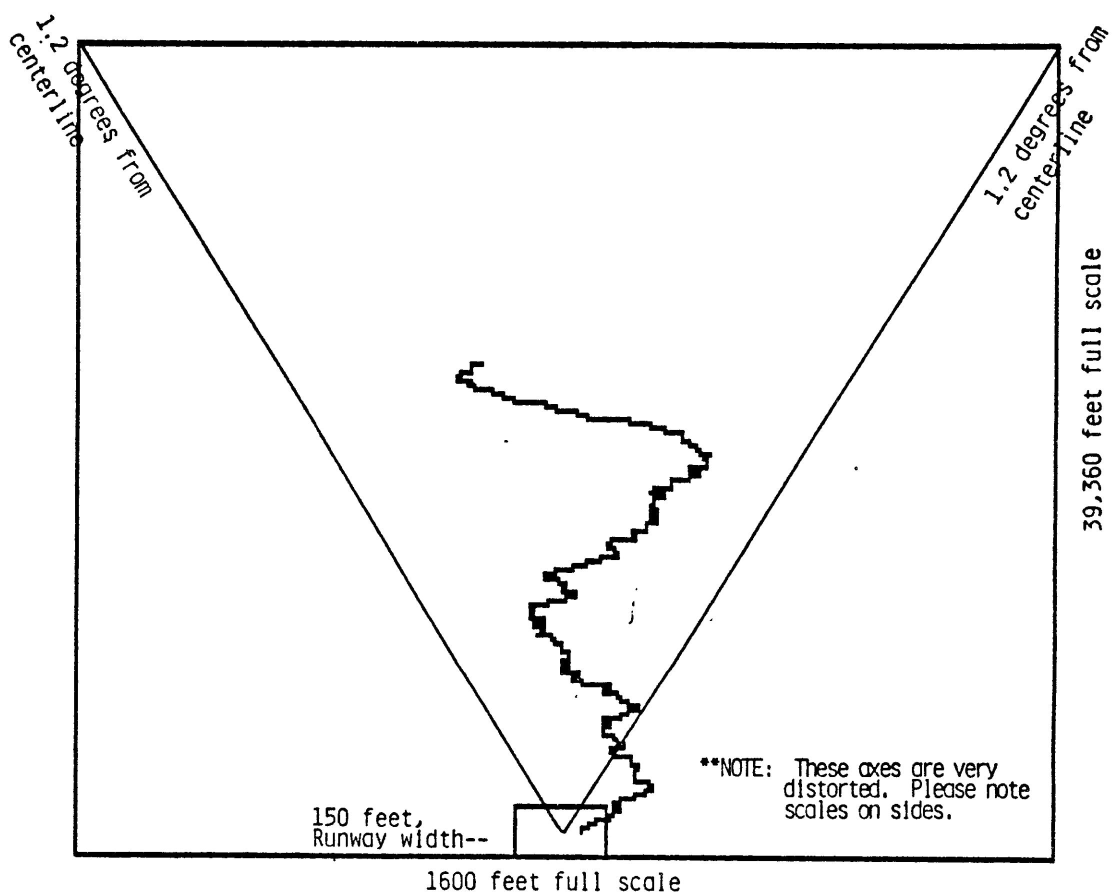

Figure 6.11: Hanscom Approach 4, XY LORAN Path

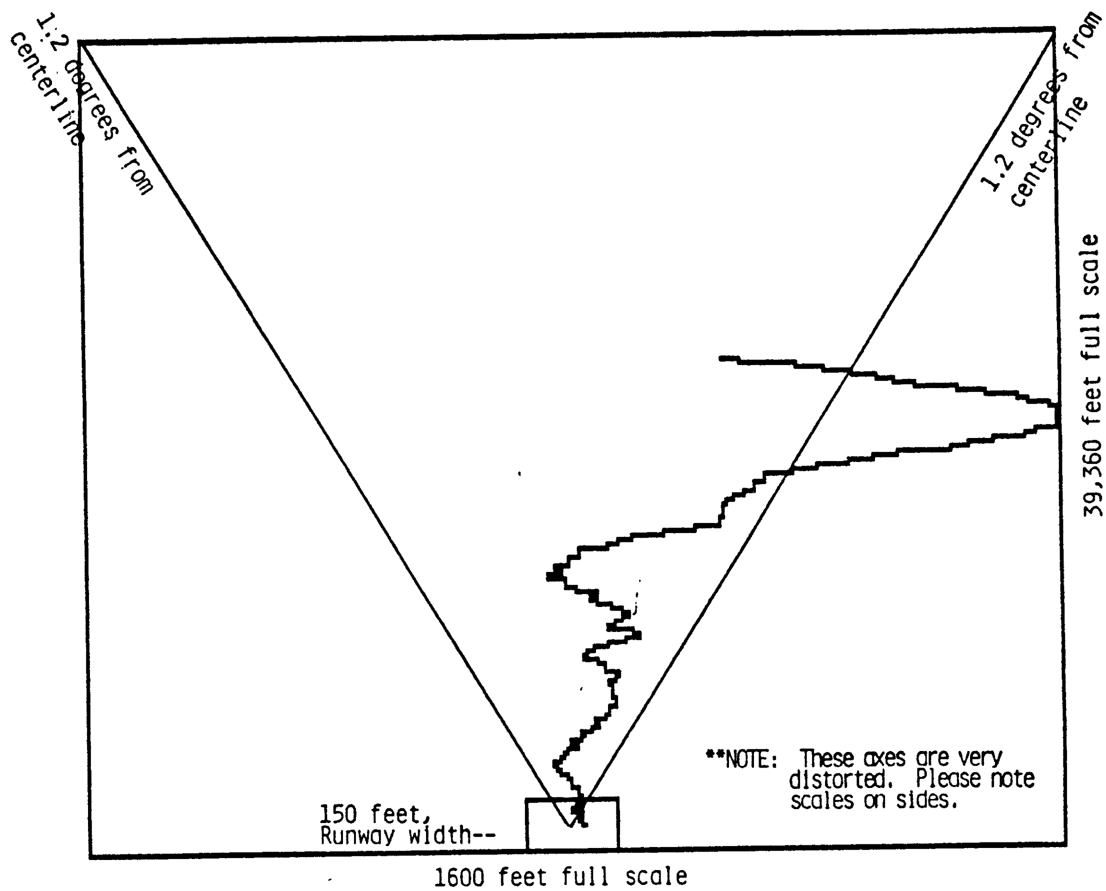

Figure 6.12: Hanscom Approach 4, XY Localizer Path

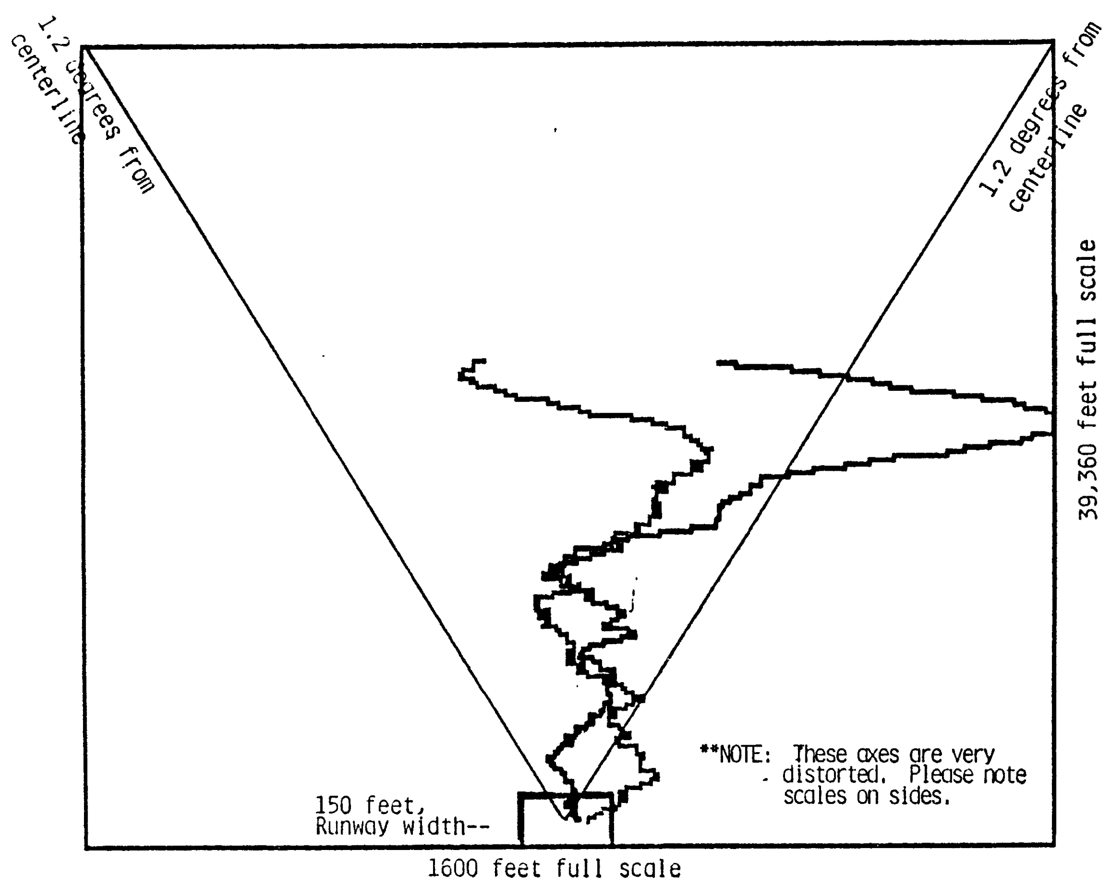

Figure 6.13: Hanscom Approach 4, XY Combined Paths

This is the data for BED AP4 XY2

# PNT	LOCALIZER ANGLE	LORAN ANGLE	DIFFERENCE LORAN-LOC
1	1.298	.2480	-1.05
2	-2.55	.2873	2.838
3	-.46	.2862	.7462
4	-.521	.3198	.8411
5	-.613	.3302	.9436
6	-.705	.2867	.9920
7	-.797	.3028	1.100
8	-.889	.2826	1.171
9	-.974	.2254	1.199
10	-1.02	.1910	1.219
11	-1.10	.1630	1.272
12	-1.24	.0656	1.310
13	-1.35	.0244	1.377
14	-1.45	-.043	1.413
15	-1.50	-.073	1.434
16	-1.58	-.168	1.415
17	-1.66	-.219	1.441
18	-1.71	-.284	1.427
19	-1.76	-.343	1.419
20	-1.76	-.396	1.366
21	-1.73	-.403	1.334
22	-1.61	-.430	1.179
23	-1.58	-.464	1.120
24	-1.48	-.478	1.004
25	-1.40	-.520	.8854
26	-1.35	-.498	.8540
27	-1.29	-.506	.7919
28	-1.19	-.513	.6769
29	-1.10	-.457	.6515
30	-1.02	-.500	.5281
31	-.92	-.457	.4620
32	-.828	-.401	.4262
33	-.736	-.394	.3414
34	-.736	-.343	.3921
35	-.705	-.327	.3773
36	-.705	-.386	.3191
37	-.674	-.349	.3251

Begin approach

Table 6.13: Hanscom Approach 4, XY Error Angles

38	-.644	-.341	.3023
39	-.613	-.333	.2797
40	-.613	-.363	.2494
41	-.613	-.341	.2717
42	-.613	-.373	.2396
43	-.613	-.334	.2783
44	-.613	-.335	.2780
45	-.521	-.288	.2331
46	-.394	-.295	.0985
47	-.262	-.212	.0498
48	-.197	-.203	-6.08
49	-.164	-.184	-.019
50	-.065	-.214	-.148
51	-.032	-.229	-.196
52	-.032	-.160	-.127
53	0	-.097	-.097
54	0	-.042	-.042
55	.0657	.0373	-.028
56	.0328	.0941	.0612
57	.0985	.0268	-.071
58	.0328	.0214	-.011
59	.0328	-2.42	-.035
60	-.032	.0104	.0432
61	-.131	-.051	.0798
62	-.098	-1.15	.0974
63	-.131	.0769	.2083
64	-.197	.1656	.3627
65	-.262	.1507	.4136
66	-.295	.1658	.4615
67	-.262	.1030	.3659
68	-.23	.1474	.3774
69	-.197	.0925	.2897
70	-.328	.1158	.4444
71	-.361	.1314	.4928
72	-.295	.0745	.3702
73	-.197	.0475	.2447
74	-.197	.0184	.2155
75	-.131	1.886	.1333
76	-.098	-.026	.0716
77	-.065	-.023	.0419
78	-.164	1.871	.1661

Table 6.14: Hanscom Approach 4, XY Error Angles Continued

79	-.197	-.040	.1570
80	-.197	7.326	.2044
81	-.295	-.091	.2044
82	-.262	-.054	.2086
83	-.23	-.122	.1070
84	-.262	-.191	.0713
85	-.262	-.299	-.036
86	-.262	-.251	.0109
87	-.295	-.350	-.054
88	-.295	-.376	-.080
89	-.262	-.429	-.166
90	-.262	-.495	-.232
91	-.23	-.435	-.205
92	-.164	-.385	-.221
93	-.197	-.281	-.084
94	-.131	-.324	-.192
95	-.065	-.301	-.235
96	-.098	-.290	-.191
97	-.065	-.377	-.312
98	0	-.411	-.411
99	-.032	-.476	-.443
100	.0328	-.378	-.411
101	.0657	-.413	-.479
102	.0985	-.542	-.641
103	.1642	-.552	-.716
104	.1314	-.643	-.775
105	.0985	-.622	-.721
106	.0328	-.619	-.651
107	0	-.647	-.647
108	0	-.780	-.780
109	-.065	-.813	-.747
110	-.065	-.776	-.710
111	-.098	-.678	-.580
112	-.032	-.559	-.526
113	-.098	-.495	-.397
114	0	-.589	-.589
115	-.098	-.523	-.424
116	-.065	-.516	-.450
117	-.098	-.380	-.281
118	-.131	-.216	-.085

AVERAGE ERROR ANGLE = .238602091
STANDARD DEVIATION = .594133246

Table 6.15: Hanscom Approach 4, XY Error Angles Continued

End approach

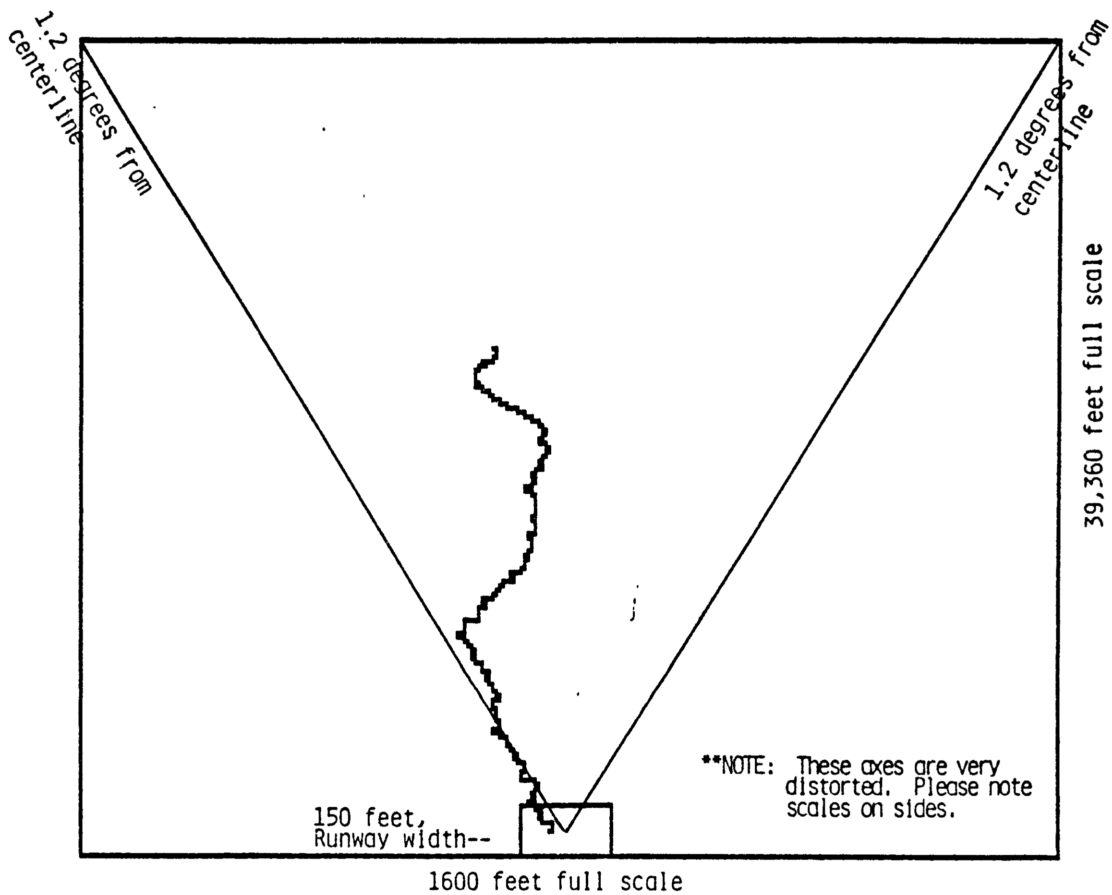

Figure 6.14: Hanscom Approach 5, WX LORAN Path

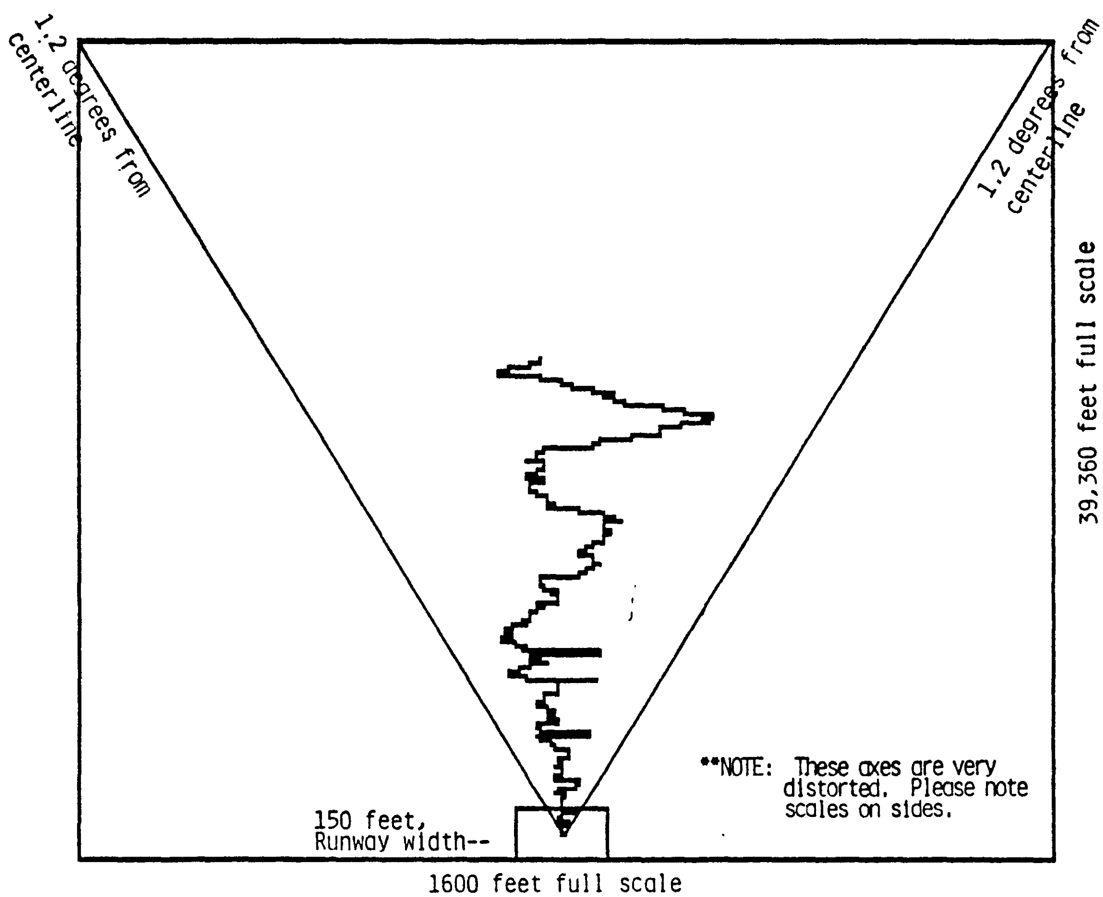

Figure 6.15: Hanscom Approach 5, WX Localizer Path

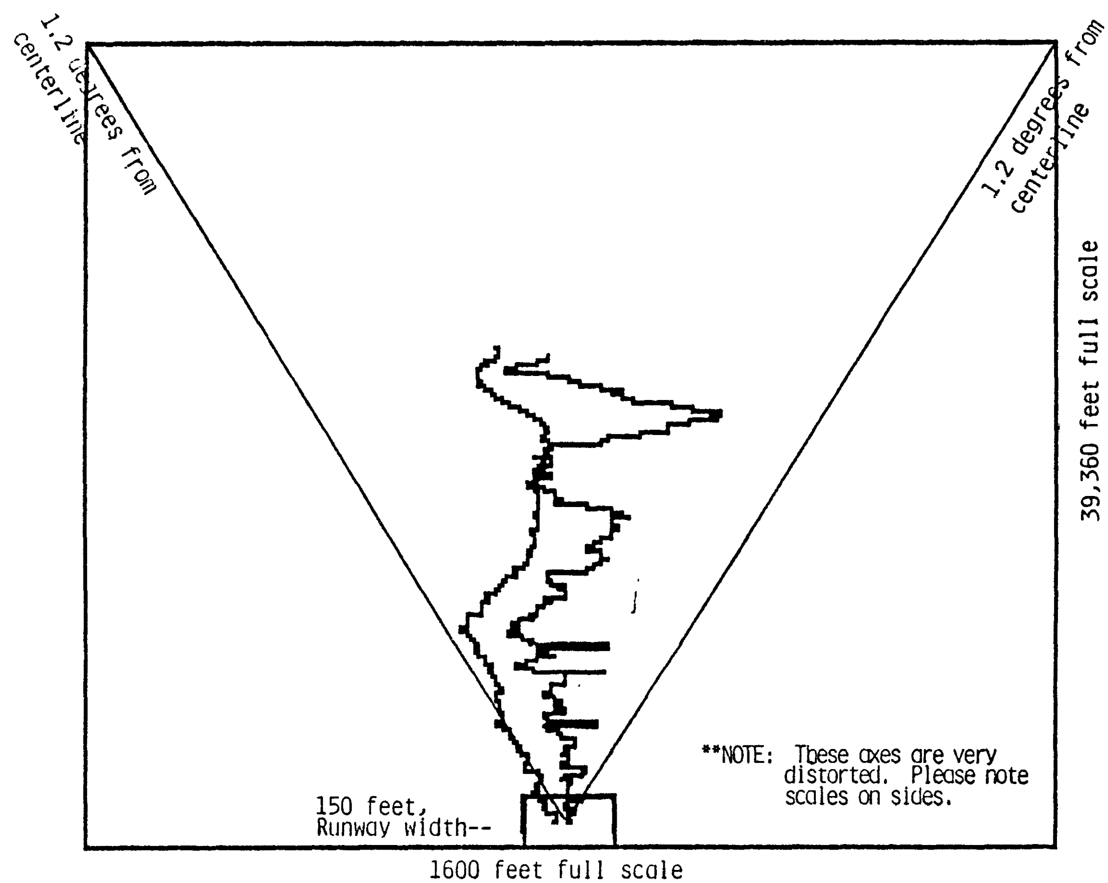

Figure 6.16: Hanscom Approach 5, WX Combined Paths

# PNT	LOCALIZER ANGLE	LORAN ANGLE	DIFFERENCE LORAN-LOC
1	-.098	.2232	.3218
2	-2.46	.2143	2.681
3	.0657	.2190	.1533
4	.0657	.2237	.1580
5	.0657	.2562	.1905
6	.0985	.2534	.1548
7	.1642	.2768	.1126
8	.1971	.2899	.0928
9	.1314	.2935	.1620
10	.0657	.2908	.2251
11	0	.2766	.2766
12	-.032	.2918	.3246
13	-.098	.2728	.3714
14	-.164	.2519	.4162
15	-.131	.2472	.3786
16	-.164	.2176	.3819
17	-.197	.2024	.3996
18	-.262	.1777	.4405
19	-.328	.1694	.4980
20	-.394	.1404	.5347
21	-.490	.1178	.6085
22	-.46	.0968	.5568
23	-.490	.0890	.5797
24	-.394	.0867	.4810
25	-.328	.0787	.4073
26	-.328	.0951	.4237
27	-.295	.1029	.3986
28	-.23	.0790	.3090
29	-.131	.0798	.2112
30	-.098	.0735	.1720
31	0	.0832	.0832
32	.0657	.0879	.0222
33	.0985	.1071	8.568
34	.0985	.0916	-6.96
35	.1314	.1057	-.025
36	.0657	.1180	.0523
37	.0657	.1326	.0668

Begin approach

Table 6.16: Hanscom Approach 5, WX Error Angles

38	.0985	.1283	.0297
39	.1314	.1335	2.154
40	.1314	.1643	.0329
41	.0657	.1678	.1021
42	.1314	.1463	.0148
43	.1314	.1321	7.239
44	.1314	.1298	-1.59
45	.0985	.1353	.0367
46	.0657	.1308	.0651
47	.0657	.1385	.0728
48	.0328	.1442	.1114
49	.0657	.1478	.0820
50	-.065	.1329	.1986
51	-.164	.1364	.3007
52	-.197	.1422	.3393
53	-.23	.1625	.3925
54	-.164	.1495	.3138
55	-.164	.1594	.3237
56	-.197	.1548	.3519
57	-.197	.1648	.3620
58	-.164	.1750	.3393
59	-.164	.1878	.3521
60	-.131	.1696	.3011
61	-.131	.1866	.3180
62	-.098	.1948	.2934
63	-.065	.2122	.2779
64	-.131	.2208	.3522
65	-.131	.2644	.3959
66	-.164	.2567	.4210
67	-.131	.2978	.4292
68	-.098	.3140	.4126
69	-.065	.3185	.3843
70	0	.3352	.3352
71	.0985	.3590	.2605
72	.0985	.4009	.3023
73	.0985	.4159	.3174
74	.0328	.4019	.3691
75	.0657	.4425	.3767
76	.0328	.4399	.4070
77	.0328	.4401	.4073

Table 6.17: Hanscom Approach 5, WX Error Angles Continued

78	.1314	.4589	.3275
79	.0985	.4853	.3868
80	.1314	.5297	.3983
81	.1642	.5409	.3767
82	.1642	.5479	.3836
83	.1971	.5654	.3683
84	.1971	.5803	.3831
85	.2628	.5513	.2885
86	.2957	.5663	.2706
87	.2628	.5459	.2831
88	.2628	.5252	.2624
89	.3285	.5120	.1835
90	.2628	.5335	.2707
91	.1971	.5378	.3406
92	.23	.5276	.2976
93	-.197	.5025	.6996
94	.1971	.5066	.3094
95	.1314	.4991	.3677
96	.0985	.4680	.3694
97	.1971	.4685	.2713
98	.2628	.4878	.2249
99	.3285	.4851	.1565
100	.23	.4858	.2558
101	-.197	.4583	.6555
102	.0328	.4693	.4365
103	.0328	.4573	.4244
104	.0328	.4323	.3994
105	.1314	.4434	.3119
106	.1314	.4844	.3530
107	.1314	.4926	.3612
108	.1642	.5047	.3404
109	.1314	.4864	.3550
110	.0985	.4852	.3866
111	.0657	.4976	.4319
112	.0985	.5144	.4158
113	.0328	.4913	.4585
114	.1642	.5003	.3360
115	.1971	.5424	.3452
116	.1642	.5042	.3400
117	-.197	.4947	.6919

Table 6.18: Hanscom Approach 5, WX Error Angles Continued

118	.1971	.4616	.2644
119	.1642	.4750	.3107
120	.0985	.4691	.3705
121	.0657	.4630	.3973
122	0	.4277	.4277
123	-.032	.4165	.4493
124	-.032	.4302	.4630
125	.0328	.4186	.3858
126	0	.3689	.3689
127	.0657	.3562	.2905
128	0	.3944	.3944
129	0	.4039	.4039
130	.0657	.4136	.3479
131	-.065	.3652	.4309
132	-.131	.3052	.4366
133	-.098	.2904	.3890
134	.0328	.3073	.2744
135	.0657	.3246	.2589
136	-.032	.3425	.3754
137	0	.3360	.3360
138	0	.3854	.3854
139	.0328	.4107	.3778
140	.0657	.3584	.2927
141	-.131	.2895	.4210
142	0	.3028	.3028
143	.0657	.3164	.2507
144	-.032	.2869	.3197
145	-.065	.2220	.2877
146	0	.1836	.1836
147	0	.1669	.1669
148	-.032	.2155	.2484

AVERAGE ERROR ANGLE = .307816709
STANDARD DEVIATION = .143478095

Table 6.19: Hanscom Approach 5, WX Error Angles Continued

End approach

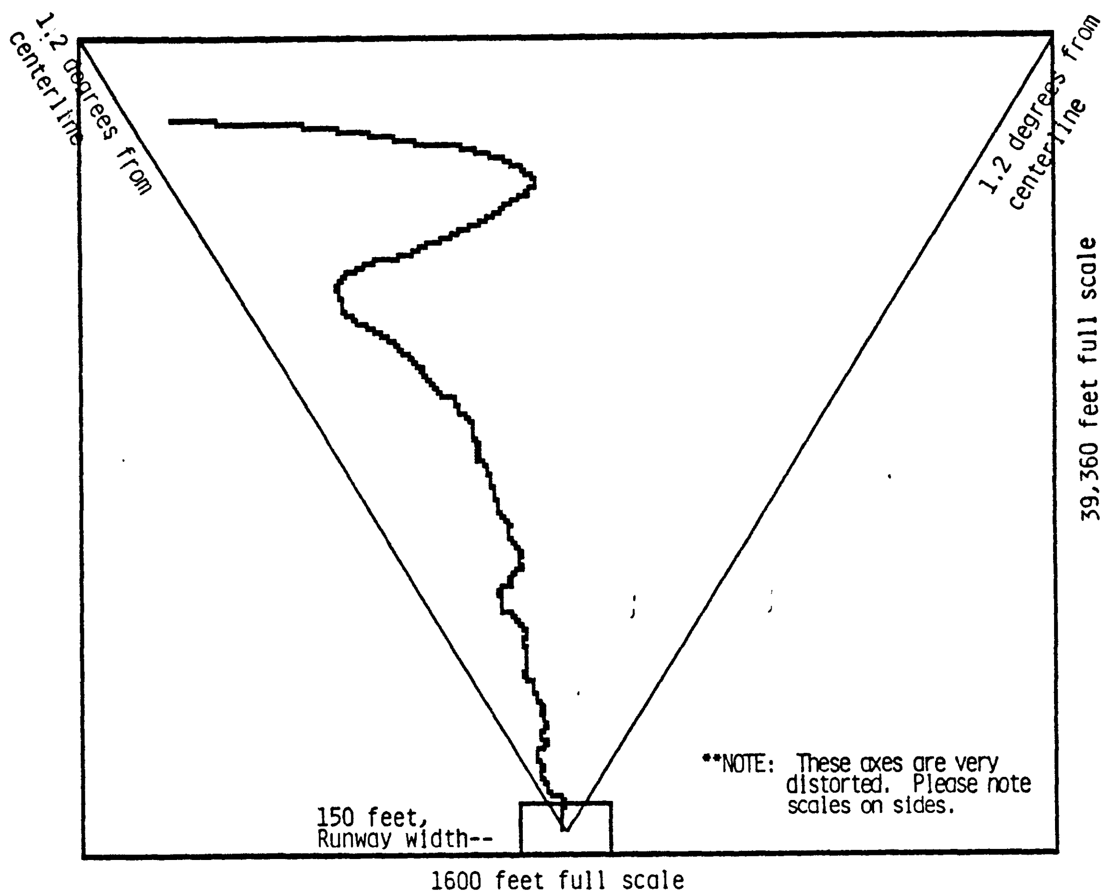

Figure 6.17: Newport Approach 1, XY LORAN Path

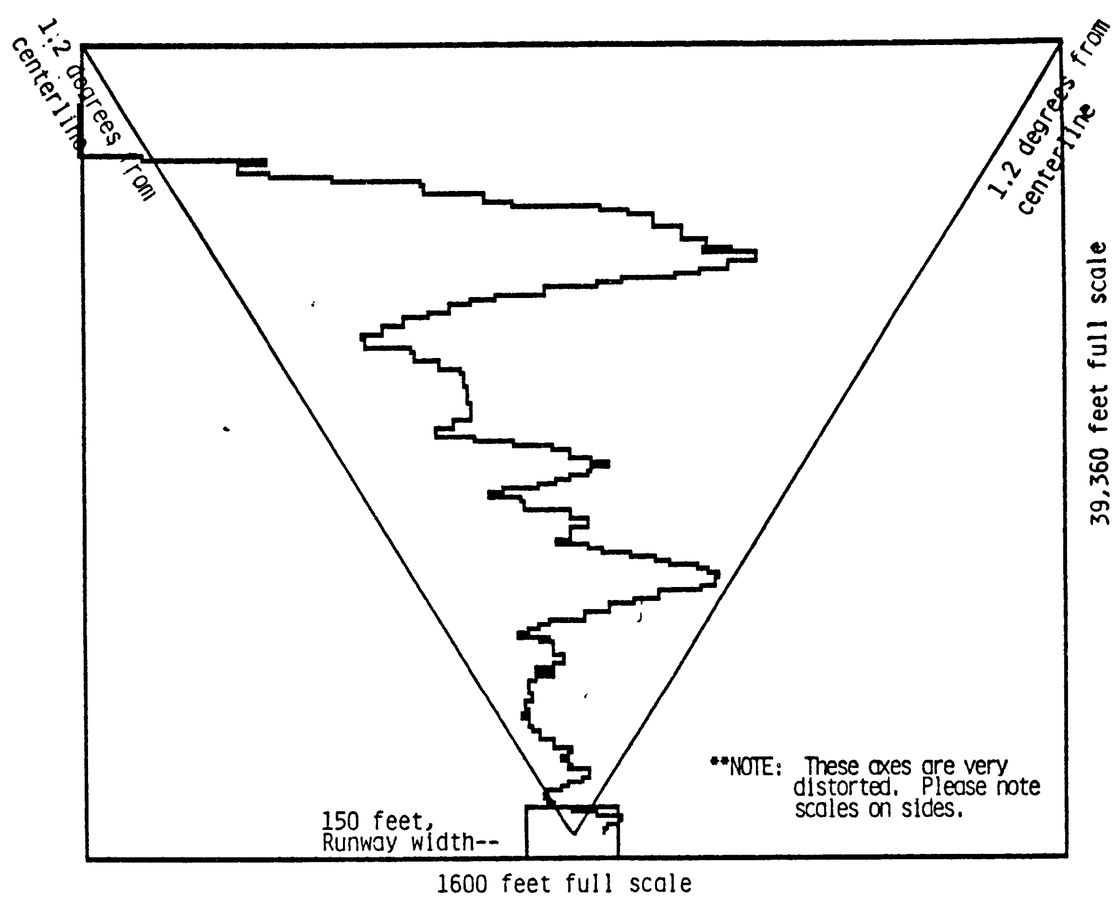

Figure 6.18: Newport Approach 1, XY Localizer Path

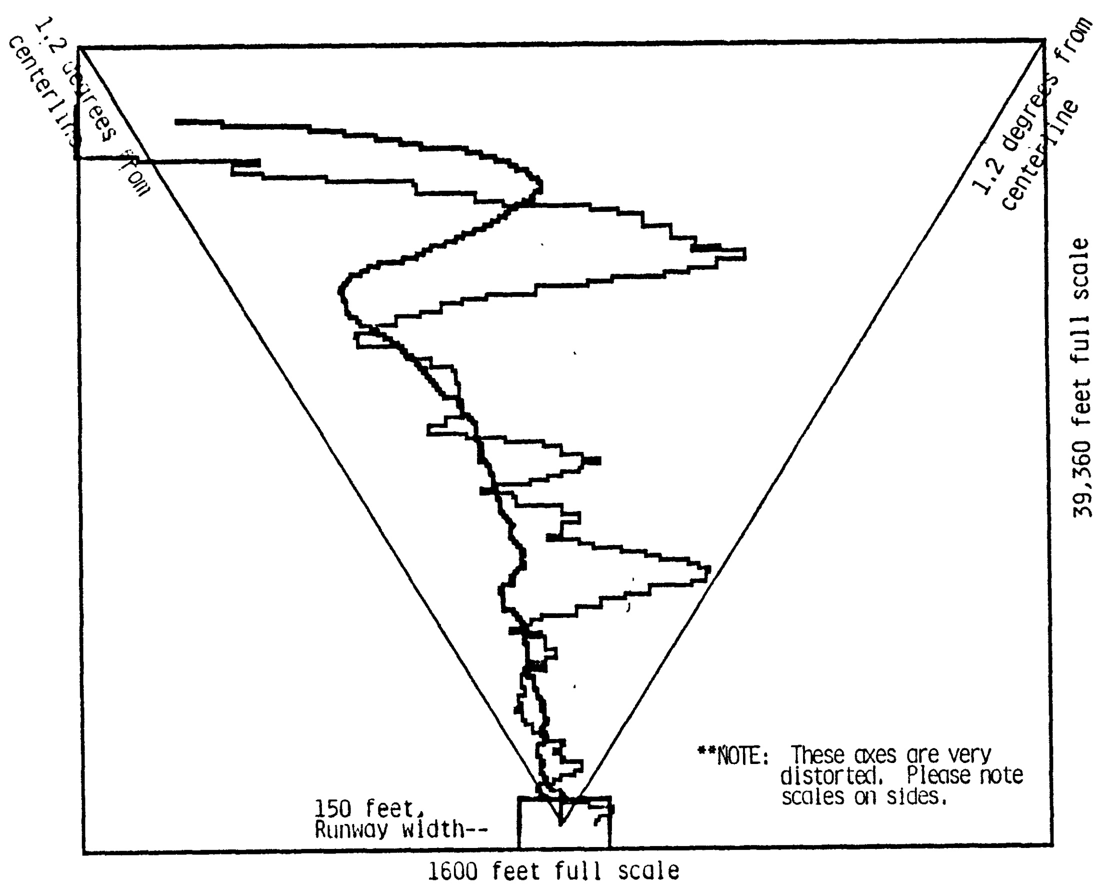

Figure 6.19: Newport Approach 1, XY Combined Paths

# PNT	LOCALIZER ANGLE	LORAN ANGLE	DIFFERENCE LORAN-LOC
1	2.807	.9752	-1.83
2	-6.40	.8662	7.273
3	1.902	.7584	-1.14
4	1.902	.6593	-1.24
5	1.823	.5714	-1.25
6	1.744	.4970	-1.24
7	1.665	.4375	-1.22
8	1.506	.3814	-1.12
9	1.506	.3228	-1.18
10	1.506	.2655	-1.24
11	1.506	.2293	-1.27
12	1.506	.1997	-1.30
13	1.427	.1615	-1.26
14	1.427	.1410	-1.28
15	1.506	.1169	-1.38
16	1.347	.1032	-1.24
17	1.11	.0912	-1.01
18	.7928	.0844	-.708
19	.8721	.0808	-.791
20	.8721	.0960	-.776
21	.7928	.1106	-.682
22	.6342	.1058	-.528
23	.3964	.1289	-.267
24	.3964	.1474	-.249
25	.3964	.1771	-.219
26	.3964	.1871	-.209
27	.2378	.2000	-.037
28	.2378	.2264	-.011
29	.1585	.2496	.0910
30	-.079	.2808	.3601
31	-.158	.3146	.4732
32	-.237	.3295	.5674
33	-.237	.3655	.6033
34	-.237	.4084	.6462
35	-.317	.4336	.7507
36	-.317	.4628	.7800
37	-.317	.5043	.8215

Begin approa

Table 6.20: Newport Approach 1, XY Error Angles

38	-.396	.5478	.9442
39	-.396	.5851	.9816
40	-.475	.6215	1.097
41	-.396	.6505	1.047
42	-.555	.6813	1.236
43	-.555	.7042	1.259
44	-.475	.7190	1.194
45	-.475	.7314	1.207
46	-.396	.7271	1.123
47	-.317	.7298	1.047
48	-.158	.7284	.8869
49	-.079	.7340	.8133
50	.0792	.7326	.6533
51	.0792	.7283	.6491
52	.2378	.7138	.4759
53	.3171	.7079	.3907
54	.3964	.7136	.3171
55	.3964	.6793	.2829
56	.3964	.6596	.2632
57	.4757	.6336	.1579
58	.555	.6193	.0643
59	.555	.6020	.0470
60	.6342	.5844	-.049
61	.6342	.5755	-.058
62	.7135	.5621	-.151
63	.7135	.5546	-.158
64	.7135	.5437	-.169
65	.555	.5217	-.033
66	.555	.5363	-.018
67	.555	.5301	-.024
68	.4757	.5127	.0370
69	.4757	.5063	.0306
70	.3964	.4933	.0968
71	.3964	.4932	.0968
72	.3964	.4829	.0865
73	.3964	.4524	.0560
74	.3964	.4398	.0433
75	.3964	.4306	.0342
76	.3964	.4251	.0287
77	.3964	.4227	.0262

Table 6.21: Newport Approach 1, XY Error Angles Continued

78	.3964	.4024	6.034
79	.3964	.3927	-3.68
80	.3964	.3880	-8.42
81	.3964	.3812	-.015
82	.3964	.3822	-.014
83	.4757	.3905	-.085
84	.4757	.3895	-.086
85	.555	.3886	-.166
86	.555	.3782	-.176
87	.3964	.3942	-2.13
88	.2378	.3837	.1458
89	.2378	.3924	.1546
90	.0792	.3718	.2925
91	0	.3565	.3565
92	0	.3531	.3531
93	-.079	.3416	.4209
94	-.158	.3482	.5068
95	-.079	.3549	.4342
96	-.079	.3535	.4328
97	0	.3394	.3394
98	.0792	.3522	.2729
99	.1585	.3485	.1899
100	.3171	.3447	.0275
101	.3964	.3384	-.057
102	.2378	.3407	.1029
103	.2378	.3280	.0901
104	.2378	.3150	.0771
105	0	.2992	.2992
106	0	.2907	.2907
107	0	.3118	.3118
108	-.079	.3047	.3840
109	-.079	.3171	.3964
110	0	.3032	.3032
111	0	.2794	.2794
112	0	.2701	.2701
113	.0792	.2567	.1774
114	-.079	.2610	.3403
115	-.158	.2738	.4324
116	-.317	.2668	.5839
117	-.475	.2641	.7398

Table 6.22: Newport Approach 1, XY Error Angles Continued

118	-.555	.2979	.8529
119	-.713	.3221	1.035
120	-.792	.3439	1.136
121	-.872	.3449	1.217
122	-.872	.3813	1.253
123	-.872	.4185	1.290
124	-.872	.4426	1.314
125	-.792	.4195	1.212
126	-.555	.4329	.9879
127	-.555	.4351	.9901
128	-.396	.4258	.8223
129	-.237	.4163	.6541
130	-.237	.3881	.6259
131	-.079	.3591	.4384
132	-.079	.3326	.4119
133	.1585	.3089	.1503
134	.2378	.2901	.0523
135	.3171	.2977	-.019
136	.3964	.2947	-.101
137	.1585	.3347	.1761
138	.2378	.3395	.1017
139	.1585	.3236	.1650
140	.1585	.3345	.1760
141	.1585	.3242	.1656
142	.0792	.3355	.2563
143	.0792	.3393	.2600
144	.1585	.3554	.1968
145	.3171	.3678	.0507
146	.1585	.3766	.2180
147	.3171	.3547	.0376
148	.3964	.3162	-.080
149	.3964	.2969	-.099
150	.3964	.3258	-.070
151	.3964	.3012	-.095
152	.3964	.3049	-.091
153	.4757	.2616	-.214
154	.4757	.2469	-.228
155	.4757	.2597	-.215
156	.4757	.2968	-.178
157	.555	.2389	-.316

Table 6.23: Newport Approach 1, XY Error Angles Continued

158	.4757	.2470	-.228
159	.4757	.2160	-.259
160	.4757	.2556	-.220
161	.3964	.3177	-.078
162	.3964	.3192	-.077
163	.2378	.2470	9.205
164	.2378	.2914	.0536
165	0	.3444	.3444
166	.0792	.4109	.3316
167	.1585	.4018	.2433
168	.0792	.4171	.3379
169	0	.4077	.4077
170	.0792	.3494	.2701
171	-.237	.4269	.6648
172	-.237	.4091	.6469
173	-.158	.3981	.5566
174	.0792	.3255	.2462
175	.2378	.3507	.1128
176	.4757	.2709	-.204
177	.555	.1607	-.394
178	.555	.1020	-.452
179	.3964	.0383	-.358
180	0	.0182	.0182
181	-.555	.1104	.6654
182	-1.11	.1573	1.267
183	-1.11	.1402	1.250
184	-.872	.1475	1.019
185	-.872	.1281	1.000
186	-.872	.1866	1.058

AVERAGE ERROR ANGLE = .159461351
STANDARD DEVIATION = .608785016

Table 6.24: Newport Approach 1, XY Error Angles Continued

End approach

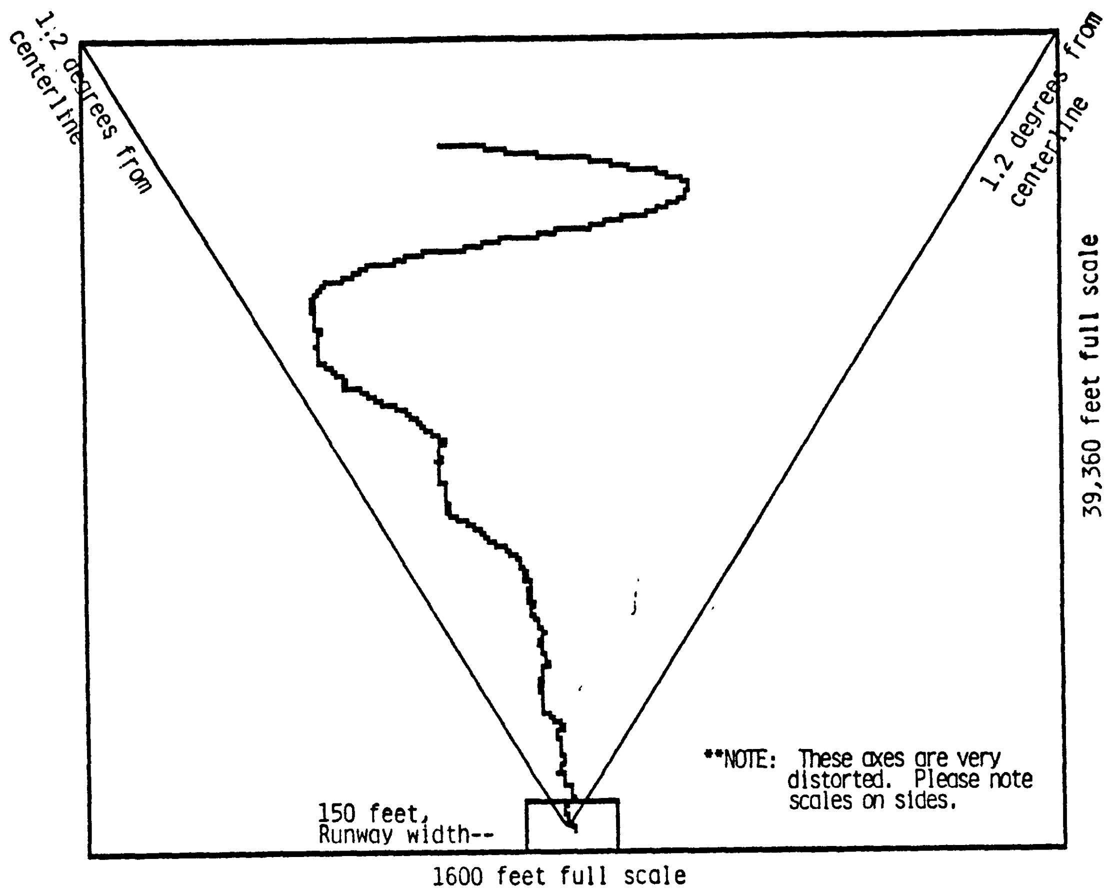

Figure 6.20: Newport Approach 2, XY LORAN Path

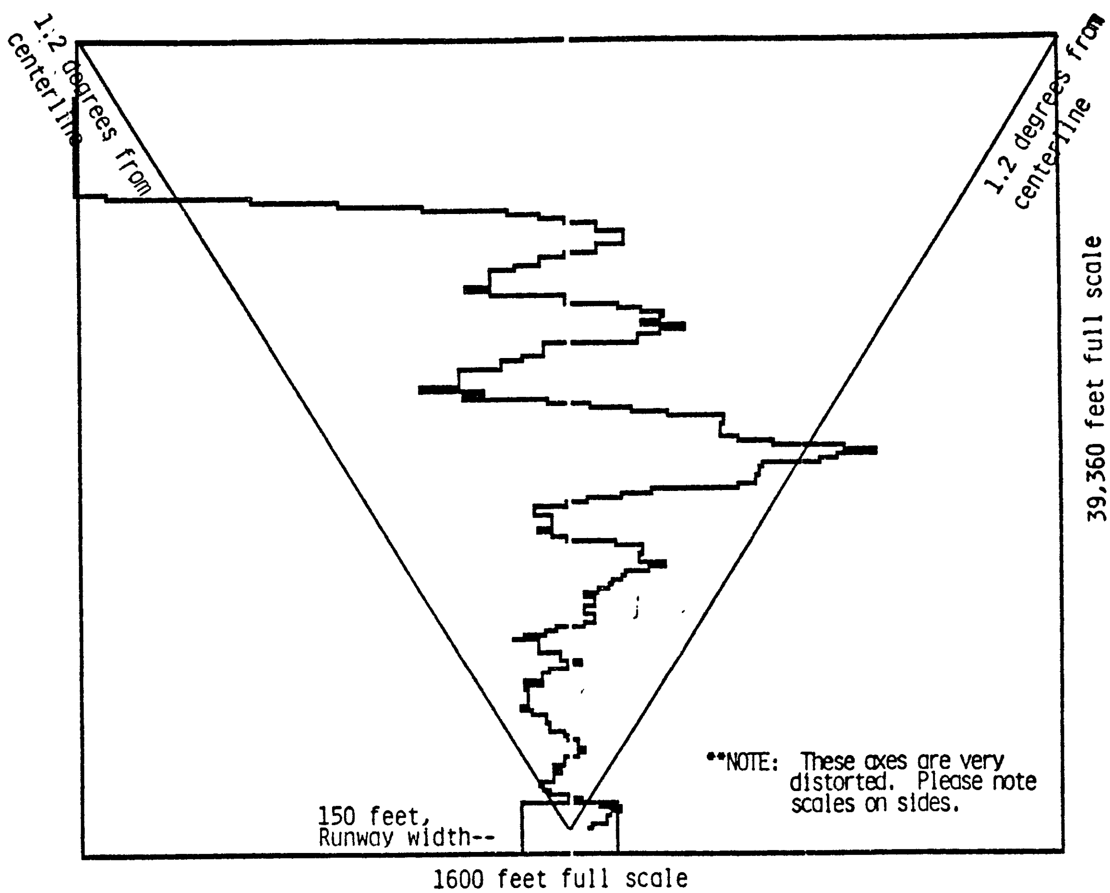

Figure 6.21: Newport Approach 2, XY Localizer Path

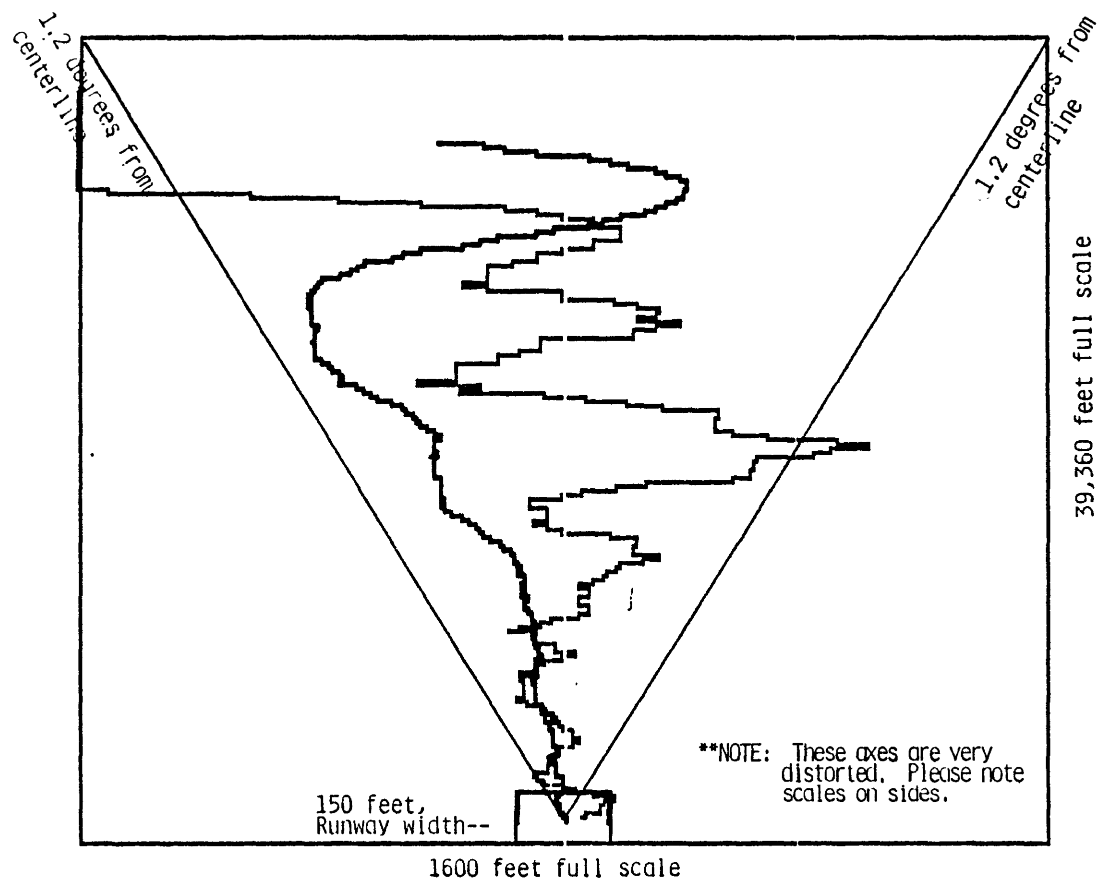

Figure 6.22: Newport Approach 2, XY Combined Paths

This is the data for NEW AP2 XY2

# PNT	LOCALIZER ANGLE	LORAN ANGLE	DIFFERENCE LORAN-LOC
1	2.807	.3264	-2.48
2	-6.40	.2679	6.675
3	3.7	.2115	-3.48
4	3.922	.1553	-3.76
5	3.922	.0781	-3.84
6	3.996	8.699	-3.98
7	4.07	-.056	-4.12
8	4.144	-.113	-4.25
9	4.218	-.166	-4.38
10	4.144	-.204	-4.34
11	4.144	-.240	-4.38
12	4.07	-.268	-4.33
13	3.996	-.293	-4.28
14	3.922	-.311	-4.23
15	3.922	-.330	-4.25
16	3.848	-.327	-4.17
17	3.774	-.332	-4.10
18	3.774	-.320	-4.09
19	3.7	-.324	-4.02
20	3.552	-.307	-3.85
21	3.33	-.294	-3.62
22	3.134	-.277	-3.41
23	2.938	-.252	-3.19
24	2.807	-.226	-3.03
25	2.546	-.192	-2.73
26	2.350	-.150	-2.50
27	2.061	-.109	-2.17
28	1.823	-.062	-1.88
29	1.823	-.015	-1.83
30	1.744	.0362	-1.70
31	1.506	.0853	-1.42
32	1.268	.1414	-1.12
33	.8721	.2031	-.668
34	.6342	.2589	-.375
35	.3964	.3137	-.082
36	.1585	.3795	.2210
37	.0792	.4413	.3620
38	0	.4927	.4927
39	0	.5313	.5313

Begin approach

Table 6.25: Newport Approach 2, XY Error Angles

40	-.079	.5837	.6630
41	-.079	.6179	.6972
42	-.158	.6525	.8110
43	-.158	.6713	.8298
44	-.158	.7065	.8650
45	-.158	.7409	.8994
46	-.079	.7699	.8492
47	-.079	.7883	.8676
48	0	.8083	.8083
49	.0792	.8201	.7409
50	.0792	.8265	.7472
51	.1585	.8385	.6799
52	.2378	.8336	.5957
53	.2378	.8458	.6079
54	.2378	.8424	.6045
55	.2378	.8476	.6097
56	.2378	.8572	.6194
57	.3171	.8582	.5411
58	.2378	.8592	.6213
59	.2378	.8528	.6149
60	0	.8522	.8522
61	0	.8711	.8711
62	-.158	.8752	1.033
63	-.237	.8778	1.115
64	-.317	.8927	1.209
65	-.317	.8877	1.204
66	-.317	.8920	1.209
67	-.237	.9057	1.143
68	-.396	.9117	1.308
69	-.317	.8910	1.208
70	-.237	.8954	1.133
71	-.237	.8726	1.110
72	-.079	.8689	.9482
73	.0792	.8440	.7647
74	.0792	.8385	.7592
75	.0792	.8526	.7733
76	.1585	.8238	.6652
77	.2378	.8013	.5634
78	.2378	.7852	.5473
79	.2378	.7621	.5242
80	.3964	.7351	.3387
81	.3964	.7063	.3098

Table 6.26: Newport Approach 2, XY Error Angles Continued

82	.3964	.6872	.2908
83	.3964	.6609	.2645
84	.555	.6431	.0881
85	.3964	.6160	.2196
86	.3171	.6084	.2913
87	.3964	.6116	.2152
88	.0792	.6000	.5207
89	-.079	.5868	.6661
90	-.237	.5623	.8001
91	-.396	.5368	.9332
92	-.555	.5431	1.098
93	-.634	.5643	1.198
94	-.634	.5689	1.203
95	-.634	.5776	1.211
96	-.634	.5726	1.206
97	-.634	.5969	1.231
98	-.713	.5863	1.299
99	-.872	.5912	1.463
100	-.872	.5999	1.472
101	-1.18	.6051	1.789
102	-1.33	.6082	1.940
103	-1.18	.5930	1.777
104	-1.11	.5921	1.702
105	-.872	.5930	1.465
106	-.872	.6005	1.472
107	-.872	.5997	1.471
108	-.872	.6092	1.481
109	-.872	.6188	1.490
110	-.872	.6073	1.479
111	-.792	.6239	1.416
112	-.634	.6234	1.257
113	-.396	.5891	.9856
114	-.237	.5745	.8124
115	-.079	.5433	.6226
116	0	.5073	.5073
117	.1585	.4797	.3212
118	.1585	.4634	.3049
119	.1585	.4537	.2951
120	.0792	.4178	.3385
121	.0792	.3882	.3089
122	.0792	.3605	.2813

Table 6.27: Newport Approach 2, XY Error Angles Continued

123	.1585	.3492	.1907
124	.0792	.3179	.2386
125	0	.2903	.2903
126	-.079	.2935	.3728
127	-.237	.2866	.5244
128	-.396	.2766	.6731
129	-.396	.2752	.6716
130	-.396	.2813	.6778
131	-.396	.2603	.6568
132	-.475	.2557	.7314
133	-.555	.2479	.8029
134	-.475	.2742	.7499
135	-.317	.2584	.5755
136	-.317	.2760	.5931
137	-.237	.2599	.4977
138	-.237	.2549	.4927
139	-.237	.2763	.5142
140	-.158	.2799	.4385
141	-.079	.2597	.3390
142	-.158	.2511	.4096
143	-.158	.2422	.4008
144	-.079	.2366	.3159
145	-.079	.2183	.2976
146	-.158	.2051	.3637
147	-.158	.2153	.3739
148	-.158	.2352	.3937
149	-.079	.2688	.3481
150	.0792	.2459	.1666
151	.1585	.2436	.0850
152	.3171	.2435	-.073
153	.3964	.2153	-.181
154	.2378	.2085	-.029
155	.2378	.1790	-.058
156	.2378	.2089	-.028
157	.0792	.2462	.1669
158	.0792	.2739	.1946
159	0	.2674	.2674
160	-.079	.2962	.3755
161	0	.3058	.3058
162	.1585	.2745	.1159
163	.2378	.3140	.0761
164	.2378	.3031	.0652
165	.3964	.3087	-.087

Table 6.28: Newport Approach 2, XY Error Angles Continued

166	.2378	.2944	.0566
167	.3964	.3098	-.086
168	.3964	.3207	-.075
169	.3964	.3009	-.095
170	.3964	.2569	-.139
171	.3964	.2352	-.161
172	.4757	.2182	-.257
173	.4757	.1398	-.335
174	.3964	.1288	-.267
175	.2378	.1058	-.132
176	.2378	.1878	-.049
177	.2378	.1982	-.039
178	.2378	.1753	-.062
179	.0792	.1639	.0846
180	0	.1808	.1808
181	0	.1624	.1624
182	-.079	.1566	.2359
183	-.079	.1851	.2643
184	-.158	.1476	.3061
185	-.079	.1082	.1875
186	0	.1786	.1786
187	.0792	.2185	.1392
188	.0792	.2286	.1493
189	.2378	.1711	-.066
190	.1585	.1266	-.031
191	.2378	.1267	-.111
192	.2378	.0385	-.199
193	.3964	.0175	-.378
194	.555	.0143	-.540
195	.4757	9.653	-.474
196	.3964	.0568	-.339
197	0	-2.76	-2.76
198	-.158	.1380	.2966
199	-.555	.2384	.7934
200	-.872	.2313	1.103
201	-1.11	.1935	1.303
202	-.872	.1715	1.043
203	-.872	.1735	1.045
204	-.872	.1892	1.061
205	-.555	.0431	.5981
206	-.475	-.043	.4326

AVERAGE ERROR ANGLE = .553590652
STANDARD DEVIATION = .510426169

Table 6.29: Newport Approach 2, XY Error Angles Continued

End approach

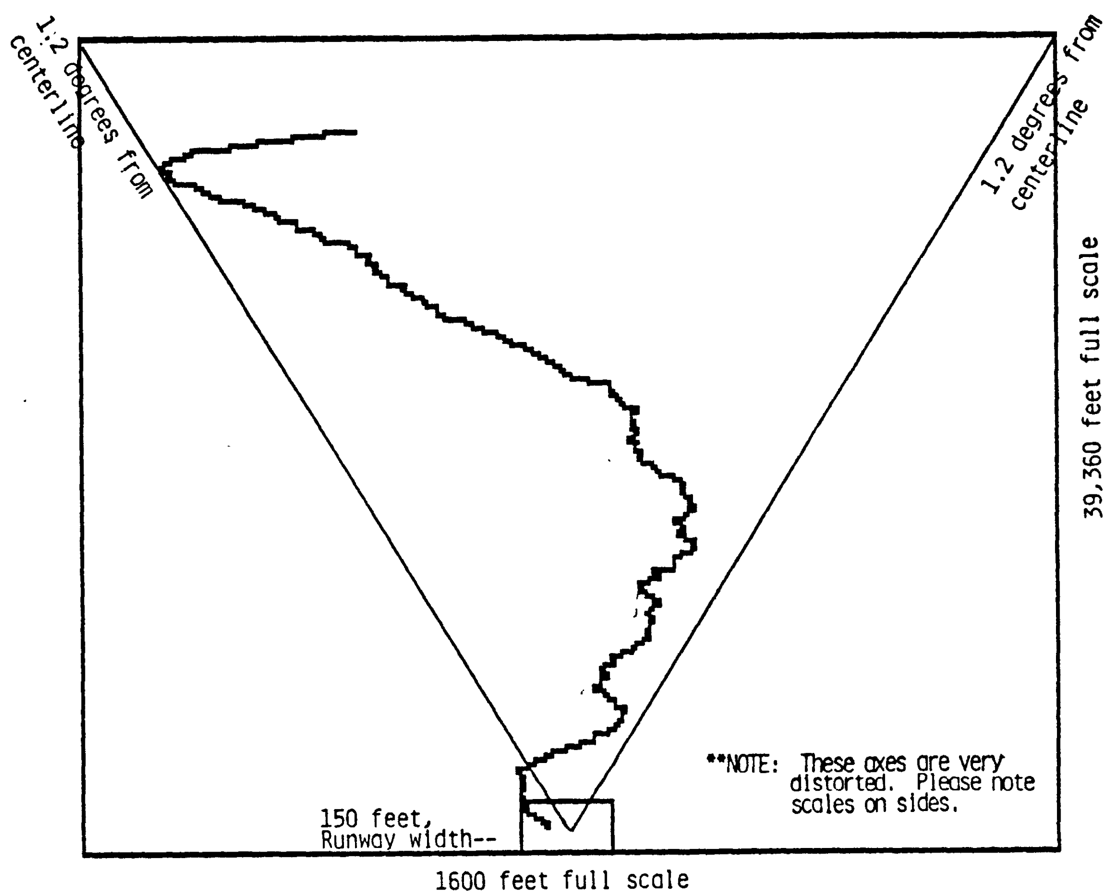

Figure 6.23: Groton Approach 1, WY LORAN Path

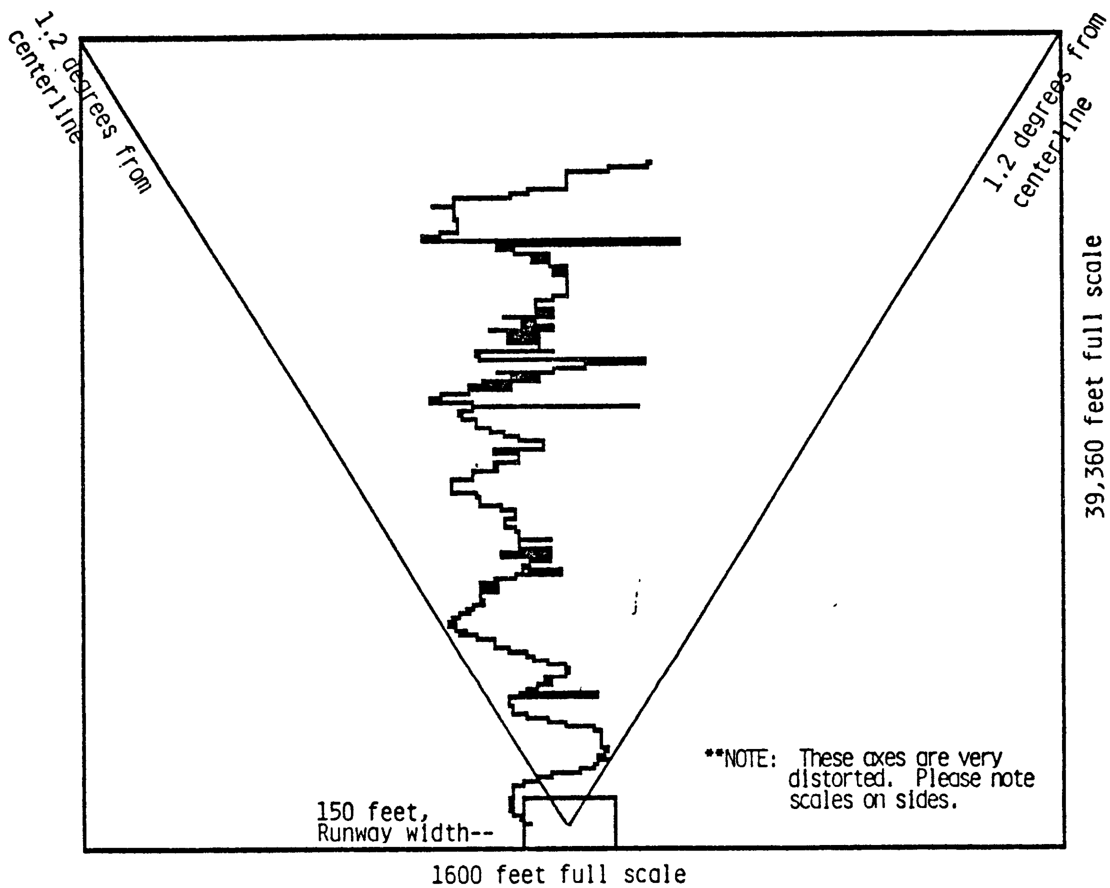

Figure 6.24: Groton Approach 1, WY Localizer Path

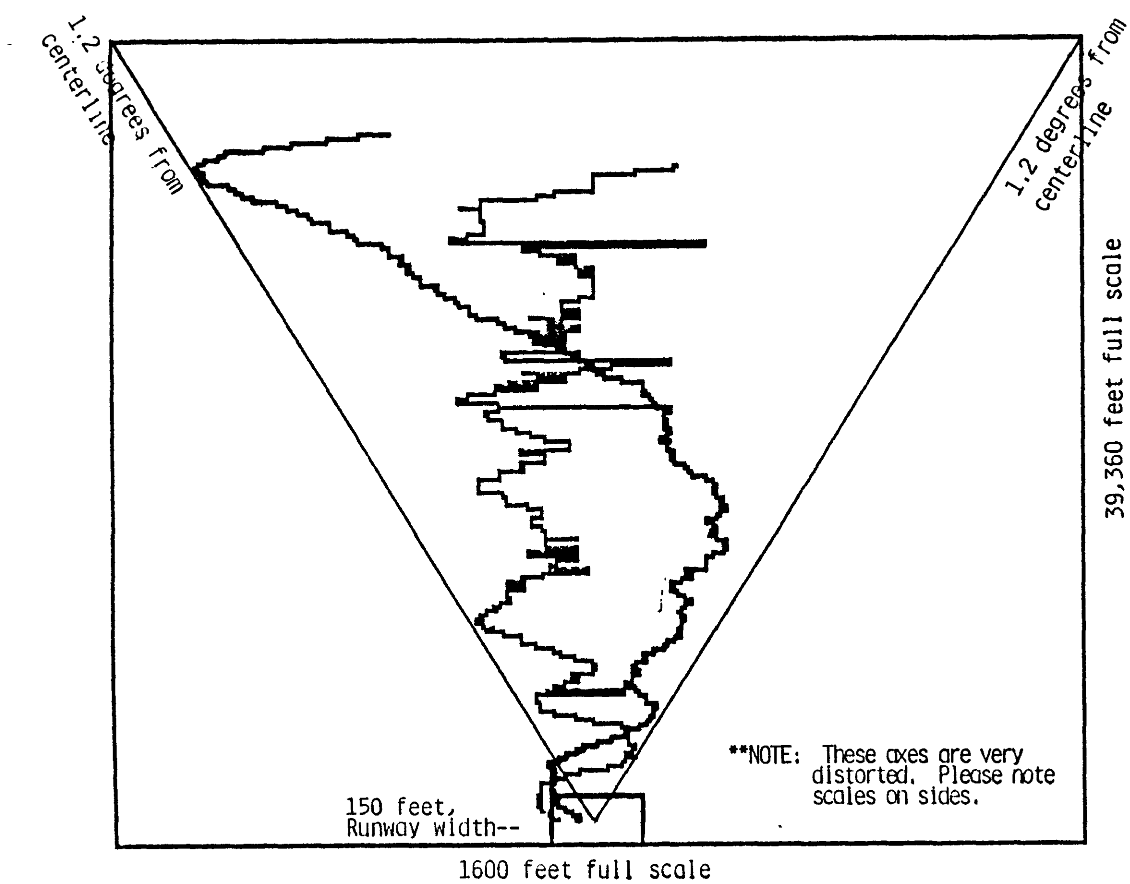

Figure 6.25: Groton Approach 1, WY Combined Paths

# PNT	LOCALIZER ANGLE	LORAN ANGLE	DIFFERENCE LORAN-LOC
1	-.202	.4235	.6263
2	-3.93	.4913	4.428
3	-.202	.5632	.7661
4	-.202	.6323	.8351
5	-.202	.6970	.8999
6	-.101	.7353	.8367
7	0	.7825	.7825
8	0	.7989	.7989
9	0	.8377	.8377
10	0	.8530	.8530
11	0	.8648	.8648
12	0	.8665	.8665
13	.1014	.8522	.7508
14	.1521	.8606	.7085
15	.2028	.8529	.6501
16	.3042	.8368	.5325
17	.3042	.8153	.5110
18	.355	.7988	.4438
19	.3042	.7875	.4833
20	.3042	.7703	.4660
21	.3042	.7459	.4416
22	.3042	.7213	.4170
23	.3042	.7040	.3997
24	.3042	.6806	.3763
25	.3042	.6625	.3582
26	.3042	.6666	.3623
27	.355	.6537	.2987
28	.4057	.6224	.2167
29	.4057	.6208	.2151
30	-.304	.5964	.9007
31	.2028	.5873	.3845
32	.1521	.5720	.4199
33	.1014	.5662	.4648
34	.0507	.5432	.4925
35	.1014	.5200	.4186
36	.0507	.5041	.4534
37	.0507	.5018	.4511
38	0	.4758	.4758
39	.0507	.4793	.4285
40	.0507	.4827	.4320
41	0	.4644	.4644
42	0	.4720	.4720
43	0	.4654	.4654

Begin approac

Table 6.30: Groton Approach 1, WY Error Angles

44	0	.4610	.4610
45	0	.4501	.4501
46	0	.4475	.4475
47	0	.4096	.4096
48	.0507	.4171	.3664
49	.1014	.4104	.3090
50	.1014	.3932	.2917
51	.0507	.3710	.3203
52	.1014	.3659	.2645
53	.0507	.3457	.2950
54	.2028	.3424	.1395
55	.1014	.3434	.2420
56	.1521	.3272	.1750
57	.0507	.2974	.2467
58	.2535	.2673	.0137
59	.2028	.2500	.0471
60	.1014	.2304	.1290
61	.1521	.2102	.0581
62	.2028	.1947	-8.06
63	.1014	.1724	.0710
64	.1014	.1541	.0526
65	.0507	.1448	.0941
66	.3042	.1146	-.189
67	.3042	.0934	-.210
68	.2535	.0811	-.172
69	-.253	.0570	.3106
70	-.050	.0586	.1093
71	.0507	.0411	-9.54
72	.2535	.0164	-.237
73	.2028	.0152	-.187
74	.1014	2.056	-.099
75	.3042	-.013	-.318
76	.355	-.063	-.418
77	.2028	-.089	-.292
78	.355	-.131	-.486
79	.4564	-.133	-.589
80	.4564	-.140	-.596
81	.5071	-.135	-.642
82	.355	-.159	-.514
83	-.253	-.164	.0886
84	.355	-.177	-.532
85	.4057	-.185	-.590
86	.4057	-.221	-.626
87	.4057	-.229	-.634
88	.355	-.203	-.558

Table 6.31: Groton Approach 1, WY Error Angles Continued

89	.355	-.208	-.563
90	.3042	-.214	-.518
91	.3042	-.219	-.524
92	.2535	-.214	-.468
93	.2028	-.223	-.426
94	.1521	-.242	-.394
95	.1014	-.226	-.327
96	.1014	-.199	-.300
97	.2535	-.243	-.497
98	.3042	-.232	-.537
99	.2028	-.233	-.435
100	.2028	-.250	-.452
101	.3042	-.256	-.560
102	.3042	-.245	-.549
103	.3042	-.259	-.564
104	.355	-.268	-.623
105	.4057	-.304	-.710
106	.4057	-.316	-.722
107	.5071	-.329	-.836
108	.5071	-.342	-.849
109	.5071	-.394	-.901
110	.5071	-.413	-.920
111	.4057	-.424	-.830
112	.4057	-.435	-.840
113	.4057	-.424	-.830
114	.4057	-.447	-.853
115	.4057	-.443	-.849
116	.3042	-.476	-.781
117	.2535	-.469	-.723
118	.2535	-.490	-.744
119	.3042	-.502	-.806
120	.3042	-.485	-.789
121	.3042	-.468	-.772
122	.3042	-.457	-.761
123	.2535	-.439	-.692
124	.2535	-.468	-.721
125	.2535	-.487	-.740
126	.1014	-.468	-.570
127	.2535	-.467	-.721
128	.2535	-.494	-.747
129	.1014	-.545	-.646
130	.3042	-.534	-.838
131	.355	-.547	-.902
132	.1014	-.550	-.652
133	.2028	-.499	-.702

Table 6.32: Groton Approach 1, WY Error Angles Continued

134	.2028	-.513	-.715
135	.2535	-.486	-.740
136	.0507	-.492	-.543
137	.1014	-.495	-.596
138	.3042	-.467	-.772
139	.4057	-.401	-.807
140	.4057	-.438	-.843
141	.5071	-.389	-.896
142	.4057	-.348	-.754
143	.5071	-.369	-.876
144	.5071	-.354	-.862
145	.5071	-.392	-.899
146	.5071	-.406	-.913
147	.5578	-.429	-.987
148	.6085	-.464	-1.07
149	.6085	-.433	-1.04
150	.6592	-.427	-1.08
151	.71	-.417	-1.12
152	.71	-.445	-1.15
153	.7607	-.452	-1.21
154	.71	-.446	-1.15
155	.6592	-.444	-1.10
156	.71	-.456	-1.16
157	.6085	-.445	-1.05
158	.6085	-.466	-1.07
159	.5071	-.478	-.985
160	.5071	-.439	-.946
161	.4057	-.403	-.808
162	.4057	-.376	-.781
163	.3042	-.368	-.672
164	.2535	-.325	-.578
165	.1521	-.275	-.427
166	.0507	-.297	-.347
167	.0507	-.251	-.301
168	0	-.225	-.225
169	0	-.225	-.225
170	.0507	-.253	-.304
171	.2028	-.215	-.418
172	.1521	-.215	-.367
173	.1521	-.238	-.390
174	.2535	-.186	-.440
175	.355	-.256	-.611
176	.4057	-.262	-.668
177	-.202	-.287	-.084
178	.5071	-.342	-.849

Table 6.33: Groton Approach 1, WY Error Angles Continued

179	.5071	-.362	-.870
180	.5071	-.434	-.941
181	.5071	-.456	-.963
182	.5071	-.428	-.935
183	.4057	-.431	-.837
184	.3042	-.428	-.733
185	.2028	-.412	-.615
186	.0507	-.408	-.459
187	0	-.356	-.356
188	-.202	-.258	-.055
189	-.304	-.244	.0594
190	-.304	-.230	.0738
191	-.304	-.110	.1934
192	-.304	-.101	.2028
193	-.304	.0258	.3301
194	-.304	.1580	.4623
195	-.405	.2216	.6274
196	-.355	.2540	.6090
197	-.304	.3566	.6609
198	-.405	.4458	.8515
199	-.304	.5388	.8431
200	-.253	.5538	.8074
201	-.101	.5235	.6250
202	.0507	.5197	.4689
203	.2535	.5069	.2533
204	.4057	.5717	.1660
205	.5071	.5481	.0410
206	.6085	.5561	-.052
207	.7607	.6269	-.133
208	.8114	.6347	-.176
209	.8114	.6130	-.198
210	.8621	.6340	-.228
211	.9128	.6666	-.246
212	.9128	.5810	-.331
213	.9128	.6897	-.223
214	.9635	.6632	-.300
215	.9635	.5581	-.405
216	.9128	.4587	-.454
217	.8621	.4509	-.411
218	.8114	.3445	-.466
219	.71	.4233	-.286

AVERAGE ERROR ANGLE = -.218157664
STANDARD DEVIATION = .574497463

Table 6.34: Groton Approach 1, WY Error Angles Continued

End approach

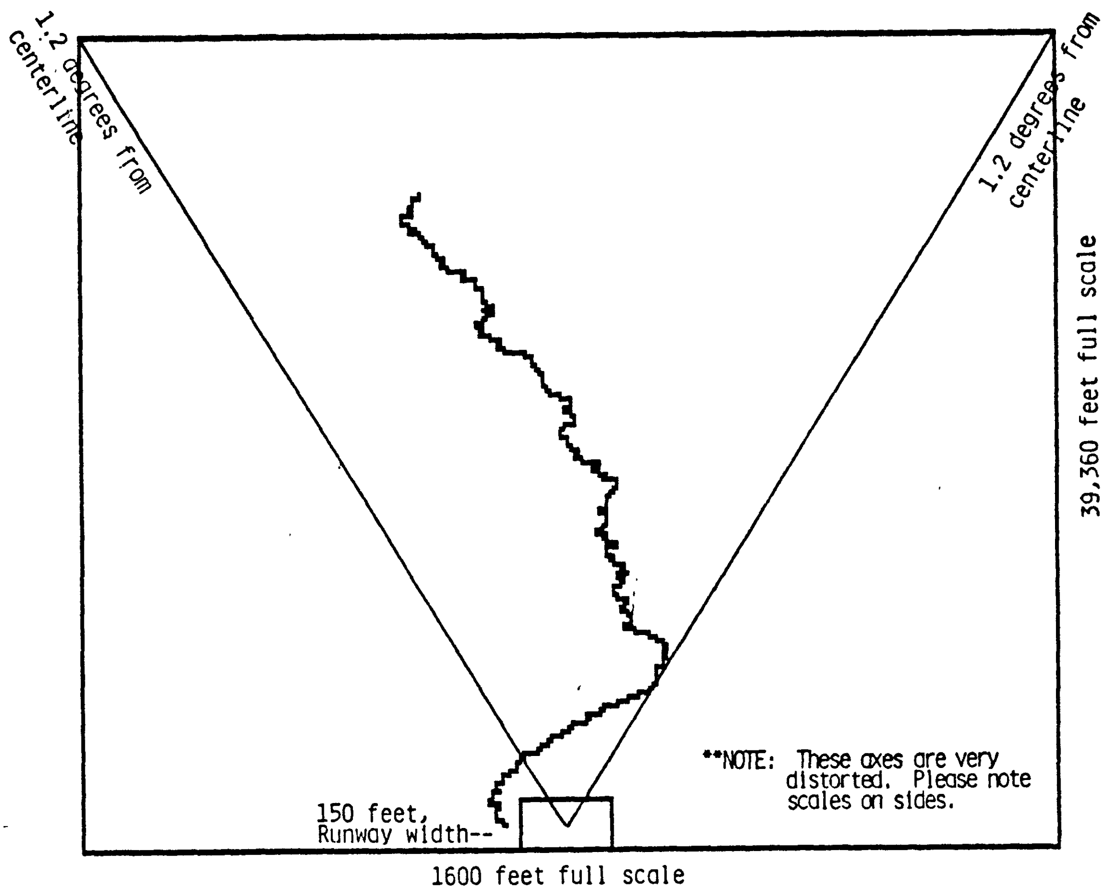

Figure 6.26: Groton Approach 2, WY LORAN Path

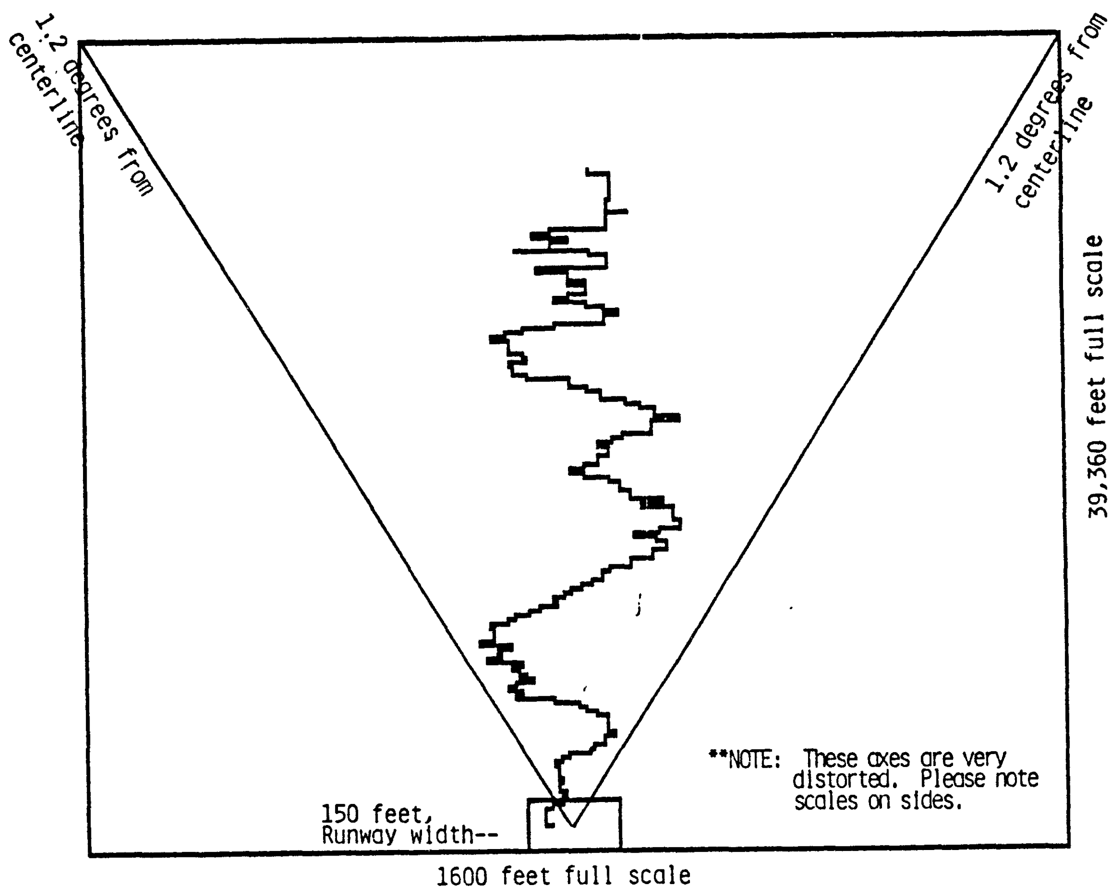

Figure 6.27: Groton Approach 2, WY Localizer Path

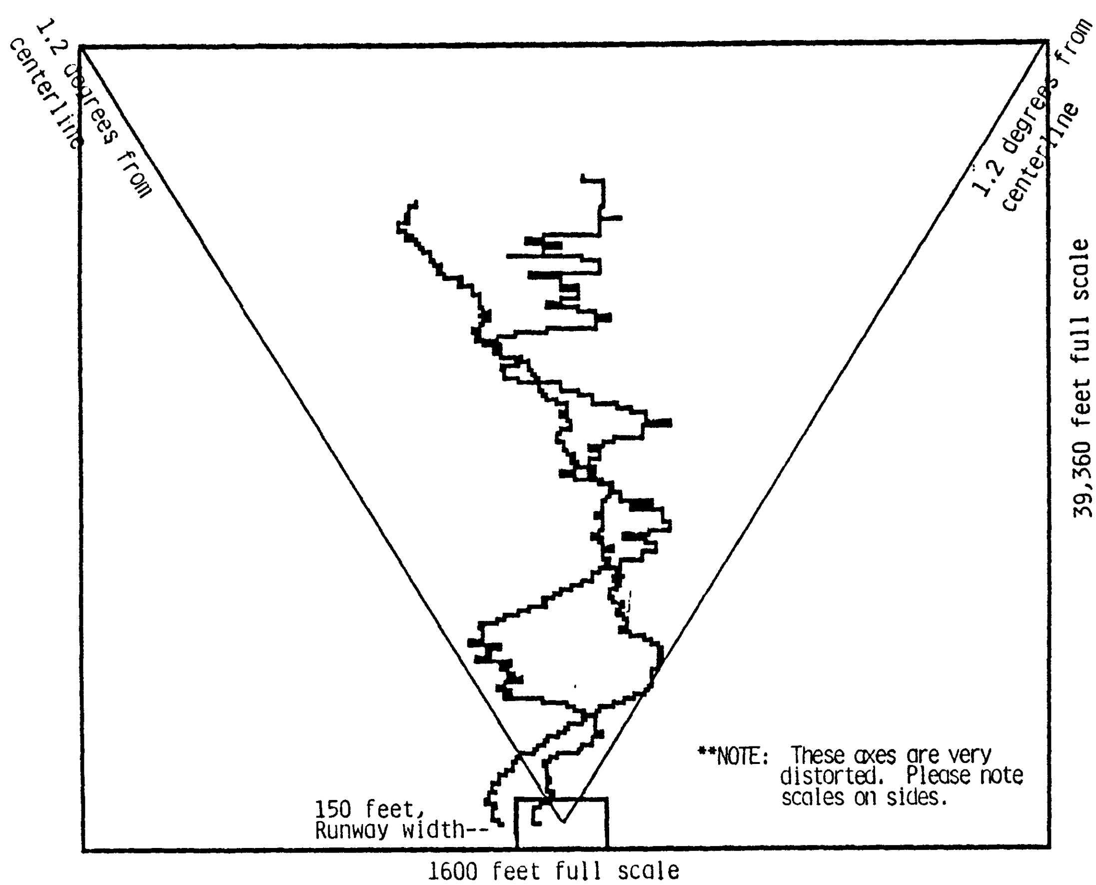

Figure 6.28: Groton Approach 2, WY Combined Paths

This is the data for GRO AP2 WY2

# PNT	LOCALIZER ANGLE	LORAN ANGLE	DIFFERENCE LORAN-LOC
1	2.004	.3248	-1.67
2	-3.93	.3290	4.266
3	-.050	.3389	.3896
4	-.050	.3469	.3976
5	-.101	.3495	.4510
6	-.101	.3539	.4553
7	-.101	.3510	.4525
8	-.101	.3779	.4793
9	-.101	.3789	.4804
10	-.101	.3800	.4815
11	-.101	.3678	.4693
12	-.101	.3516	.4531
13	-.101	.3639	.4653
14	-.101	.3475	.4490
15	-.101	.3349	.4363
16	-.152	.3297	.4819
17	-.101	.3191	.4205
18	-.101	.3141	.4155
19	-.101	.3171	.4185
20	-.101	.3139	.4153
21	-.050	.2989	.3496
22	.0507	.2997	.2489
23	.1014	.3105	.2090
24	0	.2929	.2929
25	.0507	.2531	.2024
26	.0507	.2638	.2131
27	.1521	.2499	.0978
28	-.050	.2257	.2764
29	-.101	.2299	.3313
30	-.101	.2114	.3128
31	-.101	.2160	.3174
32	.0507	.2140	.1633
33	.1014	.2120	.1105
34	0	.2037	.2037
35	0	.1909	.1909
36	-.050	.2146	.2653
37	0	.1933	.1933

Begin approach

Table 6.35: Groton Approach 2, WY Error Angles

38	-.050	.2108	.2615
39	-.050	.2197	.2704
40	0	.2200	.2200
41	.0507	.2446	.1939
42	-.050	.2225	.2732
43	-.101	.2361	.3376
44	-.101	.2208	.3222
45	-.152	.2099	.3620
46	-.101	.1828	.2843
47	-.101	.1944	.2959
48	-.050	.1785	.2292
49	.0507	.1530	.1022
50	.1521	.1158	-.036
51	.2028	.0944	-.108
52	.2535	.1010	-.152
53	.2535	.0959	-.157
54	.2028	.0907	-.112
55	.2028	.0783	-.124
56	.2028	.0706	-.132
57	.1521	.0750	-.077
58	.1521	.0669	-.085
59	.1521	.0713	-.080
60	.2028	.0607	-.142
61	.2028	.0500	-.152
62	.2028	.0368	-.166
63	.1521	.0207	-.131
64	.1014	-.010	-.112
65	0	-.011	-.011
66	0	4.837	4.837
67	-.050	1.044	.0517
68	-.101	-.018	.0831
69	-.101	-.027	.0737
70	-.152	-.021	.1311
71	-.202	-.022	.1806
72	-.253	2.981	.2565
73	-.304	.0179	.3222
74	-.304	.0140	.3183
75	-.304	.0211	.3254
76	-.405	-4.67	.4010
77	-.304	-3.18	.3010

Table 6.36: Groton Approach 2, WY Error Angles Continued

78	-.304	-.021	.2830
79	-.304	-.025	.2787
80	-.304	-.035	.2686
81	-.202	-.034	.1685
82	-.152	-.055	.0962
83	-.101	-.066	.0350
84	-.152	-.114	.0373
85	-.152	-.096	.0555
86	-.101	-.119	-.018
87	-.101	-.148	-.047
88	-.101	-.139	-.037
89	-.050	-.180	-.130
90	0	-.192	-.192
91	-.050	-.183	-.132
92	-.050	-.180	-.129
93	-.152	-.170	-.018
94	-.202	-.148	.0544
95	-.202	-.151	.0517
96	-.253	-.157	.0965
97	-.253	-.150	.1032
98	-.253	-.124	.1295
99	-.405	-.152	.2530
100	-.304	-.155	.1486
101	-.456	-.158	.2978
102	-.456	-.161	.2947
103	-.456	-.154	.3017
104	-.456	-.144	.3123
105	-.507	-.126	.3804
106	-.507	-.164	.3431
107	-.456	-.153	.3032
108	-.405	-.173	.2319
109	-.304	-.212	.0918
110	-.405	-.216	.1895
111	-.456	-.180	.2758
112	-.456	-.183	.2727
113	-.456	-.212	.2435
114	-.405	-.197	.2077
115	-.405	-.216	.1892
116	-.304	-.269	.0351
117	-.304	-.247	.0572

Table 6.37: Groton Approach 2, WY Error Angles Continued

118	-.202	-.285	-.083
119	-.202	-.244	-.041
120	-.152	-.275	-.123
121	-.152	-.264	-.112
122	-.101	-.229	-.128
123	-.050	-.225	-.175
124	-.050	-.237	-.187
125	0	-.250	-.250
126	.0507	-.254	-.305
127	.1014	-.317	-.419
128	.1014	-.297	-.399
129	.1521	-.285	-.438
130	.2028	-.325	-.528
131	.2535	-.326	-.580
132	.355	-.354	-.709
133	.4057	-.347	-.753
134	.5071	-.326	-.833
135	.5071	-.332	-.839
136	.5071	-.384	-.891
137	.5071	-.465	-.972
138	.5071	-.511	-1.01
139	.6085	-.548	-1.15
140	.6085	-.576	-1.18
141	.4057	-.605	-1.01
142	.5071	-.585	-1.09
143	.5071	-.615	-1.12
144	.6085	-.625	-1.23
145	.5071	-.615	-1.12
146	.355	-.620	-.975
147	.4564	-.583	-1.04
148	.4057	-.577	-.983
149	.355	-.593	-.948
150	.4057	-.598	-1.00
151	.3042	-.604	-.908
152	.4564	-.621	-1.07
153	.5071	-.615	-1.12
154	.4057	-.586	-.991
155	.4564	-.508	-.964
156	.2535	-.452	-.706
157	.1521	-.456	-.608
158	-.050	-.397	-.346

Table 6.38: Groton Approach 2, WY Error Angles Continued

159	-.101	-.292	-.191
160	-.202	-.268	-.065
161	-.304	-.144	.1598
162	-.304	-.182	.1213
163	-.304	-.141	.1630
164	-.304	-.050	.2538
165	-.304	-4.81	.2994
166	-.405	.0357	.4414
167	-.304	.0551	.3594
168	-.304	.1357	.4400
169	-.304	.1816	.4859
170	-.202	.2453	.4481
171	-.152	.2882	.4404
172	0	.3181	.3181
173	.0507	.4556	.4049
174	.1521	.5067	.3545
175	.2028	.5503	.3474
176	.2028	.5777	.3749
177	.2028	.6627	.4598
178	.2028	.7327	.5299
179	.2028	.7670	.5641
180	.1521	.7711	.6190
181	.2028	.8795	.6767
182	.2028	.9238	.7209
183	.1014	.9137	.8122
184	.1014	1.013	.9118
185	.2028	1.038	.8357
186	.2028	1.133	.9311
187	.355	1.029	.6746
188	.4564	1.130	.6741
189	.5071	1.163	.6559
190	.5071	1.170	.6631
191	.5071	1.206	.6992
192	.5071	1.144	.6374
193	.4057	1.113	.7081

AVERAGE ERROR ANGLE = .0457058082
STANDARD DEVIATION = .484348923

Table 6.39: Groton Approach 2, WY Error Angles Continued

End approach

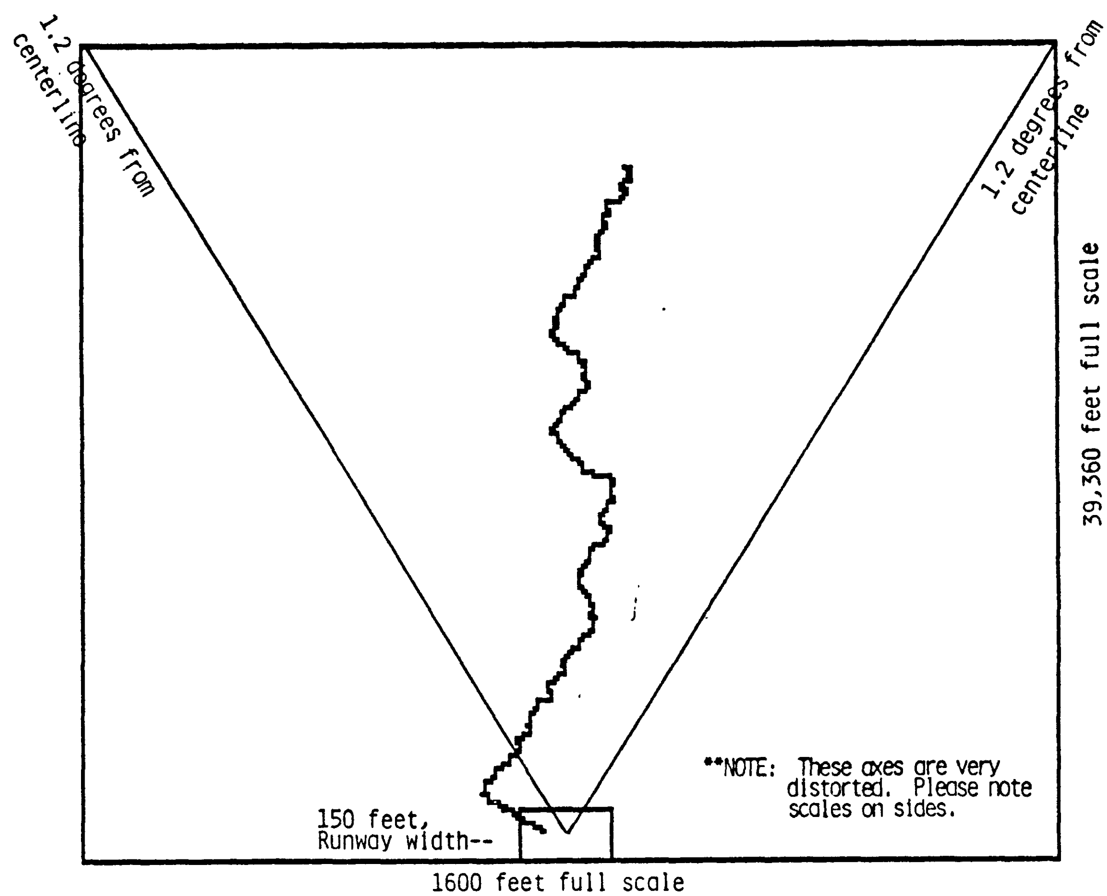

Figure 6.29: Groton Approach 3, XY LORAN Path

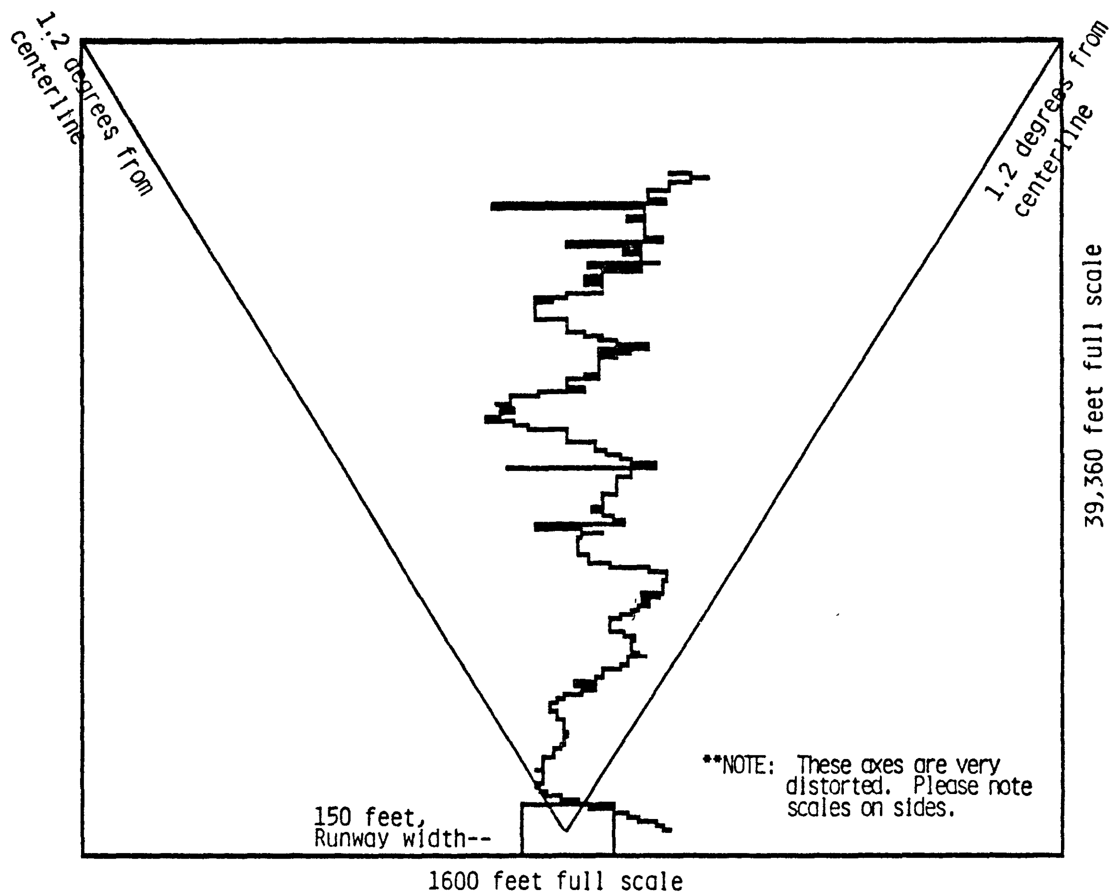

Figure 6.30: Groton Approach 3, XY Localizer Path

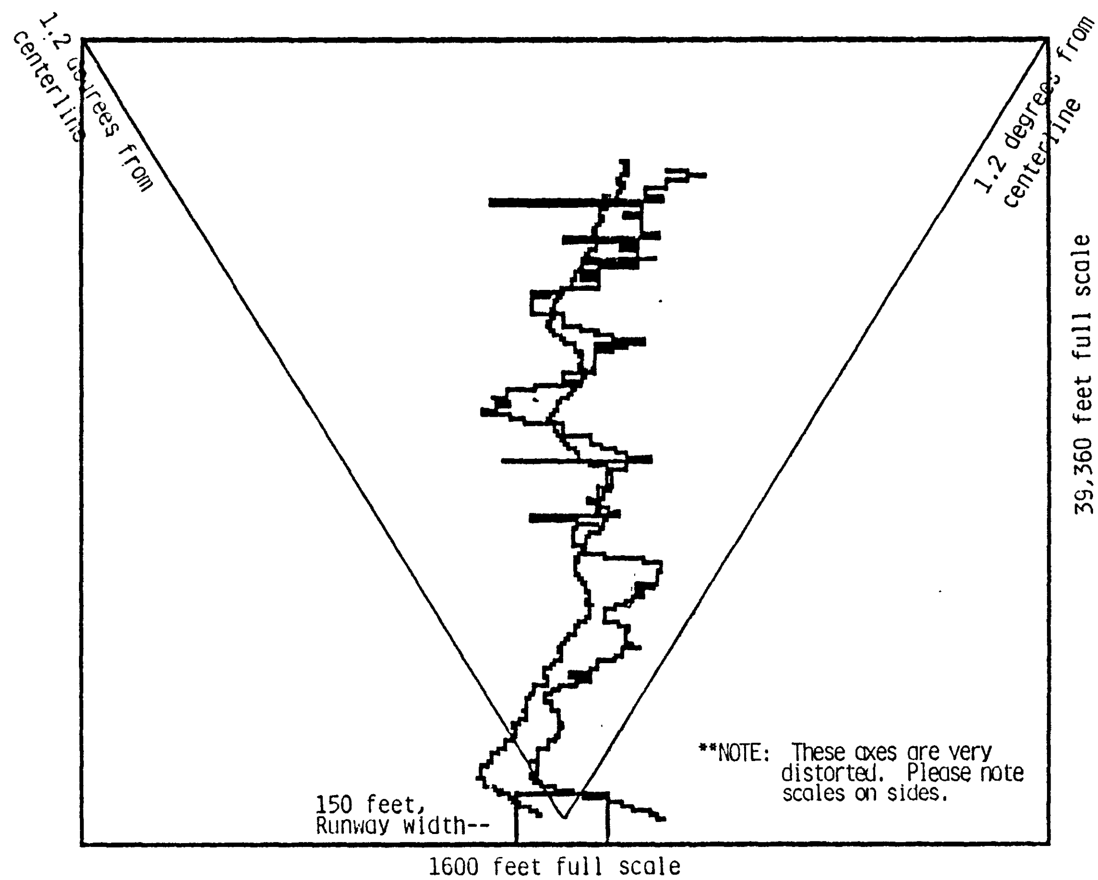

Figure 6.31: Groton Approach 3, XY Combined Paths

This is the data for GRO AP3 XY1

# PNT	LOCALIZER ANGLE	LORAN ANGLE	DIFFERENCE LORAN-LOC
1	-.507	-.124	.3828
2	3.937	-.138	-4.07
3	-.253	-.129	.1243
4	-.304	-.134	.1693
5	-.355	-.137	.2174
6	-.304	-.128	.1755
7	-.253	-.128	.1248
8	-.253	-.119	.1343
9	-.253	-.133	.1199
10	-.202	-.127	.0754
11	-.202	-.118	.0847
12	-.253	-.103	.1505
13	-.253	-.093	.1598
14	.2028	-.093	-.296
15	-.202	-.095	.1072
16	-.202	-.092	.1106
17	-.202	-.085	.1172
18	-.152	-.085	.0670
19	-.202	-.093	.1092
20	-.202	-.090	.1127
21	-.202	-.083	.1197
22	-.202	-.079	.1235
23	-.202	-.072	.1304
24	-.253	-.081	.1725
25	-.253	-.071	.1823
26	0	-.070	-.070
27	-.202	-.076	.1266
28	-.152	-.078	.0732
29	-.152	-.069	.0830
30	-.202	-.065	.1377
31	-.202	-.054	.1480
32	-.253	-.050	.2025
33	-.050	-.047	3.623
34	-.202	-.043	.1593
35	-.101	-.039	.0622
36	-.050	-.031	.0190
37	-.101	-.031	.0702
38	-.050	-.026	.0239
39	-.101	-.022	.0791
40	-.101	-.021	.0800

Begin approach

Table 6.40: Groton Approach 3, XY Error Angles

41	-.101	-6.75	.0946
42	0	7.645	7.645
43	.1014	1.884	-.099
44	.0507	9.901	-.040
45	.1014	.0140	-.087
46	.1014	.0218	-.079
47	.1014	.0230	-.078
48	.1014	.0350	-.066
49	.1014	.0292	-.072
50	0	.0267	.0267
51	0	.0314	.0314
52	0	.0400	.0400
53	0	.0341	.0341
54	-.050	.0316	.0823
55	-.101	.0256	.1270
56	-.101	4.796	.1062
57	-.152	-1.43	.1507
58	-.253	-.015	.2383
59	-.101	-.033	.0683
60	-.202	-.032	.1707
61	-.152	-.057	.0942
62	-.101	-.041	.0597
63	-.101	-.052	.0489
64	-.101	-.051	.0498
65	-.101	-.046	.0544
66	-.101	-.049	.0517
67	-.050	-.060	-.010
68	-.101	-.071	.0301
69	0	-.054	-.054
70	0	-.041	-.041
71	-.050	-.040	.0100
72	.0507	-.039	-.090
73	.1014	-.030	-.131
74	.2028	-.020	-.223
75	.2028	-6.94	-.209
76	.2535	7.028	-.246
77	.2535	.0171	-.236
78	.2028	.0190	-.183
79	.2535	.0249	-.228
80	.3042	.0358	-.268
81	.3042	.0374	-.266
82	.2028	.0477	-.155
83	.1521	.0278	-.124

Table 6.41: Groton Approach 3, XY Error Angles Continued

84	.0507	.0252	-.025
85	0	.0230	.0230
86	0	.0203	.0203
87	0	3.911	3.911
88	-.050	-4.12	.0465
89	-.101	-.010	.0904
90	-.101	-.023	.0782
91	-.152	-.040	.1117
92	-.202	-.052	.1498
93	-.202	-.060	.1424
94	-.253	-.092	.1612
95	-.355	-.124	.2303
96	.2535	-.152	-.406
97	-.253	-.171	.0824
98	-.253	-.165	.0877
99	-.202	-.159	.0429
100	-.202	-.163	.0389
101	-.202	-.168	.0344
102	-.202	-.172	.0302
103	-.202	-.156	.0460
104	-.152	-.155	-3.85
105	-.152	-.155	-3.02
106	-.152	-.149	2.812
107	-.152	-.137	.0142
108	-.101	-.137	-.035
109	-.101	-.152	-.050
110	-.152	-.162	-.010
111	-.202	-.172	.0307
112	-.202	-.166	.0367
113	-.253	-.165	.0882
114	.1521	-.158	-.310
115	-.050	-.129	-.078
116	-.152	-.116	.0358
117	-.050	-.103	-.052
118	-.050	-.102	-.051
119	-.050	-.101	-.050
120	-.050	-.093	-.042
121	-.050	-.080	-.029
122	-.050	-.066	-.016
123	-.101	-.053	.0479
124	-.101	-.069	.0318
125	-.101	-.048	.0525
126	-.202	-.053	.1489

Table 6.42: Groton Approach 3, XY Error Angles Continued

127	-.355	-.058	.2965
128	-.405	-.075	.3298
129	-.507	-.069	.4380
130	-.507	-.093	.4134
131	-.507	-.112	.3945
132	-.507	-.119	.3879
133	-.507	-.138	.3684
134	-.507	-.131	.3755
135	-.405	-.131	.2737
136	-.507	-.124	.3825
137	-.405	-.152	.2534
138	-.456	-.144	.3114
139	-.405	-.144	.2607
140	-.405	-.138	.2670
141	-.355	-.132	.2227
142	-.304	-.125	.1792
143	-.253	-.080	.1732
144	-.253	-.081	.1719
145	-.253	-.073	.1799
146	-.253	-.066	.1873
147	-.304	-.042	.2618
148	-.355	-.027	.3279
149	-.405	-3.05	.4026
150	-.405	-.011	.3944
151	-.405	4.177	.4098
152	-.405	.0292	.4349
153	-.405	.0290	.4347
154	-.456	.0207	.4772
155	-.507	.0212	.5283
156	-.405	.0655	.4712
157	-.405	.0583	.4640
158	-.355	.0766	.4316
159	-.304	.0870	.3913
160	-.253	.1240	.3776
161	-.253	.1343	.3879
162	-.202	.1266	.3294
163	-.101	.1187	.2201
164	-.050	.1214	.1721
165	-.202	.1891	.3919
166	-.101	.2110	.3124
167	.0507	.2151	.1644
168	.0507	.2078	.1571
169	.1014	.2508	.1494

Table 6.43: Groton Approach 3, XY Error Angles Continued

170	.1521	.2759	.1237
171	.1521	.2896	.1375
172	.1521	.2952	.1430
173	.1014	.2785	.1771
174	.1014	.3257	.2242
175	.0507	.3077	.2570
176	.0507	.3126	.2619
177	.0507	.3176	.2669
178	.0507	.3682	.3175
179	.0507	.4326	.3818
180	0	.4287	.4287
181	.0507	.4248	.3741
182	.0507	.4434	.3927
183	.1014	.4657	.3643
184	.1014	.4973	.3959
185	.1521	.5688	.4167
186	.1521	.5671	.4149
187	.2535	.5775	.3239
188	.3042	.6704	.3661
189	.3042	.7269	.4226
190	.3042	.7558	.4516
191	.4057	.7859	.3802
192	.3042	.8370	.5327
193	.3042	.8723	.5680
194	.3042	.9369	.6326
195	.4057	.9759	.5702
196	.4057	.9683	.5626
197	.4057	1.039	.6337
198	.3042	1.000	.6957
199	.2535	1.005	.7517
200	.1014	.9976	.8962
201	-.101	.9379	1.039
202	-.304	.8526	1.156
203	-.507	.8948	1.401
204	-.659	.8037	1.463
205	-.912	.7469	1.659
206	-1.11	.6898	1.805
207	-1.31	.6263	1.944
208	-1.50	.5360	2.039
209	-1.67	.4430	2.113
210	-1.83	.4115	2.249

AVERAGE ERROR ANGLE = .225084218
STANDARD DEVIATION = .396718361

Table 6.44: Groton Approach 3, XY Error Angles Continued

End approach

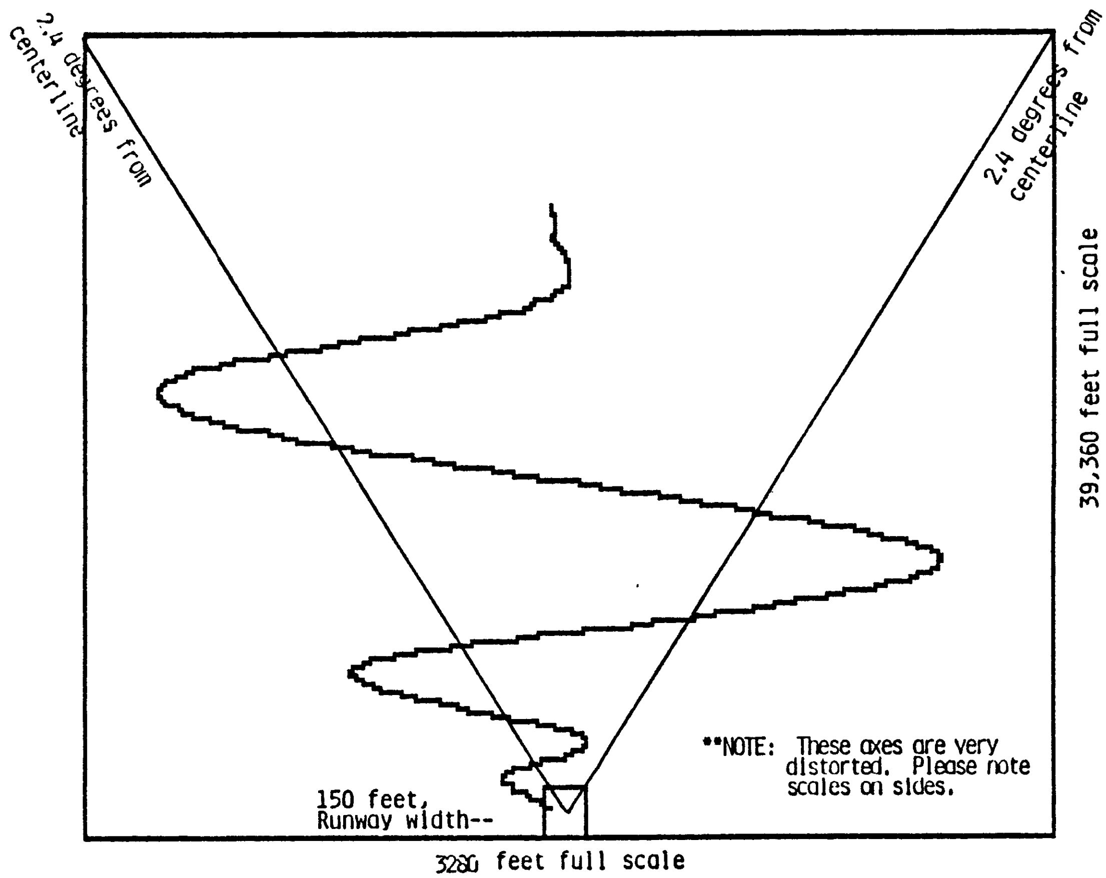

Figure 6.32: Groton Approach 4, XY LORAN Path

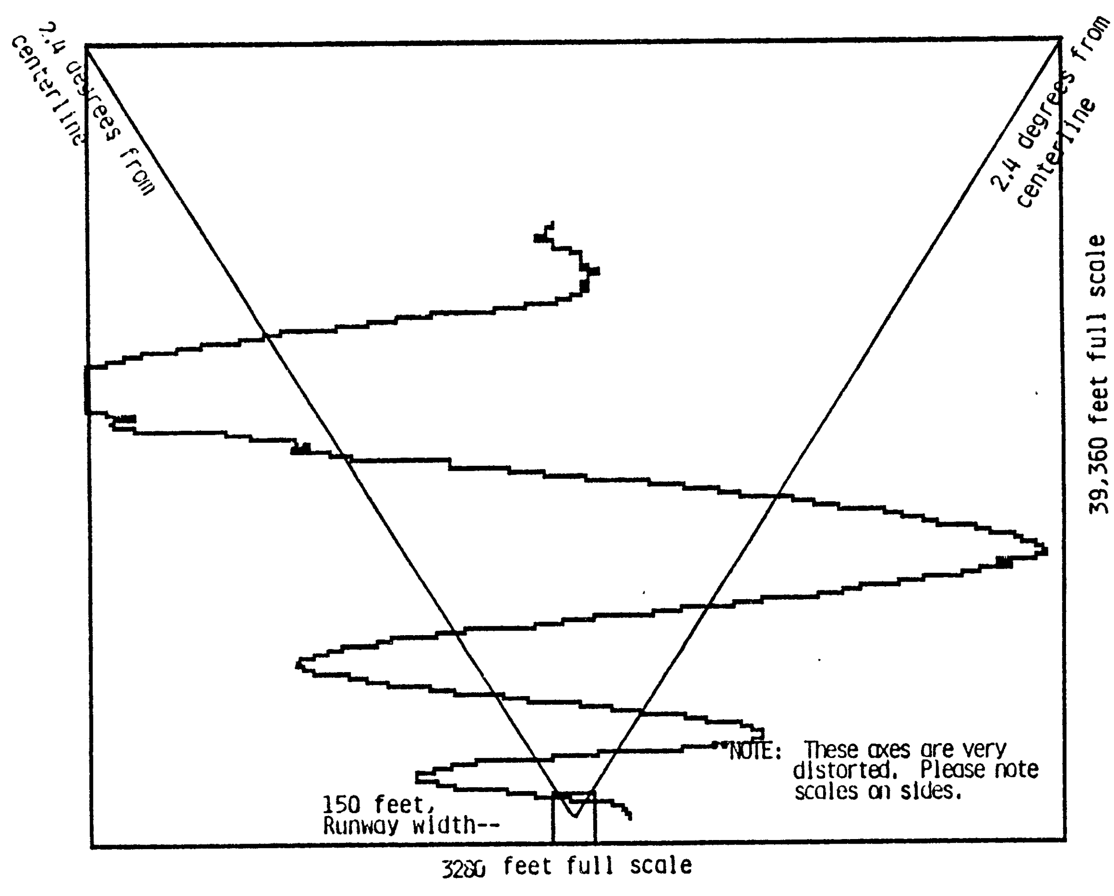

Figure 6.33: Groton Approach 4, XY Localizer Path

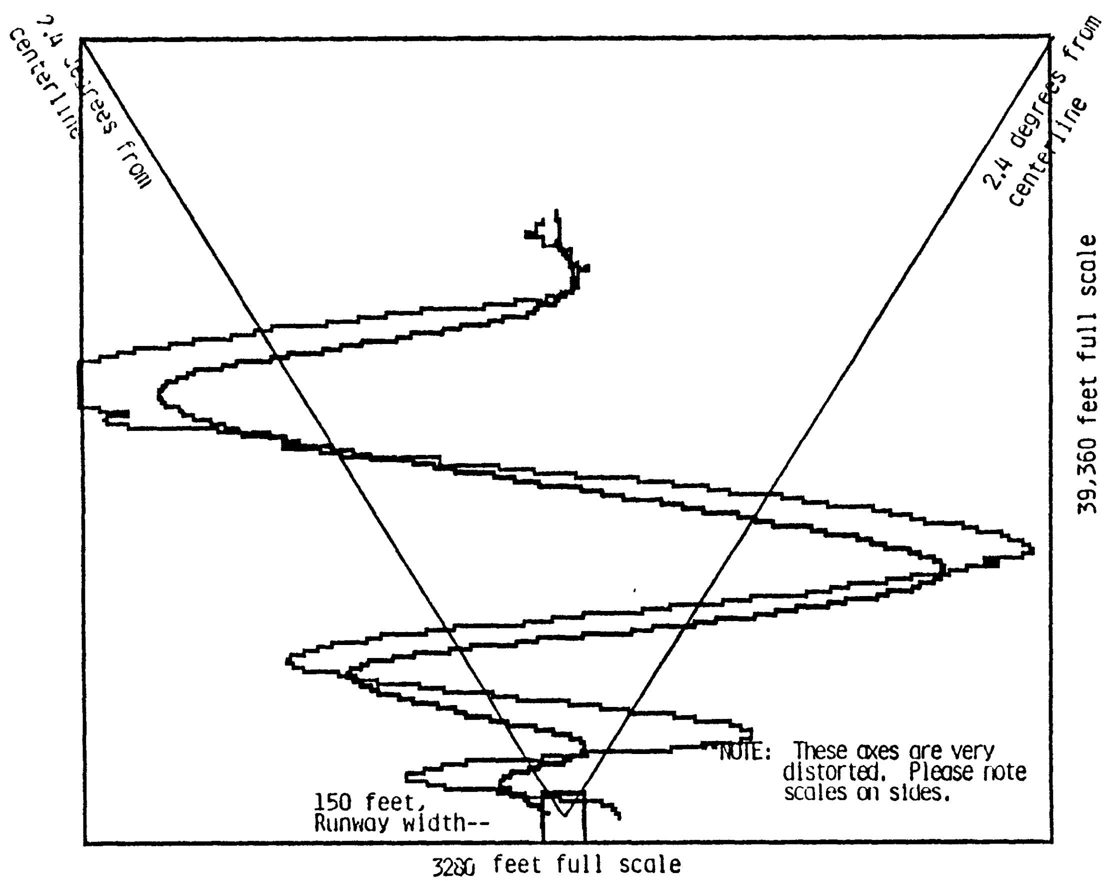

Figure 6.34: Groton Approach 4, XY Combined Paths

This is the data for GRO AP4 XY2

# PNT	LOCALIZER ANGLE	LORAN ANGLE	DIFFERENCE LORAN-LOC
1	-2.00	.0648	2.069
2	3.937	.0627	-3.87
3	.1014	.0747	-.026
4	.1014	.0669	-.034
5	.1521	.0590	-.093
6	.1521	.0596	-.092
7	.1521	.0602	-.091
8	.2028	.0556	-.147
9	.1521	.0623	-.089
10	.1014	.0571	-.044
11	.1014	.0582	-.043
12	0	.0651	.0651
13	-.050	.0654	.1161
14	-.050	.0604	.1111
15	-.050	.0521	.1029
16	-.050	.0435	.0943
17	-.050	.0323	.0830
18	-.101	.0238	.1252
19	-.050	9.505	.0602
20	-.152	.0128	.1649
21	-.101	-1.40	.1000
22	-.101	-7.37	.1006
23	-.101	-6.29	.0951
24	-.050	-.011	.0388
25	-.101	-.011	.0901
26	-.050	-.010	.0406
27	-.050	-.016	.0346
28	0	-.012	-.012
29	.0507	-5.01	-.055
30	.1014	.0217	-.079
31	.3042	.0354	-.268
32	.5071	.0561	-.450
33	.71	.0842	-.625
34	.8993	.1219	-.777
35	1.136	.1634	-.972
36	1.230	.1925	-1.03
37	1.325	.2313	-1.09
38	1.545	.2944	-1.25
39	1.670	.3617	-1.30

Begin approach

Table 6.45: Groton Approach 4, XY Error Angles

40	1.921	.4333	-1.48
41	2.046	.4984	-1.54
42	2.208	.5878	-1.62
43	2.327	.6684	-1.65
44	2.485	.7605	-1.72
45	2.682	.8493	-1.83
46	2.84	.9363	-1.90
47	2.941	1.027	-1.91
48	3.076	1.137	-1.93
49	3.211	1.241	-1.96
50	3.414	1.354	-2.06
51	3.516	1.456	-2.05
52	3.582	1.560	-2.02
53	3.711	1.669	-2.04
54	3.808	1.786	-2.02
55	3.905	1.885	-2.01
56	3.969	1.980	-1.98
57	4.034	2.083	-1.95
58	4.034	2.158	-1.87
59	4.034	2.214	-1.81
60	4.066	2.281	-1.78
61	4.001	2.328	-1.67
62	3.969	2.379	-1.59
63	3.969	2.407	-1.56
64	3.872	2.441	-1.43
65	3.775	2.451	-1.32
66	3.711	2.475	-1.23
67	3.55	2.472	-1.07
68	3.347	2.462	-.885
69	3.516	2.442	-1.07
70	3.582	2.415	-1.16
71	3.582	2.401	-1.18
72	3.414	2.361	-1.05
73	3.042	2.317	-.725
74	2.761	2.266	-.494
75	2.563	2.208	-.355
76	2.366	2.127	-.238
77	2.248	2.038	-.209
78	2.13	1.955	-.174
79	2.287	1.874	-.412
80	2.248	1.786	-.461
81	2.004	1.673	-.331
82	1.837	1.573	-.264

Table 6.46: Groton Approach 4, XY Error Angles Continued

83	1.587	1.444	-.142
84	1.041	1.335	.2946
85	1.041	1.207	.1663
86	.71	1.072	.3626
87	.5578	.9356	.3777
88	.2535	.7966	.5430
89	-.101	.6659	.7673
90	-.202	.5228	.7257
91	-.659	.3874	1.046
92	-.963	.2263	1.189
93	-1.06	.0770	1.142
94	-1.31	-.084	1.234
95	-1.50	-.243	1.259
96	-1.71	-.395	1.316
97	-2.00	-.564	1.439
98	-2.22	-.711	1.513
99	-2.46	-.861	1.600
100	-2.69	-1.02	1.675
101	-2.91	-1.18	1.732
102	-3.10	-1.32	1.773
103	-3.28	-1.47	1.816
104	-3.36	-1.61	1.745
105	-3.51	-1.78	1.731
106	-3.72	-1.95	1.774
107	-3.94	-2.09	1.844
108	-4.11	-2.25	1.861
109	-4.36	-2.38	1.984
110	-4.43	-2.52	1.916
111	-4.50	-2.66	1.840
112	-4.68	-2.78	1.897
113	-4.79	-2.91	1.880
114	-4.82	-3.03	1.796
115	-4.93	-3.13	1.803
116	-4.93	-3.21	1.720
117	-4.89	-3.29	1.605
118	-4.50	-3.35	1.158
119	-4.68	-3.39	1.289
120	-4.61	-3.39	1.219
121	-4.43	-3.41	1.023
122	-4.29	-3.40	.8945
123	-4.08	-3.35	.7253
124	-3.94	-3.33	.6100

Table 6.47: Groton Approach 4, XY Error Angles Continued

125	-3.69	-3.27	.4194
126	-3.51	-3.20	.3120
127	-3.28	-3.11	.1734
128	-3.13	-3.02	.1125
129	-2.87	-2.90	-.027
130	-2.60	-2.77	-.170
131	-2.22	-2.63	-.408
132	-1.92	-2.47	-.554
133	-1.67	-2.35	-.679
134	-1.31	-2.16	-.841
135	-.963	-1.98	-1.01
136	-.608	-1.80	-1.19
137	-.253	-1.60	-1.35
138	.1521	-1.37	-1.52
139	.5071	-1.15	-1.66
140	1.041	-.935	-1.97
141	1.461	-.716	-2.17
142	1.837	-.470	-2.30
143	2.088	-.197	-2.28
144	2.485	.0885	-2.39
145	2.721	.3637	-2.35
146	2.975	.6089	-2.36
147	3.279	.8820	-2.39
148	3.482	1.159	-2.32
149	3.711	1.406	-2.30
150	3.872	1.654	-2.21
151	4.034	1.900	-2.13
152	4.098	2.150	-1.94
153	4.098	2.342	-1.75
154	4.098	2.524	-1.57
155	3.969	2.660	-1.30
156	3.775	2.797	-.978
157	3.55	2.885	-.664
158	3.279	2.924	-.354
159	3.009	2.947	-.061
160	2.721	2.943	.2221
161	2.406	2.894	.4882
162	2.004	2.876	.8722
163	1.670	2.812	1.141
164	1.230	2.711	1.480
165	.8046	2.599	1.795
166	.3042	2.477	2.172

Table 6.48: Groton Approach 4, XY Error Angles Continued

167	-.101	2.317	2.418
168	-.659	2.178	2.837
169	-1.21	1.995	3.212
170	-1.67	1.779	3.450
171	-2.04	1.628	3.674
172	-2.50	1.406	3.915
173	-2.95	1.232	4.184
174	-3.25	.9886	4.239
175	-3.51	.7674	4.280
176	-3.72	.5067	4.234
177	-3.86	.2365	4.106
178	-3.90	.0636	3.968
179	-3.76	-.103	3.659
180	-3.51	-.276	3.236
181	-3.06	-.367	2.697
182	-2.41	-.410	2.003
183	-1.58	-.375	1.211
184	-.557	-.353	.2044
185	.5578	-.234	-.792
186	1.545	-.124	-1.66
187	2.406	.0736	-2.33
188	3.076	.3533	-2.72
189	3.582	.6016	-2.98
190	3.937	.8310	-3.10
191	4.163	1.065	-3.09
192	4.227	1.301	-2.92
193	4.098	1.508	-2.59
194	3.872	1.624	-2.24
195	3.482	1.682	-1.79
196	2.907	1.691	-1.21
197	2.088	1.739	-.348
198	1.230	1.557	.3263
199	.2028	1.506	1.304
200	-.557	1.378	1.936
201	-1.21	1.264	2.481
202	-1.58	1.161	2.748
203	-1.79	1.032	2.828
204	-1.83	.9125	2.750
205	-1.92	.7269	2.648
206	-2.04	.5918	2.638

AVERAGE ERROR ANGLE = 9.98287284E-03
STANDARD DEVIATION = 1.72854893

Table 6.49: Groton Approach 4, XY Error Angles Continued

End approach

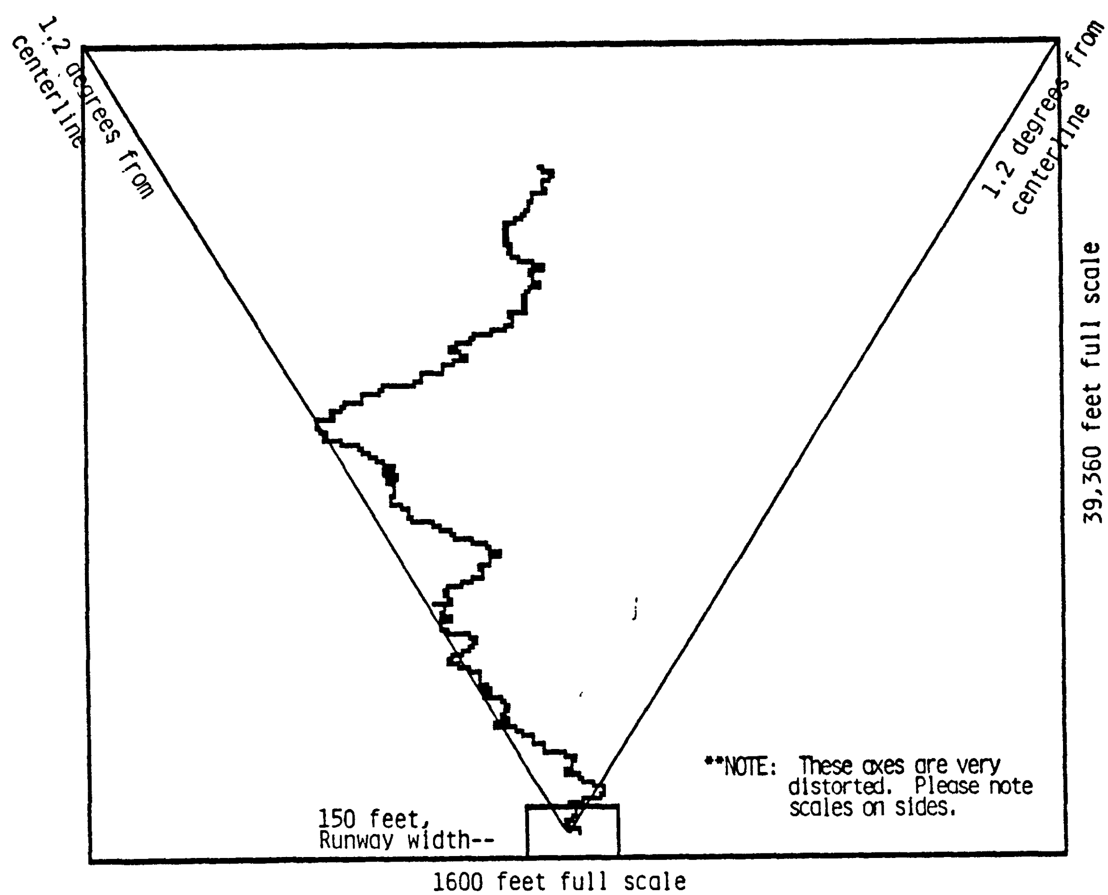

Figure 6.35: Bar Harbor Approach 1, WX LORAN Path

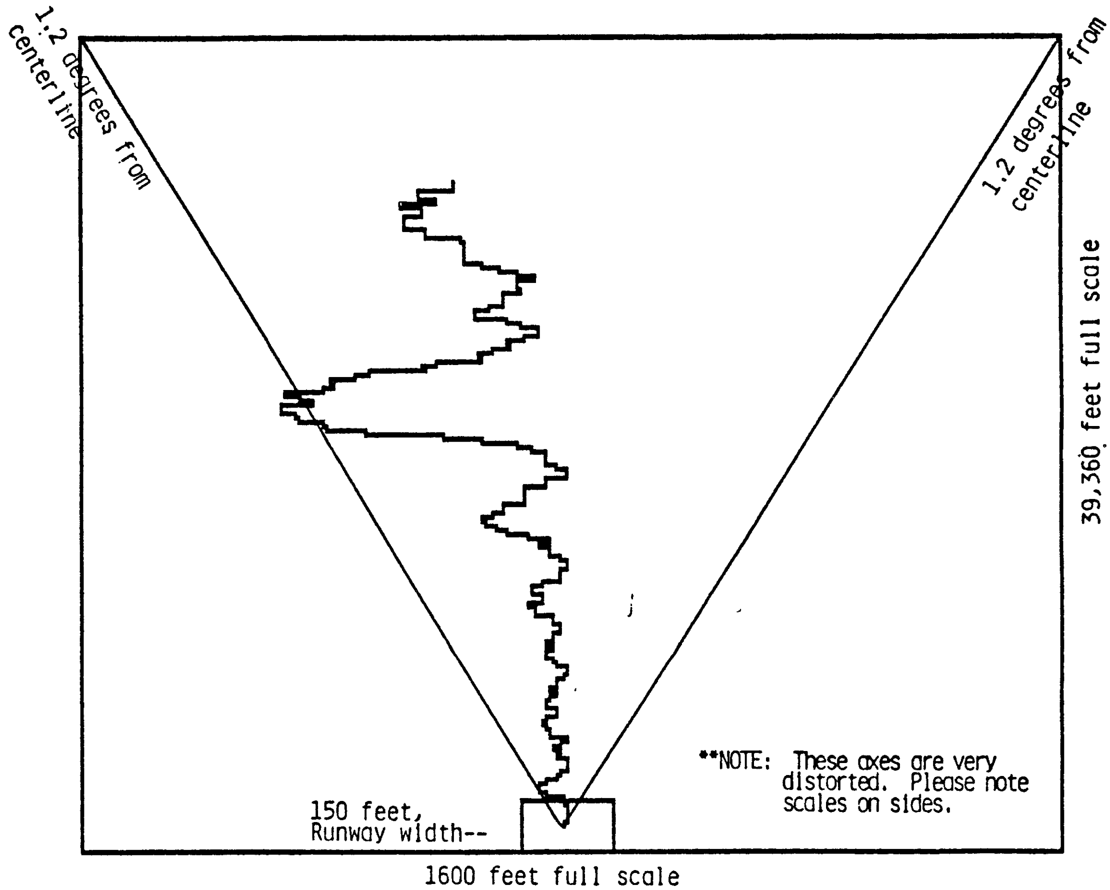

Figure 6.36: Bar Harbor Approach 1, WX Localizer Path

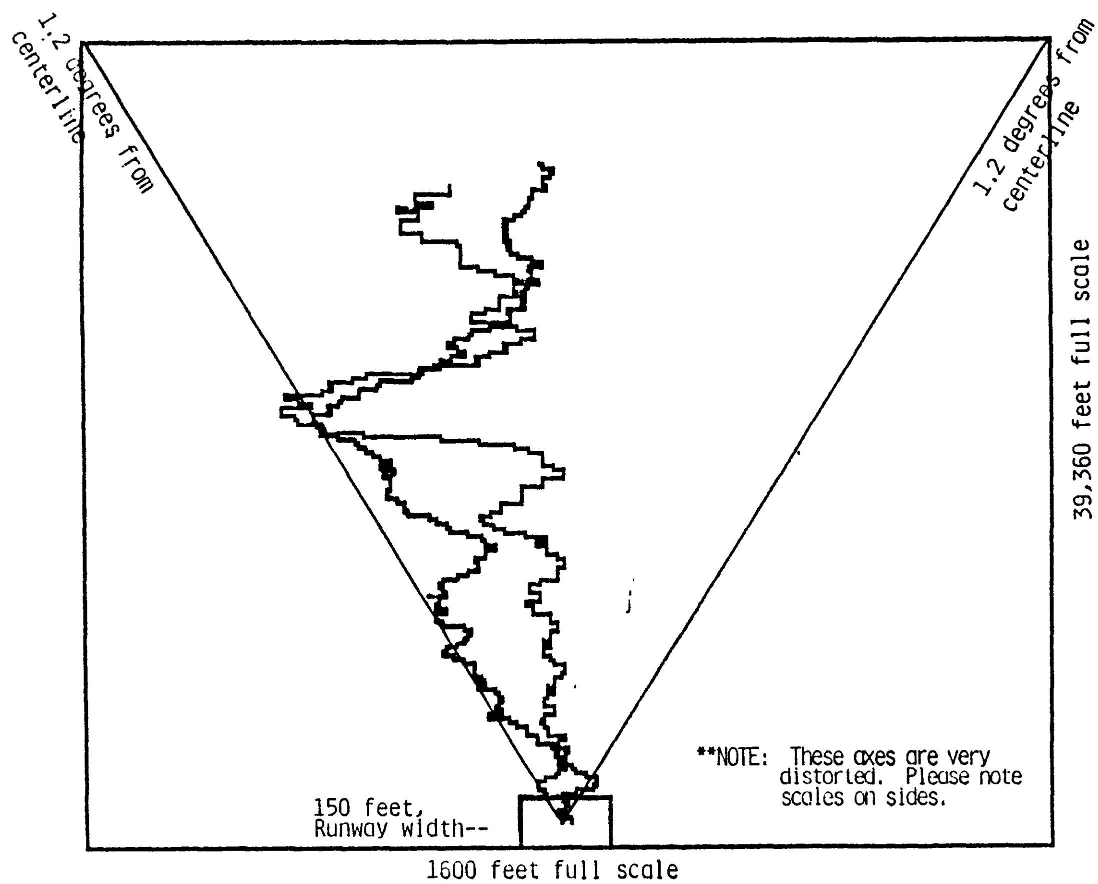

Figure 6.37: Bar Harbor Approach 1, WX Combined Paths

This is the data for BAR AP1 WX1

# PNT	LOCALIZER ANGLE	LORAN ANGLE	DIFFERENCE LORAN-LOC
1	-.437	.0714	.5086
2	3.709	.0622	-3.64
3	.2914	.0384	-.252
4	.2914	.0482	-.243
5	.2914	.0678	-.223
6	.3885	.0632	-.325
7	.3885	.0586	-.329
8	.34	.0910	-.248
9	.4371	.0914	-.345
10	.3885	.1093	-.279
11	.3885	.1048	-.283
12	.3885	.1155	-.273
13	.4371	.1288	-.308
14	.4371	.1423	-.294
15	.4371	.1714	-.265
16	.3885	.1619	-.226
17	.3885	.1732	-.215
18	.2914	.1688	-.122
19	.2914	.1776	-.113
20	.2914	.1600	-.131
21	.2914	.1688	-.122
22	.2914	.1643	-.127
23	.2914	.1381	-.153
24	.2914	.1089	-.182
25	.2428	.0794	-.163
26	.1942	.1127	-.081
27	.1942	.1104	-.083
28	.1457	.1110	-.034
29	.0971	.1087	.0116
30	.1457	.0868	-.058
31	.1457	.1154	-.030
32	.1457	.1245	-.021
33	.1942	.1394	-.054

Begin approac

Table 6.50: Bar Harbor Approach 1, WX Error Angles

34	.1942	.1343	-.059
35	.1942	.1379	-.056
36	.1942	.1299	-.064
37	.2428	.1364	-.106
38	.2914	.1871	-.104
39	.2914	.1792	-.112
40	.1942	.1802	-.014
41	.1457	.2021	.0564
42	.0971	.2484	.1513
43	.0971	.2680	.1709
44	.1457	.3031	.1574
45	.1457	.3232	.1775
46	.1942	.3683	.1740
47	.1942	.3922	.1979
48	.2428	.3539	.1110
49	.2914	.3433	.0519
50	.2914	.3770	.0856
51	.4371	.3951	-.041
52	.4857	.4328	-.052
53	.4857	.4321	-.053
54	.68	.4997	-.180
55	.7253	.5094	-.215
56	.816	.5323	-.283
57	.816	.5755	-.240
58	.8613	.6527	-.208
59	.9973	.6671	-.330
60	.952	.7360	-.215
61	.9066	.7376	-.169
62	.9973	.8045	-.192
63	1.042	.8204	-.222
64	1.042	.8714	-.171
65	.9973	.8668	-.130
66	.9973	.9293	-.068
67	.9066	.9361	.0294
68	.9066	.9430	.0363
69	.7706	.9463	.1756

Table 6.51: Bar Harbor Approach 1, WX Error Angles Continued

70	.5828	.9170	.3341
71	.4857	.9422	.4565
72	.34	.8792	.5392
73	.1942	.8152	.6210
74	.1457	.8105	.6648
75	.0971	.7978	.7007
76	.0971	.7737	.6766
77	.0971	.7493	.6521
78	.0485	.7284	.6798
79	0	.7226	.7226
80	0	.7680	.7680
81	0	.7227	.7227
82	.0971	.7610	.6639
83	.0971	.7471	.6500
84	.1942	.7534	.5591
85	.1942	.7555	.5612
86	.1942	.7870	.5927
87	.1942	.7938	.5995
88	.2428	.7545	.5117
89	.2914	.7228	.4314
90	.2914	.7292	.4378
91	.34	.7184	.3784
92	.3885	.6635	.2749
93	.3885	.6297	.2412
94	.34	.6177	.2777
95	.2914	.5737	.2822
96	.2914	.5608	.2694
97	.1942	.4694	.2752
98	.0971	.4089	.3118
99	.1457	.3941	.2484
100	.0971	.3601	.2630
101	.0971	.4017	.3045
102	.0485	.4153	.3668
103	0	.4633	.4633
104	0	.4825	.4825
105	.0485	.4675	.4189

Table 6.52: Bar Harbor Approach 1, WX Error Angles Continued

106	.0485	.4672	.4186
107	.0485	.5276	.4790
108	.0485	.5845	.5359
109	.1457	.6734	.5277
110	.1942	.7015	.5073
111	.1942	.6826	.4883
112	.1457	.6791	.5334
113	.1457	.7842	.6385
114	.1942	.7324	.5382
115	.2428	.7351	.4922
116	.1942	.7601	.5658
117	.1942	.7063	.5120
118	.0971	.7773	.6802
119	.0971	.7978	.7006
120	.0485	.7719	.7233
121	.0485	.6858	.6372
122	.0971	.6518	.5546
123	.0971	.6169	.5198
124	.0971	.6367	.5395
125	.1457	.6818	.5361
126	.0971	.7280	.6309
127	.1457	.8141	.6684
128	.1457	.8308	.6851
129	.0971	.7820	.6848
130	.0971	.7790	.6819
131	.0485	.7282	.6797
132	0	.6489	.6489
133	0	.6786	.6786
134	.0485	.6876	.6390
135	.0971	.6473	.5501
136	.0971	.7071	.6100
137	.1457	.6291	.4834
138	.0971	.7058	.6086
139	.1457	.5651	.4193
140	.1942	.5433	.3490
141	.1942	.5359	.3416

Table 6.53: Bar Harbor Approach 1, WX Error Angles Continued

142	.1942	.5601	.3658
143	.0971	.6171	.5200
144	.0971	.5536	.4565
145	.1942	.5878	.3935
146	.2428	.6918	.4490
147	.1942	.5219	.3276
148	.1942	.4692	.2750
149	.1942	.3613	.1670
150	.1942	.3679	.1736
151	0	.2909	.2909
152	.0971	.3060	.2088
153	.1457	.0886	-.057
154	.0971	-.018	-.115
155	.1457	.0309	-.114
156	0	.0312	.0312
157	0	.0314	.0314
158	0	.1072	.1072
159	0	-.056	-.056
160	.0971	-.091	-.188
161	.1457	-.221	-.367
162	.2914	-.345	-.637
163	.3885	-.367	-.755
164	.3885	-.327	-.715
165	.2914	-.246	-.538
166	.2428	-.096	-.339
167	.0971	.0618	-.035
168	.0971	-.033	-.130
169	0	-.049	-.049
170	0	.0510	.0510
171	0	.1278	.1278
172	0	.0844	.0844
173	.0971	-.042	-.139
174	.0971	-.110	-.208

AVERAGE ERROR ANGLE = .175588065
STANDARD DEVIATION = .356684976

Table 6.54: Bar Harbor Approach 1, WX Error Angles Continued

End approach

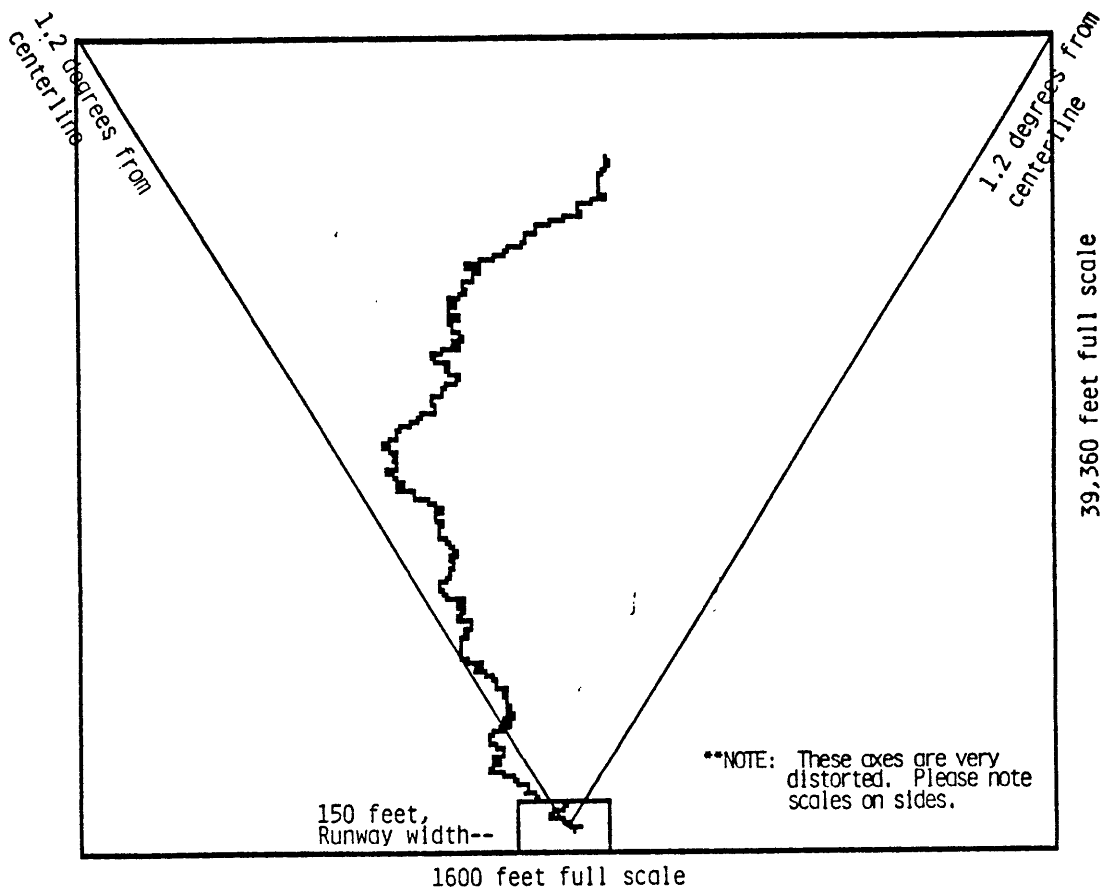

Figure 6.38: Bar Harbor Approach 2, WX LORAN Path

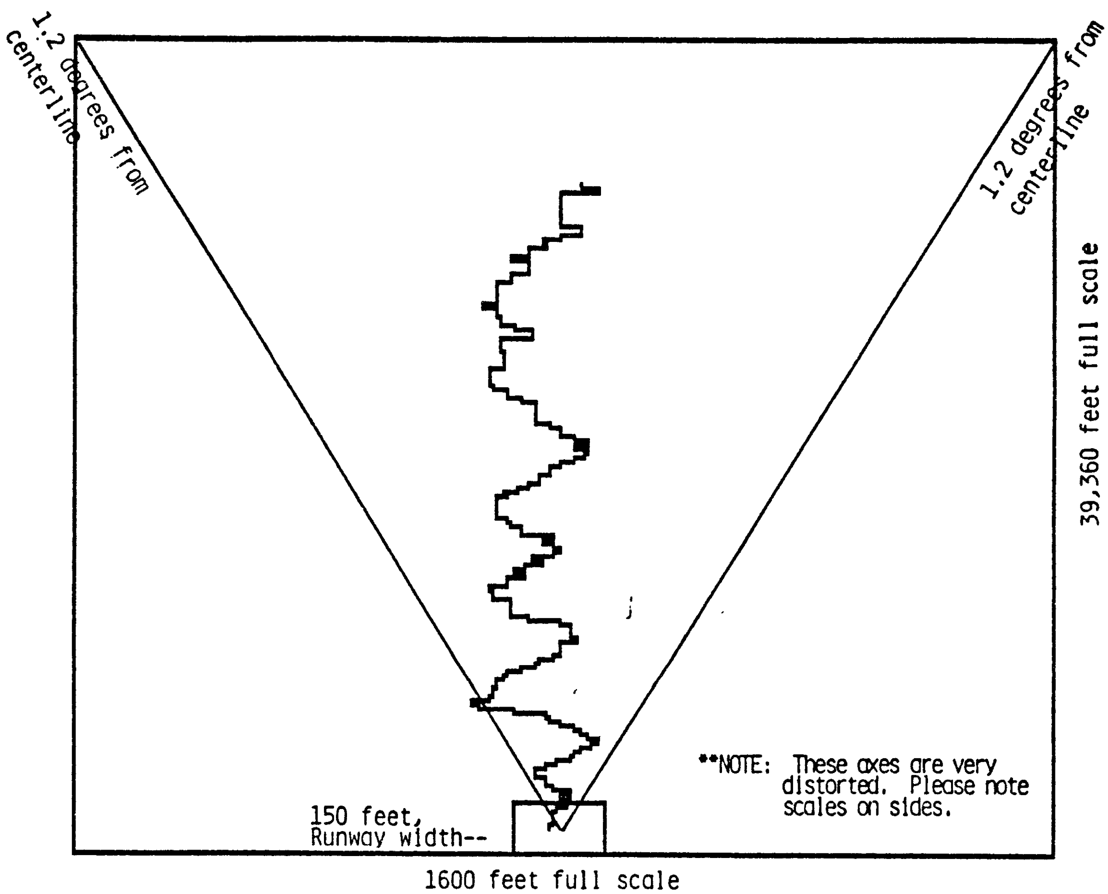

Figure 6.39: Bar Harbor Approach 2, WX Localizer Path

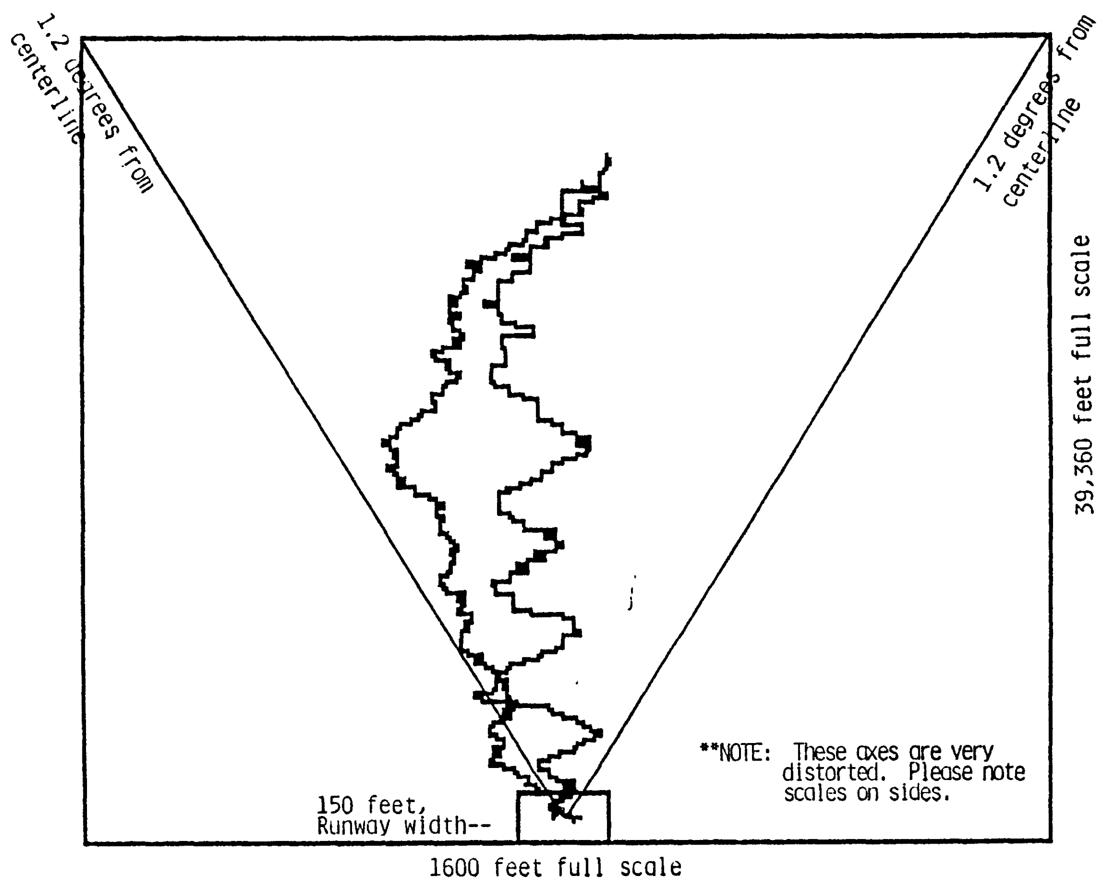

Figure 6.40: Bar Harbor Approach 2, WX Combined Paths

This is the data for BAR AP2 WX2

# PNT	LOCALIZER ANGLE	LORAN ANGLE	DIFFERENCE LORAN-LOC
1	-.437	-.111	.3261
2	3.709	-.118	-3.82
3	-.048	-.105	-.056
4	-.048	-.103	-.054
5	-.097	-.097	1.371
6	0	-.095	-.095
7	0	-.098	-.098
8	0	-.098	-.098
9	0	-.097	-.097
10	0	-.110	-.110
11	0	-.075	-.075
12	0	-.053	-.053
13	0	-.039	-.039
14	0	-.054	-.054
15	-.048	-3.78	.0447
16	-.048	.0322	.0807
17	0	.0712	.0712
18	0	.0689	.0689
19	.0485	.0771	.0285
20	.0485	.1039	.0553
21	.0971	.1124	.0153
22	.0971	.1505	.0533
23	.1457	.1620	.0163
24	.0971	.1737	.0766
25	.0971	.1965	.0994
26	.0971	.2333	.1361
27	.1457	.2761	.1303
28	.1457	.2360	.0903
29	.1942	.2625	.0682
30	.1942	.2669	.0726
31	.1942	.2940	.0997
32	.1942	.3016	.1073
33	.1942	.2920	.0977
34	.1942	.3111	.1169
35	.2428	.3481	.1052

Begin approach

Table 6.55: Bar Harbor Approach 2, WX Error Angles

36	.1942	.3297	.1354
37	.1942	.3466	.1523
38	.1942	.3488	.1545
39	.1942	.3241	.1299
40	.1942	.3533	.1590
41	.1457	.3497	.2039
42	.0971	.3551	.2579
43	.0971	.3329	.2357
44	.1942	.3259	.1316
45	.1942	.3561	.1618
46	.1942	.3428	.1485
47	.1942	.3959	.2016
48	.1942	.4305	.2362
49	.1942	.4272	.2329
50	.1942	.3786	.1843
51	.1942	.3976	.2033
52	.2428	.3873	.1445
53	.2428	.3603	.1175
54	.2428	.3697	.1268
55	.2428	.4160	.1732
56	.2428	.4225	.1797
57	.1942	.4291	.2349
58	.1942	.4738	.2795
59	.1457	.4671	.3214
60	.0971	.4639	.3667
61	.0971	.5169	.4197
62	.0971	.5423	.4452
63	.0971	.5682	.4711
64	.0971	.6164	.5193
65	.0971	.6326	.5354
66	.0485	.6415	.5929
67	0	.6730	.6730
68	0	.7050	.7050
69	-.048	.6847	.7333

Table 6.56: Bar Harbor Approach 2, WX Error Angles Continued

70	-.097	.6679	.7651
71	-.048	.6776	.7261
72	-.097	.6679	.7651
73	-.097	.6858	.7829
74	-.097	.7238	.8209
75	-.048	.7066	.7552
76	0	.6969	.6969
77	.0485	.6791	.6305
78	.0485	.7101	.6615
79	.0971	.6505	.5533
80	.0971	.6527	.5556
81	.1457	.5956	.4499
82	.1942	.5759	.3816
83	.2428	.5513	.3085
84	.2428	.5874	.3446
85	.2914	.5846	.2931
86	.2914	.5684	.2770
87	.2914	.5879	.2965
88	.2914	.5989	.3075
89	.2914	.6055	.3141
90	.2428	.5703	.3274
91	.2428	.5526	.3097
92	.1942	.5398	.3455
93	.1942	.5702	.3759
94	.1457	.5569	.4112
95	.0485	.5634	.5148
96	.0971	.5849	.4878
97	.0485	.5920	.5434
98	0	.6197	.6197
99	.0485	.6687	.6201
100	.1457	.6771	.5314
101	.0971	.6693	.5722
102	.1942	.6509	.4567
103	.2428	.5773	.3344
104	.1942	.6127	.4184
105	.1942	.5870	.3927

Table 6.57: Bar Harbor Approach 2, WX Error Angles Continued

106	.2914	.6176	.3262
107	.2914	.6373	.3459
108	.3885	.5642	.1757
109	.3885	.5777	.1891
110	.3885	.6161	.2275
111	.2914	.6126	.3212
112	.2914	.6711	.3797
113	.2914	.6812	.3897
114	.2914	.6974	.4059
115	.1942	.6883	.4940
116	.0971	.6721	.5749
117	0	.5685	.5685
118	-.048	.6312	.6798
119	-.048	.6338	.6824
120	-.048	.5663	.6149
121	-.097	.5251	.6222
122	0	.5113	.5113
123	0	.5189	.5189
124	0	.4598	.4598
125	.0485	.4970	.4484
126	.1457	.4506	.3049
127	.1942	.4730	.2787
128	.1942	.4564	.2621
129	.2914	.4953	.2039
130	.3885	.4209	.0324
131	.4371	.4521	.0149
132	.4857	.5264	.0407
133	.4857	.4832	-2.45
134	.5342	.5952	.0609
135	.5342	.5689	.0346
136	.5828	.6584	.0756
137	.7253	.7144	-.010
138	.7253	.7258	4.809
139	.68	.6999	.0199
140	.3885	.6818	.2932
141	.1457	.6045	.4588

Table 6.58: Bar Harbor Approach 2, WX Error Angles Continued

142	.0971	.6136	.5165
143	0	.6334	.6334
144	-.097	.7560	.8532
145	-.194	.7161	.9104
146	-.242	.7698	1.012
147	-.34	.8142	1.154
148	-.291	.8712	1.162
149	-.291	.8633	1.154
150	-.194	.7305	.9248
151	-.145	.6168	.7625
152	-.097	.6159	.7130
153	.0485	.5676	.5190
154	.1942	.4928	.2985
155	.2914	.4895	.1981
156	.2914	.4733	.1819
157	.1942	.5205	.3262
158	.1942	.4124	.2181
159	.0971	.3667	.2696
160	0	.2926	.2926
161	-.097	-6.08	.0910
162	0	.0498	.0498
163	-.145	.1084	.2541
164	-.097	.1988	.2960
165	.0971	.2331	.1359
166	.1457	.0527	-.092
167	.1457	.0377	-.107
168	.1457	-.075	-.220
169	.1942	-.276	-.470
170	.1942	-.147	-.342

AVERAGE ERROR ANGLE = .306073739
STANDARD DEVIATION = .289293795

Table 6.59: Bar Harbor Approach 2, WX Error Angles Continued

End approach

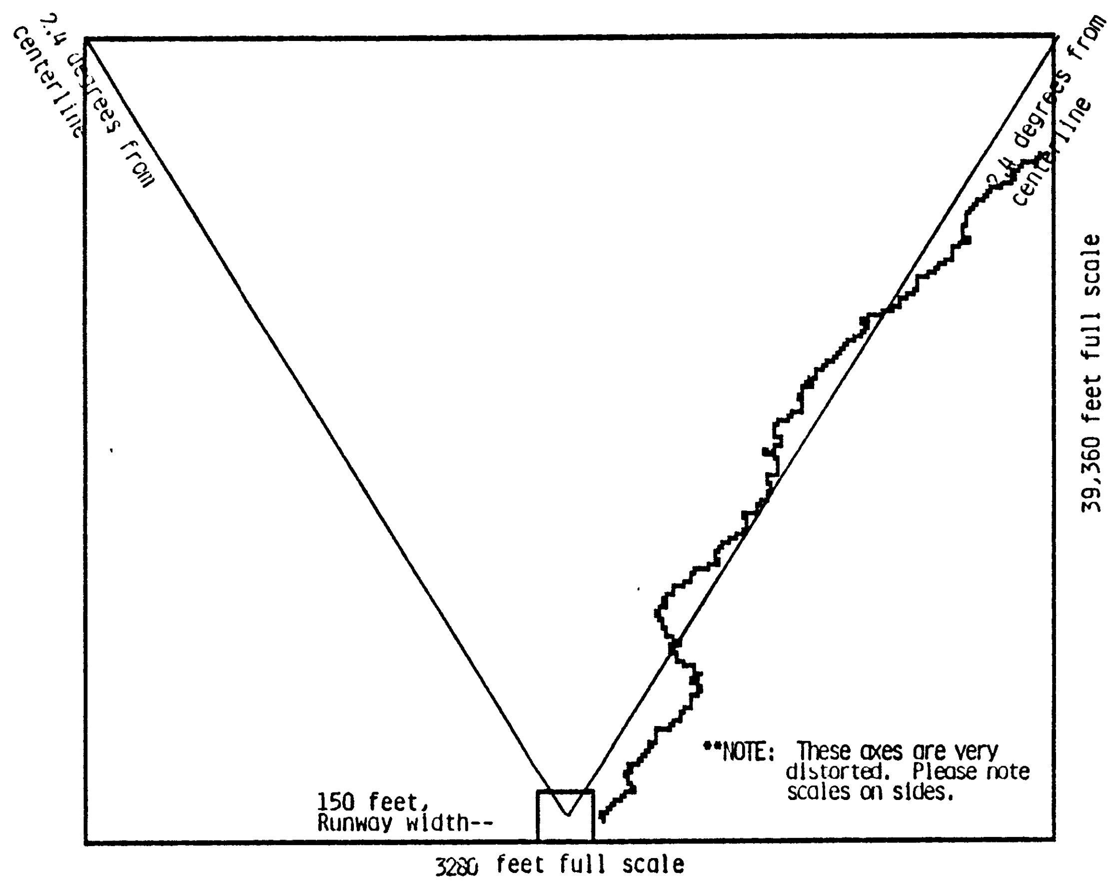

Figure 6.41: Bar Harbor Approach 3, WX LORAN Path

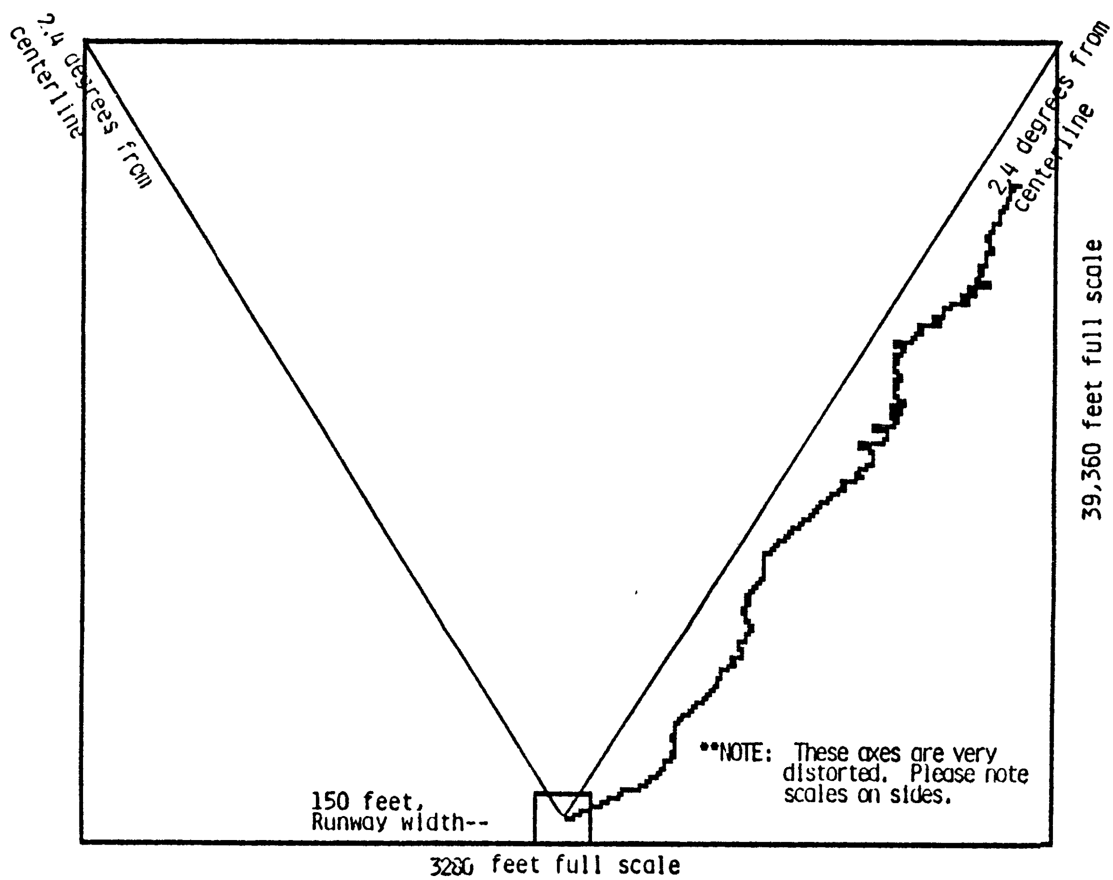

Figure 6.42: Bar Harbor Approach 3, WX Localizer Path

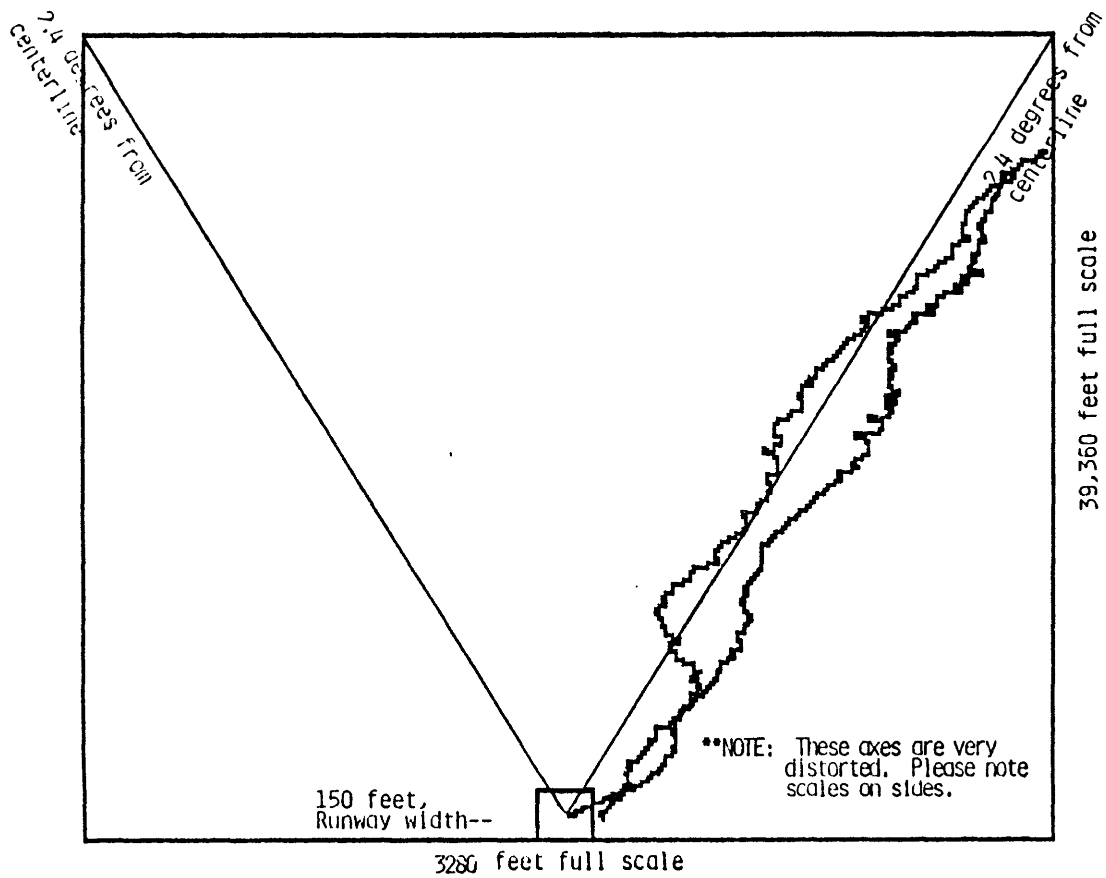

Figure 6.43: Bar Harbor Approach 3, WX Combined Paths

# PNT	LOCALIZER ANGLE	LORAN ANGLE	DIFFERENCE LORAN-LOC
1	-1.92	-3.86	-1.94
2	3.770	-3.85 *	-7.62
3	-3.77	-3.83	-.059
4	-3.70	-3.79	-.086
5	-3.74	-3.75	-.010
6	-3.74	-3.75	-.016
7	-3.77	-3.72	.0450
8	-3.74	-3.75	-.014
9	-3.77	-3.75	.0226
10	-3.77	-3.69	.0750
11	-3.74	-3.62	.1140
12	-3.77	-3.61	.1566
13	-3.77	-3.61	.1606
14	-3.77	-3.57	.1993
15	-3.77	-3.54	.2242
16	-3.77	-3.55	.2191
17	-3.77	-3.54	.2332
18	-3.77	-3.55	.2217
19	-3.80	-3.58	.2229
20	-3.84	-3.55	.2825
21	-3.87	-3.57	.2998
22	-3.91	-3.61	.2953
23	-3.87	-3.68	.1909
24	-3.87	-3.63	.2432
25	-3.91	-3.59	.3134
26	-3.87	-3.61	.2568
27	-3.91	-3.61	.2951
28	-3.91	-3.58	.3218
29	-3.91	-3.53	.3765
30	-4.04	-3.54	.5053
31	-4.01	-3.48	.5270
32	-3.91	-3.42	.4867
33	-3.97	-3.44	.5322

Begin approach

Table 6.60: Bar Harbor Approach 3, WX Error Angles

34	-3.87	-3.44	.4359
35	-3.97	-3.43	.5437
36	-3.80	-3.38	.4265
37	-3.77	-3.36	.4114
38	-3.80	-3.36	.4464
39	-3.70	-3.33	.3748
40	-3.74	-3.24	.4934
41	-3.84	-3.10	.7353
42	-3.63	-3.07	.5584
43	-3.70	-3.14	.5630
44	-3.63	-3.14	.4917
45	-3.63	-3.12	.5133
46	-3.46	-3.06	.4037
47	-3.60	-3.01	.5933
48	-3.63	-2.98	.6503
49	-3.60	-2.96	.6396
50	-3.57	-2.97	.5974
51	-3.60	-2.93	.6690
52	-3.60	-2.87	.7254
53	-3.63	-2.85	.7841
54	-3.67	-2.80	.8698
55	-3.74	-2.82	.9100
56	-3.77	-2.77	.9966
57	-3.70	-2.76	.9421
58	-3.77	-2.84	.9292
59	-3.77	-2.76	1.010
60	-3.80	-2.77	1.030
61	-3.87	-2.77	1.104
62	-3.97	-2.82	1.157
63	-3.84	-2.83	1.006
64	-3.97	-2.84	1.134
65	-4.01	-2.74	1.267
66	-3.94	-2.73	1.213
67	-4.04	-2.63	1.409
68	-4.01	-2.59	1.412
69	-3.77	-2.60	1.167

Table 6.61: Bar Harbor Approach 3, WX Error Angles Continued

70	-3.97	-2.64	1.328
71	-4.01	-2.76	1.243
72	-4.01	-2.76	1.242
73	-4.01	-2.72	1.288
74	-3.77	-2.71	1.057
75	-3.94	-2.63	1.313
76	-4.01	-2.76	1.242
77	-4.04	-2.84	1.197
78	-4.04	-2.87	1.166
79	-4.01	-2.89	1.115
80	-3.94	-2.91	1.029
81	-3.94	-2.81	1.125
82	-4.04	-2.83	1.211
83	-4.01	-2.88	1.126
84	-3.84	-2.91	.9306
85	-3.91	-2.87	1.030
86	-3.84	-2.92	.9201
87	-3.77	-2.89	.8761
88	-3.77	-2.87	.9006
89	-3.70	-2.85	.8493
90	-3.70	-2.86	.8391
91	-3.70	-2.71	.9892
92	-3.70	-2.77	.9269
93	-3.67	-2.78	.8917
94	-3.60	-2.80	.7964
95	-3.57	-2.81	.7522
96	-3.50	-2.71	.7870
97	-3.46	-2.62	.8399
98	-3.43	-2.54	.8923
99	-3.4	-2.50	.8985
100	-3.4	-2.46	.9303
101	-3.36	-2.50	.8569
102	-3.36	-2.61	.7498
103	-3.29	-2.60	.6883
104	-3.32	-2.46	.8675
105	-3.32	-2.26	1.065

Table 6.62: Bar Harbor Approach 3, WX Error Angles Continued

106	-3.4	-2.20	1.193
107	-3.43	-2.24	1.190
108	-3.46	-2.14	1.325
109	-3.46	-1.99	1.473
110	-3.46	-2.02	1.447
111	-3.43	-1.87	1.555
112	-3.4	-1.86	1.531
113	-3.36	-1.92	1.437
114	-3.36	-1.84	1.515
115	-3.43	-1.75	1.676
116	-3.43	-1.87	1.559
117	-3.43	-1.94	1.487
118	-3.43	-1.98	1.448
119	-3.53	-2.12	1.413
120	-3.57	-2.13	1.430
121	-3.70	-2.32	1.385
122	-3.80	-2.49	1.316
123	-3.80	-2.46	1.346
124	-3.84	-2.32	1.516
125	-3.84	-2.38	1.458
126	-3.84	-2.57	1.263
127	-3.77	-2.58	1.187
128	-3.84	-2.74	1.095
129	-3.94	-3.03	.9063
130	-4.01	-3.13	.8745
131	-3.77	-3.29	.4756
132	-3.97	-3.27	.7053
133	-4.01	-3.15	.8535
134	-3.91	-3.43	.4799
135	-3.80	-3.49	.3124
136	-3.80	-3.50	.3077
137	-3.77	-3.45	.3177
138	-3.80	-3.41	.3971
139	-3.80	-3.39	.4085
140	-3.80	-3.46	.3384
141	-3.80	-3.32	.4845

Table 6.63: Bar Harbor Approach 3, WX Error Angles Continued

142	-3.77	-3.39	.3794
143	-3.77	-3.32	.4455
144	-3.67	-3.36	.3080
145	-3.60	-3.29	.3088
146	-3.57	-3.24	.3288
147	-3.43	-3.05	.3751
148	-3.43	-2.88	.5461
149	-3.36	-2.90	.4633
150	-3.36	-3.01	.3531
151	-3.50	-2.82	.6721
152	-3.50	-2.90	.5972
153	-3.53	-2.89	.6363
154	-3.67	-2.82	.8423
155	-3.77	-2.75	1.017
156	-3.77	-2.66	1.113
157	-3.84	-2.53	1.302
158	-3.97	-2.43	1.543
159	-3.97	-2.51	1.465
160	-3.84	-2.32	1.512
161	-3.84	-2.47	1.365
162	-3.80	-2.55	1.253
163	-3.77	-2.58	1.185
164	-3.63	-2.85	.7813
165	-3.53	-3.04	.4875
166	-3.32	-2.96	.3666
167	-3.11	-2.78	.3285
168	-2.62	-2.68	-.050
169	-2.62	-2.37	.2586
170	-2.08	-2.39	-.313
171	-1.8	-2.21	-.418
172	-1.44	-2.24	-.804
173	-.874	-2.01	-1.13
174	-.485	-1.86	-1.38
175	-.145	-2.05	-1.91

AVERAGE ERROR ANGLE = .720015422
STANDARD DEVIATION = .556600398

Table 6.64: Bar Harbor Approach 3, WX Error Angles Continued

End approach

Chapter 7

DISCUSSION OF RESULTS

This chapter contains some discussion on the results presented in the last two chapters. As the static and flight tests were split into two chapters, the discussion on the results will be divided into two parts.

7.1 DISCUSSION OF STATIC TESTS

The original intent of this work was to examine if FAA AC90-45A accuracy standards could be met by LORAN-C navigation during the approach stage. The semi-diameters of the long term ellipses are for the most part in the 100 to 300 foot range. The largest ellipses occur at Hanscom AFB, using the non-optimal triad of Nantucket-Carolina Beach, with semi-diameters as large as 395 feet. The AC90-45A standards for non-precision approach call for an accuracy of .3 nautical miles or 1800 feet. The largest ellipse is a factor of $4\frac{1}{2}$ better than that.

One point that shouldn't be overlooked is that this approach plate update scenario would involve predicting the mean TDs for the forthcoming approach plate time period. The ellipses generated here were done so using the maximum standard deviations, but did not take into account errors that would be introduced by forecasting the mean TDs.

In most cases, the standard deviation of the mean from year to year is a good fraction of the TD standard deviations. As an example, for Nahant, 1 July-30 September, the σ for the mean for Nantucket is .060 and the σ for the TDs is only .039. This implies that the mean varies more from year to year than do the TDs surrounding the mean. This would introduce a large amount of error over and above the .039 σ_{xmax}. By the same token, Bristol from 1 October to 31 December for Carolina Beach has a σ_{ymax} of .122 and a $\sigma_{\bar{y}}$ of only .003. IN this case, the standard deviation of the mean would have no influence on the errors. Outside of these extreems, the $\sigma_{\bar{n}}$ is a sizeable fraction of the σ_{nmax}.

The short term update scheme offers a significant reduction in the errors. For the two cases presented at Hanscom, the semi-diameters were reduced by a factor of 2 (Caribou and Nantucket)and 3 (Nantucket and Carolina Beach). Perhaps the most striking example is the reduction of the semi-major axis for Newport. The short term semi-diameter is almost a factor of *four* smaller than its long term counterpart. The question is, is it worth the cost and effort to radio the TD corrections to the pilot? It is clear that the accuracy is greatly improved over the approach plate update scheme.

However, the latter provides more than enough accuracy to surpass AC90-45A standards. I believe that the approach plate scheme is a viable one, and the errors are small enough that it should warrent consideration.

The comparisons between the short term ellipses and the scatter plots show that virtually all of the points fall within the ellipses. This is expected because the ellipses are 3σ ellipses and should contain approximately 98% of the points. Note that only between 100 and 140 data points are visible in each case. This is because many points are repeated. Following the normal approximation theory, most of the repeated points will fall nearer the center of the ellipse. This shows that the normal approximation is a good one, and that generating an error ellipse from known standard deviations will produce a good measure of the expected error. This leads to the conclusion that predicting the long term errors with this method should also be successful.

7.2 DISCUSSION OF FLIGHT TESTS

A summary of the average difference in error angles and the standard deviations is contained in table 7.1. The table also contains values for the mean plus one standard deviation angle, and the equivalent of that value in localizer indicator dots.

As can be seen by the averages, there seems to be a constant bias towards the left, as seen from the runway looking out at the plane. Looking

Approach	Triad	Average	σ	Ave+1σ	Loc Dots
Hanscom AFB					
1	W-X	.0589	.4558	.5147	$1\frac{1}{8}$
2	W-X	.1649	.4281	.5930	$1\frac{1}{3}$
3	X-Y	.0408	.3048	.3456	$\frac{3}{4}$
4	X-Y	.2386	.5941	.8327	$1\frac{4}{5}$
5	W-X	.3078	.1435	.4513	1
Bar Harbor					
1	W-X	.1756	.3567	.5323	$\frac{3}{4}$
2	W-X	.3061	.2893	.5954	$\frac{9}{10}$
3	W-X	.7200	.5566	1.276	$1\frac{9}{10}$
Newport					
1	X-Y	.1595	.6088	.7683	$\frac{7}{10}$
2	X-Y	.5536	.5104	1.064	1
Groton					
1	W-Y	-.218	.5745	-.792	$1\frac{1}{10}$
2	W-Y	.0457	.4843	.5300	$\frac{3}{4}$
3	X-Y	.2251	.3967	.6218	$\frac{9}{10}$
4	X-Y	.0099	1.728	1.738	$2\frac{1}{2}$

Table 7.1: Summary of Angle Differences

first at the averages, the worst case is approach three at Bar Harbor, with an average error of .72 degrees. This is the approach flown three dots right on the ILS indicator. This corresponds to 73 feet at the runway threshold and 381 feet at the outer marker. The best case is approach four at Groton with an average error of .0099 degrees. This corresponds to 1 foot at the threshold and 6 feet at the outer marker.

Because of the oscillatory nature of the two curves, looking at the mean plus one standard deviation will give a more accurate look at the LORAN error. The worse case is approach four at Groton, which was the oscillatory approach with a 15 degree intercept angle. Looking at the 'straight in' approaches, the worst case is approach two at Newport. This has a mean plus one standard deviation error of 1.276 degrees. This corresponds to 80 feet at the threshold and 815 feet at the outer marker.

Another way of looking at these angles is in terms of ILS indicator dots. The equivalent number of dots for each angle are indicated in table 7.1. It should be kept in mind that the angle to dot transformation is unique to each airport, so that one degree error at one airport in ILS dots is not going to be the same at another airport.

The errors in terms of the ILS dots are all within 2 dots of center (with the exception of the oscillatory approach at Groton), and many are within one dot.

Chapter 8

CONCLUSIONS

The following are the conclusions drawn from this research:

1) The data taking schemes and procedures used and presented in this report have been successful in producing real and useful data. It is possible to construct and receive FAA approval for a data taking pallet of equipment to measure both LORAN-C and localizer information. The equipment problems encountered verify that vibration and movement of the plane needs to be a strong consideration in the design of airborne systems.

2) The LORAN-C system of navigation surpasses the accuracy standards set forth in FAA AC90-45A for non precision aproaches. When compared with the localizer at four different airports, the LORAN-C error was less than 1.276 degrees, or $1\frac{9}{10}$ dots on the localizer indicator. The average error of all fourteen approaches (mean plus one standard deviation) was .648 degrees, or $1\frac{4}{10}$ dots on the localizer indicator at Hanscom AFB, and $\frac{6}{10}$ of a dot at Newport. This represents an error of 97 and 40 feet at the

runway threshold and 271 and 413 feet at the outer marker respectively. The LORAN tracked the ILS approach very well.

3) The errors associated with a TD correction scenario of publishing corrections every eight weeks in the approach plates were well within AC90-45A standards. Every ellipse had 3σ semi diameters of less than 400 feet, with most around 100 to 200 feet compared to the 1800 feet of allowable cross track error stated in AC90-45A

4) The short term ellipses corresponding to the correction scenario of radioing the corrections to the pilot were a large improvement over the long term ellipses. The cases examined showed improvement by factors between two and four. The question to be answered is whether or not the extra accuracy is necessary. Continually updating the TD corrections daily or hourly would be a more expensive process than publishing them once every eight weeks.

5) Comparison of the short term scatter plots with the short term ellipses confirm the position error ellipse method of presenting expected error as a good one. Virtually all of the scatter points fell within their respective 3σ ellipses. This suggests that the long term predictions formulated by the same method are most likely quite good.

Appendix A

POSITION ERROR ELLIPSE PROGRAMS

A.1 Loran Main Program

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C**********************************************************
C**********************************************************
C**********************************************************
C***********   POSITION ERROR ELLIPSE MAIN PROGRAM   ******
C**********************************************************
C**********************************************************
C
C THE PURPOSE OF THIS PROGRAM IS TO PRODUCE A BIVARIATE
C NORMAL DISTRIBUTION POSITION ERROR ELLIPSE FROM LORAN-C
C ERROR DATA.  GIVEN THE POSITION OF THE POINT IN QUESTION,
C THE LORAN-C CHAIN AND TRIAN USED, AND THE MEASURED
C STANDARD DEVIATIONS IN THE TD SIGNALS, THE PROGRAM WILL
C PRODUCE THE SEMI MAJOR AND MINOR AXES AND THE ORIENTATION
C OF THE RESULTING ERROR ELLIPSE.  IT WILL ALSO PRODUCE
C OTHER VALUES OF INTEREST SUCH AS THE GRADIENTS, CROSSING
C ANGLE OF THE LOPs, AND GDOP.  TWO SUBROUTINES ARE CALLED
C DURING THE OPERATION OF THIS PROGRAM, AND ARE THEMSELVES
C LISTED AFTER THE MAIN PROGRAM.
C
C**********          PARAMETER DEFINITION:         **********
C
```

```
C  MAS    = MASTER TRANSMITTER (3 LETTERS)
C  SL1    = SECONDARY NUMBER ONE (3 LETTERS)
C  SL2    = SECONDARY NUMBER TWO (3 LETTERS)
C  AIR    = NAME OF AIRPORT (3 LETTERS)
C  UDT    = UPDATE SCENARIO LABEL (10 LETTERS)
C
C  RWY    = RUNWAY NUMBER
C  CHN    = LORAN-C CHAIN (in GRI)
C  LOT    = LONGITUDE OF TOUCHDOWN POINT (REAL DEGREES)
C  LAT    = LATITUDE OF TOUCHDOWN POINT (REAL DEGREES)
C  LOM    = LONGITUDE OF MASTER TRANSMITTER (REAL DEGREES)
C  LAM    = LATITUDE OF MASTER TRANSMITTER (REAL DEGREES)
C  LO1    = LONGITUDE OF SECONDARY ONE TRANSMITTER (R DEG)
C  LA1    = LATITUDE OF SECONDARY ONE TRANSMITTER (R DEG)
C  LO2    = LONGITUDE OF SECONDARY TWO TRANSMITTER (R DEG)
C  LA2    = LATITUDE OF SECONDARY TWO TRANSMITTER ( R DEG)
C
C  NU     = TRANSMITTED FREQUENCY (Hz)
C
C  STD    = STANDARD DEVIATION IN TDs ($\mu$s)
C  S1L    = LONG TERM STD FOR SECONDARY ONE ($\mu$s)
C  S2L    = LONG TERM STD FOR SECONDARY TWO ($\mu$s)
C  S1S    = SHORT TERM STD FOR SECONDARY ONE ($\mu$s)
C  S2S    = SHORT TERM STD FOR SECONDARY TWO ($\mu$s)
C  S1     = TOTAL STD FOR SECONDARY ONE ($\mu$s)
C  S2     = TOTAL STD FOR SECONDARY TWO ($\mu$s)
C
C  MAP    = ABBREVIATION USED FOR TOUCHDOWN POINT
C
C  LOTD   = DEGREES OF LONGITUDE FOR MAP (INTEGER DEGREES)
C  LOTM   = MINUTES OF LONGITUDE FOR MAP (INTEGER MINUTES)
C  LOTS   = SECONDS OF LONGITUDE FOR MAP (INTEGER SECONDS)
C  LATD   = DEGREES OF LATITUDE FOR MAP (INTEGER DEGREES)
C  LATM   = MINUTES OF LATITUDE FOR MAP (INTEGER MINUTES)
C  LATS   = SECONDS OF LATITUDE FOR MAP (INTEGER SECONDS)
C
C  EQR    = RADIUS OF EARTH AT THE EQUATOR (FEET)
C  POR    = RADIUS OF EARTH AROUND THE POLES (FEET)
C  C      = SPEED OF LIGHT (FEET/SEC)
```

```
C  HEAD   = HEADING OF RUNWAY (DEGREES)
C  BW     = BANDWIDTH OF RECEIVER (HZ)
C
C  BR     = REDUCED LATITUDE OF RECEIVER (RADIANS)
C  BM     = REDUCED LATITUDE OF MASTER TRANSMITTER (RADIANS)
C  B1     = REDUCED LATITUDE OF SECONDARY ONE (RADIANS)
C  B2     = REDUCED LATITUDE OF SECONDARY TWO (RADIANS)
C
C  CPM      BEARING ANGLE AT THE RECEIVER OF THE GEODESIC
C  CP1    = ARC FROM RECEIVER TO TRANSMITTER, MEASURED FROM
C  CP2      TRUE NORTH (RADIANS)
C
C  G1     = GRADIENT FOR SECONDARY ONE AT RECEIVER
C           ($\mu$s/FOOT)
C  G2     = GRADIENT FOR SECONDARY TWO AT RECEIVER
C  GR1    = COMPONENT OF GRADIENT ONE PARALLEL TO RUNWAY
C           DIRECTION ($\mu$s/FOOT)
C  GR2    = COMPONENT OF GRADIENT TWO PARALLEL TO RUNWAY
C              DIRECTION ($\mu$s/FOOT)
C  GO1    = COMPONENT OF GRADIENT ONE PERPENDICULAR TO
C              RUNWAY DIRECTION ($\mu$s/FOOT)
C  GO2    = COMPONENT OF GRADIENT TWO PERPENDICULAR TO
C              RUNWAY DIRECTION ($\mu$s/FOOT)
C
C  CA     = CROSSING ANGLE OF LOPs (RADIANS)
C  GDOP   = GEOMETRIC DILUTION OF PRECISION
C  COV    = COVARIANCE
C
C  ALPHA = VARIANCE ONE OF PRINCIPAL AXES COVARIANCE
C              MATRIX (FEET)
C  GAMMA = VARIANCE TWO OF PRINCIPAL AXES COVARIANCE
C              MATRIX (FEET)
C  BETA  = COVARIANCE TERM IN PRINCIPAL AXES COVARIANCE
C              MATRIX (FEET)
C
C  ROE    = CORRELATION COEFFICIENT
C  CTHETA= ANGLE PRINCIPAL AXES ARE ROTATED FROM RUNWAY
C              COORDINATE AXES (RADIANS)
C
```

```
C .SFMX  = SEMI-MAJOR DIAMETER FOR ONE SIGMA ELLIPSE (FEET)
C  SFMN  = SEMI-MINOR DIAMETER FOR ONE SIGMA ELLIPSE (FEET)
C**********************************************************
C**********************************************************
C**********           GIVEN PARAMETERS:          **********


      CHARACTER * 3  MAS,SL1,SL2
      CHARACTER * 4  AIR
      CHARACTER * 10 UDT(10)
      INTEGER RWY,CHN
      REAL LOT,LAT,LOM,LAM,LO1,LA1,LO2,LA2,NU,S1L(10),

     1 S2L(10),S1S(10),S2S(10),S1(10),S2(10),LOTD,LOTM,LOTS,
     2 LATD,LATM,LATS

      DATA PI,EQR,POR/3.141592,6378135.,6356750.5,/
      DATA NU/1000000./
      PARAMETER S=PI/2
      PARAMETER EF=(EQR-POR)/EQR
      PARAMETER C=(299792500.0*3.2808399)

C
C***  OPEN DATA AND OUTPUT FILES  ***
C

      OPEN(UNIT=1,FILE='LORAN.DAT',FORM='FORMATTED',ACCESS=
     1 'SEQUENTIAL',STATUS='OLD')
      OPEN(UNIT=2,FILE='LORAN.OUT',FORM='FORMATTED',ACCESS=
     1 'SEQUENTIAL', STATUS='NEW')
      OPEN(UNIT=5,FILE='LORAN.LST',FORM='FORMATTED',ACCESS=
     1 'SEQUENTIAL',STATUS='NEW')
      WRITE(UNIT=5,FMT=100)'SEMI','SEMI'
100   FORMAT(52X,A,5X,A)
      WRITE(UNIT=5,FMT=101)'MAX','MIN'
101   FORMAT(52X,A,6X,A)
      WRITE(UNIT=5,FMT=102)'SEC','SEC','3sig','3sig'
102   FORMAT(14X,A,1X,A,31X,A,5X,A)
```

```
      WRITE(UNIT=5,FMT=103)'SITE','RWY','MAS','ONE','TWO',
     1 'UPDATE', 'CA','GDOP','ROE','(feet)','(feet)'
103   FORMAT(1X,A,1X,A,1X,A,1X,A,1X,A,1X,A,6X,A,4X,A,1X,A,
     1 3X,A,3X,A)
      WRITE(UNIT=5,FMT=104)'-----------------------------
     1 -----------------------------------'
104
      READ(UNIT=1,FMT='(I3)')N
C
      DO 10 NENT=1,N
           READ(UNIT=1,FMT='(A4,I3,F6.2,F4.0,F3.0,F5.2,F4.0,
     1      F3.0,F5.2,I4,A3,A3,A3,F6.3)') AIR,RWY,HEAD,LOTD,
     2      LOTM,LOTS,LATD,LATM,LATS,CHN,MAS,SL1,SL2,BW
C
C***  DETERMINE LORAN-C CHAIN AND TRIAD LOCATION  ***
C
           LOT=((LOTD)+(LOTM/60.)+(LOTS/3600.))
           LAT=((LATD)+(LATM/60.)+(LATS/3600.))
           IF(CHN.EQ.5930)THEN
                CALL SUB5930(MAS,SL1,SL2,LOM,LAM,LO1,LA1,
     1           LO2,LA2)
           ELSEIF(CHN.EQ.7980)THEN
                CALL SUB7980(MAS,SL1,SL2,LOM,LAM,LO1,LA1,
     1           LO2,LA2)
           ELSEIF(CHN.EQ.8970)THEN
                CALL SUB8970(MAS,SL1,SL2,LOM,LAM,LO1,LA1,
     1           LO2,LA2)
           ELSEIF(CHN.EQ.9940)THEN
                CALL SUB9940(MAS,SL1,SL2,LOM,LAM,LO1,LA1,
     1           LO2,LA2)
           ELSEIF(CHN.EQ.9960)THEN
                CALL SUB9960(MAS,SL1,SL2,LOM,LAM,LO1,LA1,
     1           LO2,LA2)
           ELSE PRINT*, 'THERE IN AN INVALID CHAIN NUMBER
     1          IN THE DATA FILE, PLEASE CHECK AND CHANGE'
           ENDIF

C
           RLAT=LAT*PI/180.
```

```
      RLAM=LAM*PI/180.
      RLA1=LA1*PI/180.
      RLA2=LA2*PI/180.
      BR=ATAN((1-EF)*TAN(RLAT))
      BM=ATAN((1-EF)*TAN(RLAM))
      B1=ATAN((1-EF)*TAN(RLA1))
      B2=ATAN((1-EF)*TAN(RLA2))
      DM=((LOT)-(LOM))
      D1=((LOT)-(LO1))
      D2=((LOT)-(LO2))
C
      RDM=DM*PI/180.
      RD1=D1*PI/180.
      RD2=D2*PI/180.
      TPM=(COS(BM))*(SIN(RDM))
      TP1=(COS(B1))*(SIN(RD1))
      TP2=(COS(B2))*(SIN(RD2))
      BTM=((COS(BR))*(SIN(BM)))-((SIN(BR))*(COS(BM))*
     1 (COS(RDM)))
      BT1=((COS(BR))*(SIN(B1)))-((SIN(BR))*(COS(B1))*
     1 (COS(RD1)))
      BT2=((COS(BR))*(SIN(B2)))-((SIN(BR))*(COS(B2))*
     1 (COS(RD2)))
C
      PM=ATAN(TPM/BTM)
      P1=ATAN(TP1/BT1)
      P2=ATAN(TP2/BT2)
      APM=PM*180/PI
      AP1=P1*180/PI
      AP2=P2*180/PI
      CALL QUAD(PM,TPM,BTM,CPM)
      CALL QUAD(P1,TP1,BT1,CP1)
      CALL QUAD(P2,TP2,BT2,CP2)
      ACPM=CPM*180/PI
      ACP1=CP1*180/PI
      ACP2=CP2*180/PI
C
C***  COMPUTE GRADIENTS  ***
C
```

```
      G1=((2*NU/C)*SIN((CP1-CPM)/2))
      G2=((2*NU/C)*SIN((CP2-CPM)/2))
      ZG1=1/G1
      ZG2=1/G2
C
C***  COMPUTE RUNWAY COORDINATE GRADIENT COMPONENTS  ***
C
      PH1=(CP1+CPM)/2
      PH2=(CP2+CPM)/2
      DPH1=PH1*180/PI
      DPH2=PH2*180/PI
      GR1=((-G1)*SIN(PH1+2*PI-HEAD))
      GO1=((G1)*COS(PH1+2*PI-HEAD))
      GR2=((-G2)*SIN(PH2+2*PI-HEAD))
      GO2=((G2)*COS(PH2+2*PI-HEAD))
      ZGR1=1/GR1
      ZGR2=1/GR2
      ZGO1=1/GO1
      ZGO2=1/GO2

C
      CA=ABS(PH1-PH2)
      CA=ABS(DPH1-DPH2)
      IF(DCA.LT.90.)THEN
           DCA=180-DCA
      ELSE
           DCA=DCA
      ENDIF
      IF(CA.LT.S)THEN
           CA=PI-CA
      ELSE
           CA=CA
      ENDIF
C
      XI=SQRT((G1**2)+(G2**2))
      XR=SQRT((G1**2)+(G2**2)-2*(ABS(G1))*(ABS(G2))*
     1 (COS(CA)))
      GDOP=XR/XI
C
```

```
          READ(UNIT=1,FMT='(I3)')NENTRY
          DO 20 J=1,NENTRY
               READ(UNIT=1,FMT='(A10,F6.4,F6.4,F6.4,F6.4,
     1          F5.3)')UDT(J),S1L(J),S1L(J),S1S(J),
     2          S2S(J),COV
20        CONTINUE
          DO 30  J=1,NENTRY
               S1(J)=SQRT(((S1L(J))**2)+((S1S(J))**2))
               S2(J)=SQRT(((S2L(J))**2)+((S1S(J))**2))
C
C***      NOW COMPUTE THE VALUES FOR THE COVARIANCE MATRIX  ***
C***                                                        ***
C***        | ALPHA   BETA  |                               ***
C***        |               |                               ***
C***        | BETA    GAMMA |                               ***
C
               COV=0.0
               ALPHA=(((GO2**2)*(S1(J)**2))-(2*(GO1)*(GO2)
     1         *COV)+((GO1**2)*(S2(J)**2)))/(((GO2*GR1)
     2         -(GO1*GR2))**2)
C
               GAMMA=(((GR2**2)*(S1(J)**2))-(2*(GR1)*(GR2)
     1         *COV)+((GR1**2)*(S2(J)**2)))/(((GO2*GR1)
     2         -(GO1*GR2))**2)
C
               BETA=((-GO2*GR2*(S1(J)**2))-(GO1*GR1*(S2(J)
     1         **2))+COV*((GR1*GO2)+(GO1*GR2)))/(((GO2*GR1)
     2         -(GO1*GR2))**2)
C
               SQA=SQRT(ALPHA)
               SQG=SQRT(GAMMA)
C
               SSQ=((SQRT(ALPHA))*(SQRT(GAMMA)))
C
               IF(SSQ.NE.O.)THEN
                    ROE = BETA/SSQ
               ELSE
                    ROE = O.
               ENDIF
```

```
C .
              IF(SSQ.NE.0.)THEN
              THETA=ATAN(((2*ROE*(SQRT(ALPHA)))*(SQRT(GAMMA)
     1        ))/ (ALPHA-GAMMA))
              ELSE
                   THETA = 0.
              ENDIF
C
              XX=(2*ROE*(SQRT(ALPHA))*(SQRT(GAMMA)))
              YY=ALPHA-GAMMA
              CALL QUAD(THETA,XX,YY,PTHETA)
              CTHETA=0.5*PTHETA
              DTHETA=CTHETA*180/PI
C
C*** COMPUTE SEMI-DIAMETERS OF THE PRINCIPAL AXES ELLIPSE **
C*** ONE SIGMA FOR AN ELLIPSE OF 46.6%   ***
C*** TWO SIGMA FOR AN ELLIPSE OF 91.0%   ***
C*** THREE SIGMA FOR AN ELLIPSE OF 99.4%   ***
C
              V=SQRT(((ALPHA-GAMMA)**2)+((2*ROE*SSQ)**2))
              SFMX=SQRT(0.5*(ALPHA+GAMMA+V))
              SFMN=SQRT(0.5*(ALPHA+GAMMA-V))
C
              S11=SFMX
              S21=SFMN
              S12=SFMX*2.
              S22=SFMN*2.
              S13=SFMX*3.
              S23=SFMN*3.


C
C***  PRINT OUT RESULTS  ***
C
              WRITE(UNIT=2,FMT=21)'This is the data for
     1         airport',AIR,'and runway',RWY
21            FORMAT (1X,A,1X,A4,2X,A,1X,I3)
              WRITE(UNIT=2,FMT=31)'Runway',RWY,'has a
     1         heading of',HEAD,'degrees'
31            FORMAT (1X,A,1X,A3,1X,A,1X,F6.2,1X,A)
```

```
      WRITE(UNIT=2,FMT=32)'MAP is at',LAT,'N',
     1 LOT,'W'
32    FORMAT (1X,A,2X,F6.3,1X,A,3X,F7.3,1X,A)
      WRITE(UNIT=2,FMT=41)'Chain is', CHN,
     1 'Master is',MAS
41    FORMAT (1X,A,1X,I4,3X,A,1X,A3)
      WRITE(UNIT=2,FMT=43)'Slaves are',SL1,
     1 'and',SL2
43    FORMAT (1X,A,2X,A3,2X,A,2X,A3)
      WRITE(UNIT=2,FMT=42)'Update frequency is'
     1 , UDT(J)
42    FORMAT (1X,A,1X,A10)
      WRITE(UNIT=2,FMT=52)'GDOP=',GDOP,'Crossing
     1 angle= ',DCA
52    FORMAT(1X,A,1X,F5.2,4X,A,1X,F5.1)
      WRITE(UNIT=2,FMT=33)'Gradient one =',ZG1,
     1 'Ft/Ms','Gradient two =',ZG2,'Ft/Ms'
33    FORMAT(1X,A,1X,F8.2,1X,A,3X,A,1X,F8.2,1X,A)
      WRITE(UNIT=2,FMT=51)'For slave', SL1,
     1 'Short term STD IS',S1S(J),
     2 'and long term STD is', S1L(J)
51    FORMAT (1X,A,1X,A3,1X,A,1X,F6.4,1X,A,1X,F6.4)
      WRITE(UNIT=2,FMT=51)'For slave', SL2,
     1 'Short term STD is', S2S(J),
     2 'And long term STD is',S2L(J)
      WRITE(UNIT=2,FMT=61)'In runway coordinates
     1 STD one is',SQA,'FEET'
61    FORMAT (1X,A,2X,F7.1,1X,A)
      WRITE(UNIT=2,FMT=71)'And STD two is',
     1 SQG,'Feet'
71    FORMAT (1X,A,2X,F7.1,1X,A)
      WRITE(UNIT=2,FMT=81)'Covariance =',BETA,
     1 'Correlation coefficient =',ROE
81    FORMAT (1X,A,2X,F11.2,4X,A,1X,F6.4)
      WRITE(UNIT=2,FMT=91)'Principal axes are
     1 rotated',DTHETA,'from runway axes.'
91    FORMAT(1X,A,1X,F6.2,1X,A)
      WRITE(UNIT=2,FMT=82)'That is the major
     1 axis',' is rotated counterclockwise from
```

```
      2           the orthogonal axis'
82                FORMAT(1X,A,A)
                  WRITE(UNIT=2,FMT=92)'Principal STD one ='
      1            ,S11,'Feet'
92                FORMAT(1X,A,F6.1,1X,A)
                  WRITE(UNIT=2,FMT=92)'Principal STD two ='
      1            ,S21,'Feet'
                  WRITE(UNIT=2,FMT=93)'For an ellipse of .466'
93                FORMAT(1X,A)
                  WRITE(UNIT=2,FMT=94)'Semi Diameter one =',
      1            S11,'Feet','Semi Diameter two =',S21,'Feet'
94                FORMAT(1X,A,1X,F8.1,1X,A,3X,A,1X,F8.1,1X,A)
                  WRITE(UNIT=2,FMT=93)'For an ellipse of .910'
                  WRITE(UNIT=2,FMT=94)'Semi Diameter one =',
      1            S12,'Feet','Semi Diameter two =',S22,'Feet'
                  WRITE(UNIT=2,FMT=93)'For an ellipse of .994'
                  WRITE(UNIT=2,FMT=94)'Semi Diameter one =',S
      1            13,'Feet','Semi Diameter two =',S23,'Feet'
                  WRITE(UNIT=2,FMT=95)' '
95                FORMAT(1X,A)
                  WRITE(UNIT=2,FMT=95)' '
                  WRITE(UNIT=5,FMT=104)AIR,RWY,MAS,SL1,SL2,
      1            UDT(J),DCA,GDOP,ROE,S13,S23
104               FORMAT(1X,A4,1X,I2,2X,A3,1X,A3,1X,A3,1X,A10,
      1            1X,F5.1,1X,F4.1,1X,F6.3,1X,F8.1,1X,F8.1)
20          CONTINUE
10     CONTINUE
       ENDFILE(UNIT=1)
       CLOSE(UNIT=1)
       STOP
       END

C
\section{Loran Subroutines}
C*************************************************************
C*************************************************************
C***********        SUBROUTINE SUBLORAN          *************
C*************************************************************
C*************************************************************
```

```
C .
C THIS SUBROUTINE FILE CONTAINS ALL OF THE SUBROUTINES
C CALLED BY THE MAIN LORAN PROGRAM.  THE FIRST GROUP
C RETURNS THE LONGITUDE AND LATITUDE OF THE LORAN-C TRIAD
C USED IN THE FLIGHT TESTS.  THE SECOND IS SIMPLY A FOUR
C QUADRANT SOLUTION ALGORITHM FOR ANY ARCTANGENT FUNCTIONS
C CALLED BY THE MAIN PROGRAM.
C
C
      SUBROUTINE SUBLORAN
C
      RETURN
      END
C
      SUBROUTINE SUB5930(MAS,SL1,SL2,LOM,LAM,LO1,LA1,LO2,LA2)
C
      CHARACTER * 3 MAS,SL1,SL2
      REAL LOM,LAM,LO1,LA1,LO2,LA2,LONAT,LANAT,LOCAR,LACAR,
     1 LOCRC,LACRC
C
C***  MASTER=CARIBOU=CAR,  NAT=NANTUCKET,  CRC=CAPE RACE  ***
C
      LOM=((67.)+(55./60.)+(37.71/3600.))
      LAM=((46.)+(48./60.)+(27.20/3600.))
      LONAT   =((69.)+(58./60.)+(39.09/3600.))
      LANAT   =((41.)+(15./60.)+(11.93/3600.))
      LOCRC   =((53.)+(10./60.)+(28.16/3600.))
      LACRC   =((46.)+(46./60.)+(32.18/3600.))
      IF(SL1.EQ.'NAT')THEN
           LO1=LONAT
           LA1=LANAT
           LO2=LOCRC
           LA2=LACRC
      ELSE
           LO1=LOCRC
           LA1=LACRC
           LO2=LONAT
           LA2=LANAT
      ENDIF
```

```
      RETURN
      END
C
C
      SUBROUTINE SUB7980(MAS,SL1,SL2,LOM,LAM,LO1,LA1,LO2,LA2)
C
      CHARACTER * 3 MAS,SL1,SL2
      REAL LOM,LAM,LO1,LA1,LO2,LA2,LOMAL,LAMAL,LOGRA,LAGRA,
     1 LORAY,LARAY,LOJUP,LAJUP,LOCBE,LACBE
C
C     MASTER=MALONE=MAL,  GRA=GRANGVILLE,  RAY=RAYMONDVILLE,
C     JUP=JUPITER,  CBE=CAROLINA BEACH
C
      LOM=((85.)+(10./60.)+(09.31/3600.))
      LAM=((30.)+(59./60.)+(38.74/3600.))
      LOGRA   =((90.)+(49./60.)+(43.60/3600.))
      LAGRA   =((30.)+(43./60.)+(33.02/3600.))
      LORAY   =((97.)+(50./60.)+(00.09/3600.))
      LARAY   =((26.)+(31./60.)+(55.01/3600.))
      LOJUP   =((80.)+(06./60.)+(53.52/3600.))
      LAJUP   =((27.)+(01./60.)+(58.49/3600.))
      LOCBE   =((77.)+(54./60.)+(46.76/3600.))
      LACBE   =((34.)+(03./60.)+(46.04/3600.))
      IF(SL1.EQ.'GRA')THEN
           LO1=LOGRA
           LA1=LAGRA
           IF(SL2.EQ.'RAY')THEN
                LO2=LORAY
                LA2=LARAY
           ELSEIF(SL2.EQ.'JUP')THEN
                LO2=LOJUP
                LA2=LAJUP
           ELSEIF(SL2.EQ.'CBE')THEN
                LO2=LOCBE
                LA2=LACBE
           ENDIF
      ELSEIF(SL1.EQ.'RAY')THEN
           LO1=LORAY
           LA1=LARAY
```

```
        IF(SL2.EQ.'GRA')THEN
            LO2=LOGRA
            LA2=LAGRA
        ELSEIF(SL2.EQ.'JUP')THEN
            LO2=LOJUP
            LA2=LAJUP
        ELSEIF(SL2.EQ.'CBE')THEN
            LO2=LOCBE
            LA2=LACBE
        ENDIF
    ELSEIF(SL1.EQ.'JUP')THEN
        LO1=LOJUP
        LA1=LAJUP
        IF(SL2.EQ.'GRA')THEN
            LO2=LOGRA
            LA2=LAGRA
        ELSEIF(SL2.EQ.'RAY')THEN
            LO2=LORAY
            LA2=LARAY
        ELSEIF(SL2.EQ.'CBE')THEN
            LO2=LOCBE
            LA2=LACBE
        ENDIF
    ELSEIF(SL1.EQ.'CBE')THEN
        LO1=LOCBE
        LA1=LACBE
        IF(SL2.EQ.'GRA')THEN
            LO2=LOGRA
            LA2=LAGRA
        ELSEIF(SL2.EQ.'RAY')THEN
            LO2=LORAY
            LA2=LARAY
        ELSEIF(SL2.EQ.'JUP')THEN
            LO2=LOJUP
            LA2=LAJUP
        ENDIF
    ENDIF
    RETURN
    END
```

```
C  .
C
C
      SUBROUTINE SUB8970(MAS,SL1,SL2,LOM,LAM,LO1,LA1,LO2,LA2)
C
      CHARACTER * 3 MAS,SL1,SL2
      REAL LOM,LAM,LO1,LA1,LO2,LA2,LODAN,LADAN,LOMAL,LAMAL
     1 LOSEN,LASEN,LOBAU,LABAU
C
C     MASTER=DANA=DAN,  MAL=MALONE,  SEN=SENECA,  BAU=BAUDETTE
C
      LAM=((39.)+(51./60.)+(07.54/3600.))
      LOM=((87.)+(29./60.)+(12.14/3600.))
      LAMAL   =((30.)+(59./60.)+(38.74/3600.))
      LOMAL   =((85.)+(10./60.)+(09.31/3600.))
      LASEN   =((42.)+(42./60.)+(50.60/3600.))
      LOSEN   =((76.)+(49./60.)+(33.86/3600.))
      LABAU   =((48.)+(36./60.)+(49.84/3600.))
      LOBAU   =((94.)+(33./60.)+(18.47/3600.))
      IF(SL1.EQ.'MAL')THEN
           LA1=LAMAL
           LO1=LOMAL
           IF(SL2.EQ.'SEN')THEN
                LA2=LASEN
                LO2=LOSEN
           ELSEIF(SL2.EQ.'BAU')THEN
                LA2=LABAU
                LO2=LOBAU
           ENDIF
      ELSEIF(SL1.EQ.'SEN')THEN
           LA1=LASEN
           LO1=LOSEN
           IF(SL2.EQ.'MAL')THEN
                LA2=LAMAL
                LO2=LOMAL
           ELSEIF(SL2.EQ.'BAU')THEN
                LA2=LABAU
                LO2=LOBAU
           ENDIF
```

```
      ELSEIF(SL1.EQ.'BAU')THEN
           LA1=LABAU
           LO1=LOBAU
           IF(SL2.EQ.'MAL')THEN
                LO2=LOMAL
                LA2=LAMAL
           ELSEIF(SL2.EQ.'SEN')THEN
                LA2=LASEN
                LO2=LOSEN
           ENDIF
      ENDIF
      RETURN
      END
C
C
C
      SUBROUTINE SUB9940(MAS,SL1,SL2,LOM,LAM,LO1,LA1,LO2,LA2)
C
      CHARACTER * 3 MAS,SL1,SL2
      REAL LOM,LAM,LO1,LA1,LO2,LA2
C
C     MASTER=FALLON=FAL, GEO=GEORGE, MID=MIDDLETOWN, SCH=SEARCHLIGHT
C
      LAM=((39.)+(33./60.)+(06.62/3600.))
      LOM=((118.)+(49./60.)+(56.37/3600.))
      LAGEO   =((47.)+(03./60.)+(47.99/3600.))
      LOGEO   =((119.)+(44./60.)+(39.53/3600.))
      LAMID   =((38.)+(46./60.)+(56.99/3600.))
      LOMID   =((122.)+(29./60.)+(44.53/3600.))
      LASCH   =((35.)+(19./60.)+(18.18/3600.))
      LOSCH   =((114.)+(48./60.)+(17.43/3600.))
      IF(SL1.EQ.'GEO')THEN
           LA1=LAGEO
           LO1=LOGEO
           IF(SL2.EQ.'MID')THEN
               LA2=LAMID
               LO2=LOMID
           ELSEIF(SL2.EQ.'SCH')THEN
               LA2=LASCH
```

```
                LO2=LOSCH
            ENDIF
      ELSEIF(SL1.EQ.'MID')THEN
            LA1=LAMID
            LO1=LOMID
            IF(SL2.EQ.'GEO')THEN
                  LA2=LAGEO
                  LO2=LOGEO
            ELSEIF(SL2.EQ.'SCH')THEN
                  LA2=LASCH
                  LO2=LOSCH
            ENDIF
      ELSEIF(SL1.EQ.'SCH')THEN
            LA1=LASCH
            LO1=LOSCH
            IF(SL2.EQ.'GEO')THEN
                  LA2=LAGEO
                  LO2=LOGEO
            ELSEIF(SL2.EQ.'MID')THEN
                  LA2=LAMID
                  LO2=LOMID
            ENDIF
      ENDIF
      RETURN
      END

C
C
C
      SUBROUTINE SUB9960(MAS,SL1,SL2,LOM,LAM,LO1,LA1,LO2,LA2)
C
      CHARACTER * 3 MAS,SL1,SL2
      REAL LOM,LAM,LO1,LA1,LO2,LA2,LOCAR,LACAR,LONAT
     1 ,LANAT,LOCBE,LACBE,LODAN,LADAN
C
C     MASTER=SENECA=SEN, CAR=CARIBOU, NAT=NANTUCKET,
C      CBE=CAROLINA BEACH,DAN=DANA
C
      LOM=(76.)+(49./60.)+(33.86/3600.)
```

```
LAM=(42.)+(42./60.)+(50.60/3600.)
LOCAR   =(67.)+(55./60.)+(37.71/3600.)
LACAR   =(46.)+(48./60.)+(27.20/3600.)
LONAT   =(69.)+(58./60.)+(39.09/3600.)
LANAT   =(41.)+(15./60.)+(11.93/3600.)
LOCBE   =(77.)+(54./60.)+(46.76/3600.)
LACBE   =(34.)+(03./60.)+(46.04/3600.)
LODAN   =(87.)+(29./60.)+(12.14/3600.)
LADAN   =(39.)+(51./60.)+(07.54/3600.)
IF(SL1.EQ.'CAR')THEN
     LA1=LACAR
     LO1=LOCAR
     IF(SL2.EQ.'NAT')THEN
          LA2=LANAT
          LO2=LONAT
     ELSEIF(SL2.EQ.'CBE')THEN
          LA2=LACBE
          LO2=LOCBE
     ELSEIF(SL2.EQ.'DAN')THEN
          LA2=LADAN
          LO2=LODAN
     ENDIF
ELSEIF(SL1.EQ.'NAT')THEN
     LA1=LANAT
     LO1=LONAT
     IF(SL2.EQ.'CAR')THEN
          LO2=LOCAR
          LA2=LACAR
     ELSEIF(SL2.EQ.'CBE')THEN
          LO2=LOCBE
          LA2=LACBE
     ELSEIF(SL2.EQ.'DAN')THEN
          LO2=LODAN
          LA2=LADAN
     ENDIF
ELSEIF(SL1.EQ.'CBE')THEN
     LA1=LACBE
     LO1=LOCBE
     IF(SL2.EQ.'CAR')THEN
```

```
                LO2=LOCAR
                LA2=LACAR
            ELSEIF(SL2.EQ.'NAT')THEN
                LO2=LONAT
                LA2=LANAT
            ELSEIF(SL2.EQ.'DAN')THEN
                LO2=LODAN
                LA2=LADAN
            ENDIF
      ELSEIF(SL1.EQ.'DAN')THEN
            LA1=LADAN
            LO1=LODAN
            IF(SL2.EQ.'CAR')THEN
                LA2=LACAR
                LO2=LOCAR
            ELSEIF(SL2.EQ.'NAT')THEN
                LA2=LANAT
                LO2=LONAT
            ELSEIF(SL2.EQ.'CBE')THEN
                LA2=LACBE
                LO2=LOCBE
            ENDIF
      ENDIF
      RETURN
      END

C
C
C
      SUBROUTINE QUAD(THETA,TOP,BOT,CCTHETA)
C
      PARAMETER PI=3.141592
      IF(THETA.GE.0.)THEN
            IF(BOT.GE.0.AND.TOP.GE.0.)THEN
                CCTHETA = THETA
            ELSEIF(BOT.LT.0.AND.TOP.GE.0.)THEN
                CCTHETA = THETA + PI/2
            ELSEIF(BOT.LT.0.AND.TOP.LT.0.)THEN
                CCTHETA = THETA + PI
```

```
          ELSEIF(BOT.GE.O.AND.TOP.LT.O.)THEN
               CCTHETA = THETA + 3*PI/2
          ENDIF
      ELSEIF(THETA.LT.O.)THEN
          IF(BOT.GE.O.AND.TOP.GE.O.)THEN
               CCTHETA = THETA + PI/2
          ELSEIF(BOT.LT.O.AND.TOP.GE.O.)THEN
               CCTHETA = THETA + PI
          ELSEIF(BOT.LT.O.AND.TOP.LT.O.)THEN
               CCTHETA = THETA + 3*PI/2
          ELSEIF(BOT.GE.O.AND.TOP.LT.O.)THEN
               CCTHETA = THETA + 2*PI
          ENDIF
      ENDIF
      RETURN
      END
C
C
C
\section{List of Abbreviations}
C***********************************************************
C***********************************************************
C This is the list of abbreviations used by LORAN.FOR and
C SUBLORAN.FOR programs.
C***********************************************************
BAUDETTE.............BAU    BAR HARBOR ME...........BAR

CAPE RACE............CRC    BRISTOL HMS.............BRI

CARIBOU..............CAR    PAWTUCKET RI............PAW

CAROLINA BEACH.......CBE    NEWPORT RI..............NEW

DANA.................DAN    AVERY PT CT.............AVE

FALLON...............FAL    GROTON CT...............GRO

GEORGE...............GEO    BUFFALO HMS.............BUF
```

GRANGVILLE...........GRA	NIAGRA FALLS NY.........NIA
JUPITER..............JUP	BATAVIA NY..............BAT
MALONE...............MAL	MASSENA HMS.............HMS
MIDDLETOWN...........MID	MASSENA NY..............MAS
NANTUCKET............NAT	ALEX BAY HMS............ALE
RAYMONDVILLE.........RAY	WATERTOWN NY............WAT
SEARCHLIGHT..........SCH	OGDENBURG NY............OGD
SENECA...............SEN	GLOUCHESTER CITY HMS....GLO
NAHANT HMS...........NAH	PHILLY NE NY............PHI
BEVERLY MA...........BEV	LEWES DE................LEW
BEDFORD MA...........BED	SALISBURY MD............SAL
BASS HARBOR ME.......MAS	

Appendix B

APPLE II PROGRAMS

```
************************************************
PROGRAM FR2.  THIS PROGRAM RECORDS DATA FROM THE
MICROLOGIC ML-3000 LORAN-C RECEIVER AND AN ILS
RECEIVER BUFFERED THROUGH AN A/D CONVERTER.
ORIGINAL PROGRAM WRITTEN BY PROFESSOR ANTONIO
ELIAS.  PROGRAM MODIFIED BY LYMAN R. HAZLETON,JR.
AND JOHN K. EINHORN.
************************************************
100  HIMEM: 8000
105 D1 =  - 16142
110 LA = 16384
120 LL = LA
130  DEF  FN RO(X) =  INT (X * P + 0.5) / P
140 P = 100:KB =  - 16384:KS =  - 16368
150 D$ = " "
160 SL = 18
170 BA =  - 28673
180 A1 = BA + 1:A2 = BA + 2:A3 = BA + 3:A4 = BA +
 4:A5 = BA + 5:A6 = BA + 6:A7 = BA + 7:A8 = BA + 8
190 A9 = BA + 9:B0 = BA + 10:B1 = BA + 11:B2 = BA +
 12:B3 = BA + 13:B4 = BA + 14:B5 = BA + 15:B6 = BA
 + 16:B7 = BA + 17:B8 = BA + 18
191 B9 = BA + 19
200 NP =  INT (20480 / SL)
210  HOME : PRINT "RECORDING A MAXIMUM OF ";NP;" POINTS."
```

```
220  INPUT "ENTER A NEW LIMIT, IF DESIRED: ";X$: IF
 X$ <  > "" THEN X =  VAL (X$): IF X < NP THEN NP = X
230  PRINT : INPUT "ENTER A FILE NAME, IF DESIRED: ";F$
240  HOME : PRINT "#      TD1      TD2    SNM SN1 SN2 D1 D2"
250  PRINT "---------------------------------------"
260  HTAB 1: VTAB 19: PRINT "----------------------------
-----------"
265  IF F$ <  > "" THEN  PRINT NP;" POINTS TO FILE ";F$
266 X =  PEEK (KS)
267  IF  PEEK (KB) < 128 GOTO 267
270  POKE 34,2: POKE 35,18: HOME
280  PRINT  CHR$ (4);"BLOAD ASS"
290 X =  PEEK (KS)
300 I = I + 1: IF I > NP THEN I = I - 1: GOTO 550
310  PRINT D$;"PR#1"
320  PRINT I
330  CALL  - 28640
340  PRINT D$;"PR#0"
345 DA =  PEEK (D1)
350 CS =  PEEK (A1) +  PEEK (A2) +  PEEK (A3) +  PEEK
 (A4) +  PEEK (A5) +  PEEK (A6) +  PEEK (A7) +  PEEK
 (A8) +  PEEK (A9)
360 CS = CS +  PEEK (B0) +  PEEK (B1) +  PEEK (B2) +
 PEEK (B3) +  PEEK (B4) +  PEEK (B5) +  PEEK (B6) +
 PEEK (B7)
370  IF (CS - 256 *  INT (CS / 256)) =  PEEK (B8)
 THEN  GOTO 420
380  IF  PEEK (KB) < 128 THEN I = I - 1: GOTO 550
390  PRINT D$ + "PR#0"
400  IF I = 1 THEN I = 0: PRINT "SYNCH ERROR, TRYING
 AGAIN...": GOTO 300
410  PRINT "
*****CHECKSUM ERROR*****": GOTO 550

420 T1 = 0.00625 * ( PEEK (A3) + 256 *  PEEK (A4)
 + 65536 *  PEEK (A5))
430 T2 = 0.00625 * ( PEEK (A8) + 256 *  PEEK (A9)
 + 65536 *  PEEK (B0))
440 S1 =  PEEK (B1):S2 =  PEEK (B3):S3 =  PEEK (B5)
```

```
450  PRINT I;: HTAB 5
460  PRINT  FN RO(T1);: HTAB 14
470  PRINT  FN RO(T2);: HTAB 23
480  PRINT S1;: HTAB 27: PRINT S2;: HTAB 31:
 PRINT S3;: HTAB 35: PRINT DA
485  POKE B8,DA
490  FOR J = 1 TO SL
500  POKE LL + J - 1, PEEK (BA + J)
510  NEXT J
520 LL = LL + SL
530  IF  PEEK (KB) > 128 THEN  GOTO 550
540  GOTO 300
550  PRINT D$ + "PR#0"
560  POKE 34,19: POKE 35,24: HOME
570  PRINT I" FRAMES READ; ";
580 I1 = 1:I2 = I
590  IF F$ <  > "" THEN  PRINT : GOTO 660
600  INPUT "FILE NAME? ";F$
610  INPUT "INITIAL FRAME? ";A$
620  IF A$ = "" THEN I1 = 1: GOTO 640
630 I1 =  VAL (A$): IF I1 < 1 OR I1 > I THEN  PRINT
 "ILLEGAL VALUE (MUST BE BETWEEN 1 AND ";I;")": GOTO 610
640  INPUT "FINAL FRAME?: ";A$: IF A$ = "" THEN
 I2 = I: GOTO 660
650 I2 =  VAL (A$): IF I2 < I1 OR I2 > I THEN  PRINT
 "ILLEGAL VALUE (MUST BE BETWEEN ";I1;" AND ";I;")": GOTO 640
660  PRINT "STORING FRAMES ";I1;" TO ";I2;" IN FILE ";F$
670 A1 = LA + SL * (I1 - 1) - 2
680 II =  INT (I / 256): POKE A1,I - 256 * II: POKE A1 + 1,II
690 L1 = 2 + SL * I2
700  PRINT  CHR$ (4) + "BSAVE " + F$ + ",A";A1;",L";L1
710  END
***********************************************
PROGRAM PLOTFILE11.  THIS PROGRAM IS DESIGNED TO
PERFORM SEVERAL SUBROUTINES ON LORAN AND ILS
DATA GATHERED BY PROGRAM FR2.  ORIGINAL PLOTFILE
PROGRAM WRITTEN BY PROFESSOR ANTONIO ELIAS.  THIS
PROGRAM MODIFIED BY LYMAN R. HAZLETON, JR. AND
JOHN K. EINHORN.
```

WRITTEN IN APPLESOFT FOR AN APPLE II COMPUTER

```
***********************************************
100  LOMEM: 24576
105 PI = 3.141592
110  GOTO 450
120 N1 =  PEEK (LL + 10):N2 =  PEEK (LL + 12):N3
 =  PEEK (LL + 14)
130  IF  PEEK (LL + 1) < 128 THEN V1 = 0.025 * (
 PEEK (LL) + 256 *  PEEK (LL + 1))
140  IF  PEEK (LL + 1) >  = 128 THEN V1 = 0.025
 * ( PEEK (LL) - 256 * (256 -  PEEK (LL + 1)))
150  IF  PEEK (LL + 6) < 128 THEN V2 = 0.025 * (
 PEEK (LL + 5) + 256 *  PEEK (LL + 6))
160  IF  PEEK (LL + 6) >  = 128 THEN V2 = 0.025
 * ( PEEK (LL + 5) - 256 * (256 -  PEEK (LL + 6)))
170 D1 = 0.00625 * ( PEEK (LL + 2) + 256 *  PEEK
 (LL + 3) + 65536 *  PEEK (LL + 4))
180 D2 = 0.00625 * ( PEEK (LL + 7) + 256 *  PEEK
 (LL + 8) + 65536 *  PEEK (LL + 9))

185 XL =  PEEK (LL + 17)
200  RETURN
210  HTAB 1: CALL  - 868: VTAB 22: HTAB 9: PRINT
 "STAND BY, PLEASE...": IF NP = 0 THEN  GOTO 610
220 A1 = 0:A2 = 0:M1 = 0:M2 = 0:M3 = 0:Q1 = 0:Q2
 = 0:W1 = 0:W2 = 0:Q3 = 0:Q4 = 0
230  FOR I = 1 TO NP
240  GOSUB 120
250 A1 = A1 + D1:A2 = A2 + D2
260 M1 = M1 + N1:M2 = M2 + N2:M3 = M3 + N3
270 W1 = W1 + V1:W2 = W2 + V2
280  NEXT I
290 X1 = A1 / NP:X2 = A2 / NP
300 X3 = W1 / NP:X4 = W2 / NP
310  HOME : PRINT "         1";: HTAB 26:
 PRINT "    2"
320  PRINT "     ---------";: HTAB 26: PRINT
 "---------": PRINT
330  PRINT "AV:  ";X1;: HTAB 26: PRINT X2
```

```
340 LL = LA
450 SE = 0.6:U1 = 1:U2 = 256:U3 = 20
460 UX = 10000.0:UY = UX * 192 / 280
470 C1 =  - 101.436:C2 =  - 92.927:C3 =
 - 191.621:C4 = 171.641
471 DLA = 7950
472 WW = 1000
473 ZZ = 25000
474 ST = 1
475 TH = 83.1
476 IC = 100
480 XB = 140:YB = 6
490  ONERR  GOTO 2520
500 LA = 16384:IN = 1
510  DEF  FN RO(X) =  INT (X * P + 0.5) / P
520 P = 100:KB =  - 16384:KS =  - 16368
530 D$ = "
"
540 SL = 18
550 BA =  - 28673
560  DIM AR(280)
570 DR$ =  STR$ ( PEEK ( - 21912))
580 SL$ =  STR$ ( PEEK ( - 21910))
590 VO$ =  STR$ ( PEEK ( - 21914))
600 SC = 140
610  PRINT "
CLOSE": TEXT : HOME
620 LL = LA
625 R1 = 14119.1829
626 R2 = 26032.0798
630  HTAB 9: PRINT "LORAN-C DATA DISPLAY PROGRAM"
640  HTAB 9: PRINT "============================"
650  HTAB 5: VTAB 4: PRINT "H - PLOT HISTOGRAM"
660  HTAB 5: PRINT "T - PLOT TD'S, SNR'S"
670  HTAB 5: PRINT "D - PLOT TD'S, TD DOT'S"
680  HTAB 5: PRINT "M - PLOT NEW MAP (O PLOTS OLD MAP)"
690  HTAB 5: PRINT "P - PRINT TD'S, SNR'S"
700  HTAB 5: PRINT "V - PRINT TD'S, TDVEL'S"
710  HTAB 5: PRINT "A - COMPUTE STATISTICS"
```

```
720  HTAB 5: PRINT "X - HARD COPY LAST PLOT"
725  HTAB 5: PRINT "F - PRINT A/D"
726  HTAB 5: PRINT "L - PLOT ILS MAP"
727  HTAB 5: PRINT "B - DIFFERENTIAL ANGLES"
730  PRINT : HTAB 5: PRINT "N - FILE NAME: ";NA$;

740  PRINT : IF NA$ < > "" THEN  HTAB 9: PRINT
 "FILE HAS ";NP;" DATA POINTS";
750  PRINT : HTAB 5: PRINT "S - SLOT: ";SL$;"
 DRIVE: ";DR$;" VOL: ";VO$;
760  PRINT : HTAB 5: PRINT "C - CATALOG"
770  HTAB 5: PRINT "R - PLOT PARAMETERS"
780  PRINT : HTAB 5: PRINT "Q - QUIT PROGRAM"
790  VTAB 23: PRINT "COMMAND -> ";
800  GET CO$
810  IF CO$ = "H" THEN  GOTO 1660
820  IF CO$ = "T" THEN  GOTO 1900
830  IF CO$ = "D" THEN  GOTO 1900
840  IF CO$ = "X" THEN  GOTO 1610
845  IF CO$ = "F" THEN  GOTO 3000
847  IF CO$ = "L" THEN  GOTO 4000
848  IF CO$ = "B" THEN  GOTO 4500
850  IF CO$ = "P" THEN  GOTO 1030
860  IF CO$ = "V" THEN  GOTO 1030
870  IF CO$ = "M" THEN  GOTO 2300
880  IF CO$ = "O" THEN  GOTO 2310
890  IF CO$ = "A" THEN  GOTO 210
900  IF CO$ = "N" THEN  GOTO 970
910  IF CO$ = "S" THEN  GOTO 1490
920  IF CO$ = "C" THEN  GOTO 1560
930  IF CO$ = "R" THEN  GOTO 1340
940  IF CO$ = "Q" THEN  HOME : END
950  GOTO 610
960  PRINT : STOP
970  INPUT "FILE NAME: ";NA$
980 F$ = NA$
990  IF NA$ = "" THEN  GOTO 1490
1000  PRINT D$ + "BLOAD ";NA$
1010 NP =  PEEK (LA - 2) + 256 *  PEEK (LA - 1)
```

```
1020  GOTO 610
1030  HOME : PRINT "LORAN FILE: ";NA$
1040  PRINT "#       TD1       TD2
 SNM SN1 SN2 FLGS"
1050  PRINT "--------------------------
 ------------"
1060  HTAB 1: VTAB 19: PRINT "----------
 ----------------------------"
1070  IF CO$ = "V" THEN  VTAB 2: HTAB 24:
 PRINT " TDVEL 1 TDVEL 2"
1080  POKE 34,3: POKE 35,18: HOME
1090 X =  PEEK (KS)
1100 I = 0
1110 I = I + 1: IF I > NP THEN  GOTO 1330
1120  GOSUB 120
1130  GOTO 1140
1140  PRINT I;: HTAB 6
1150  PRINT  FN RO(D1);: HTAB 15
1160  PRINT  FN RO(D2);: HTAB 24
1170  IF CO$ = "P" THEN  PRINT N1;: HTAB 28:
 PRINT N2;: HTAB 32: PRINT N3;" "; PEEK (LL +
 11); PEEK (LL + 13); PEEK (LL + 15); PEEK
 (LL + 16)
1180  IF CO$ <  > "V" THEN  GOTO 1310
1190  PRINT " ";
1200  IF  ABS (V1) < 100 THEN  PRINT " ";:
 IF  ABS (V1) < 10 THEN  PRINT " ";
1210  IF V1 > 0 THEN  PRINT " ";
1220  IF V1 < 0 THEN  PRINT "-";
1230  IF  ABS (V1) < 1 THEN  PRINT "0";

1240  PRINT  FN RO( ABS (V1));: HTAB 33
1250  IF  ABS (V2) < 100 THEN  PRINT " ";:
 IF  ABS (V2) < 10 THEN  PRINT " ";
1260  IF V2 > 0 THEN  PRINT " ";
1270  IF V2 < 0 THEN  PRINT "-";
1280  IF  ABS (V2) < 1 THEN  PRINT "0";
1290  PRINT  FN RO( ABS (V2))
1310  IF  PEEK (KB) > 128 THEN  GOTO 1330
```

```
1320  GOTO 1110
1330  GET A$: GOTO 610
1340  HOME :PL$ = "PLOT SPLIT":PV = SE:
 GOSUB 2580: IF PV > 0 AND PV < 1 THEN SE = PV
1350 PL$ = "PLOTTING INCREMENT":PV = IN:
 GOSUB 2580:IN = PV
1360 PL$ = "MAP STYLE, 0=DOTS, 1=LINES":
 PV = ST: GOSUB 2580:ST = PV
1370 PL$ = "TD FULL SCALE, MSEC":PV = U1:
 GOSUB 2580:U1 =  ABS (PV)
1380 PL$ = "TDDOT FULL SCALE, NSEC/SEC":PV
 = U3: GOSUB 2580:U3 =  ABS (PV)
1390 PL$ = "MAP FULL SCALE X(M.)":PV = UX:
 GOSUB 2580:UX =  ABS (PV)
1395 PL$ = "MAP FULL SCALE Y(M)":PV = UW:
 GOSUB 2580:UW =  ABS (PV)
1400 PL$ = "REFERENCE TD1":PV = R1: GOSUB
 2580:R1 = PV
1410 PL$ = "REFERENCE TD2":PV = R2: GOSUB
 2580:R2 = PV
1420 PL$ = "A11":PV = C1: GOSUB 2580:C1 = PV
1430 PL$ = "A12":PV = C2: GOSUB 2580:C2 = PV
1440 PL$ = "A21":PV = C3: GOSUB 2580:C3 = PV
1450 PL$ = "A22":PV = C4: GOSUB 2580:C4 = PV
1455 PL$ = "THETA":PV = TH: GOSUB 2580:TH = PV
1460 PL$ = "X BIAS":PV = XB: GOSUB 2580:XB = PV
1470 PL$ = "Y BIAS":PV = YB: GOSUB 2580:YB
 =  ABS (PV)
1472 PL$ = "ILS CENTER":PV = IC: GOSUB 2580:
 IC =  ABS (PV)
1474 PL$ = "APPROACH SPEED (kts)":PV = APS:
 GOSUB 2580:APS =  ABS (PV)
1475 PL$ = "MAP TO LOCALIZER ARRAY (FT)":PV
 = DLA: GOSUB 2580:DLA =  ABS (PV)
1476 PL$ = "ILS X-TRACK FULL SCALE":PV = WWW:
 GOSUB 2580:WWW =  ABS (PV)
1477 PL$ = "ILS ALONG TRACK FULL SCALE (ft)":
 PV = ZZZ: GOSUB 2580:ZZZ =  ABS (PV)
1480  GOTO 610
```

```
1490  GOSUB 1650: INPUT "SLOT? ";SL$
1500  GOSUB 1650: INPUT "DRIVE? ";DR$
1510  GOSUB 1650: INPUT "VOLUME? ";VO$
1520  IF DR$ = "" THEN DR$ =  STR$ ( PEEK ( - 21912))
1530  IF SL$ = "" THEN SL$ =  STR$ ( PEEK ( - 21910))
1540  IF VO$ = "" THEN VO$ =  STR$ ( PEEK ( - 21914))
1550  GOTO 610
1560  PRINT
1570  PRINT "
CATALOG,S" + SL$ + ",D" + DR$ + ",V" + VO$
1580  VTAB 23: HTAB 35: PRINT "--->";
1590  GET A$
1600  GOTO 610
1610  PRINT  CHR$ (4);"PR#1"
1620  CALL 768
1630  PRINT  CHR$ (4);"PR#0"

1640  GOTO 610
1650  VTAB 23: HTAB 1: CALL  - 868: RETURN
1660  HOME : HGR
1670  FOR I = 1 TO 280:AR(I) = 0: NEXT
1680  HCOLOR= 7
1690  HPLOT 0,160 TO 279,160
1700  HPLOT 140,8 TO 140,0
1710  HPLOT 0,8 TO 0,0: HPLOT 279,8 TO 279,0
1720  FOR I = 10 TO 270 STEP 10: HPLOT I,4
 TO I,0: NEXT I
1730  FOR I = 160 TO 10 STEP  - 10: HPLOT 0,I
 TO 2,I: NEXT I
1740  FOR I = 1 TO NP
1750  GOSUB 170
1760  IF R1 = 0 THEN R1 = D1
1770  IF R2 = 0 THEN R2 = D2
1780 VA = 70 + SC * (D1 - R1)
1790  IF VA > 279 THEN VA = 279
1800  IF VA < 0 THEN VA = 0
1810  IF AR(VA) < 150 THEN AR(VA) = AR(VA) + 1
1820  HPLOT VA,150 - AR(VA)
1830 VB = 210 + SC * (D2 - R2)
```

```
1840  IF VB > 279 THEN VB = 279
1850  IF VB < 0 THEN VB = 0
1860  IF AR(VB) < 150 THEN AR(VB) = AR(VB) + 1
1870  HPLOT VB,150 - AR(VB)
1880  NEXT I
1890  GET A$: GOTO 610
1900  HGR
1910 E1 = 0.5 * (192 * SE):E2 = 0.5 * (192
 * (1 - SE))
1920 P1 = (0.5 * E1) - 1:P2 = P1 + E1:P3 = E1 +
 E1 + 0.5 * E2 - 1:P4 = P3 + E2
1930 S1 = 0.5 * E1 / U1:S2 = 0.5 * E2 / U2:S3
 = 0.5 * E2 / U3
1940  POKE  - 16302,0
1950  POKE  - 16368,0
1960  HCOLOR= 7
1970  HPLOT 0,0 TO 279,0 TO 279,191 TO
 0,191 TO 0,0
1980  HPLOT 0,E1 - 1 TO 279,E1 - 1: HPLOT 0,E1
 + E1 - 1 TO 279,E1 + E1 - 1
1990  HPLOT 0,E1 + E1 + E2 - 1 TO 279,E1 + E1 + E2 - 1
2000  HPLOT 0,P1 TO 8,P1: HPLOT 272,P1 TO 279,P1
2010  HPLOT 0,P2 TO 8,P2: HPLOT 272,P2 TO 279,P2
2020  HPLOT 0,P3 TO 8,P3: HPLOT 272,P3 TO 279,P3
2030  HPLOT 0,P4 TO 8,P4: HPLOT 272,P4 TO 279,P4
2040 OS = SL
2050 NN = 0:R1 = 0:R2 = 0
2060 SL = SL * IN
2070  FOR N = 0 TO NP - 1 STEP IN
2080  GOSUB 120
2090  IF R1 = 0 THEN R1 = D1
2100  IF R2 = 0 THEN R2 = D2
2110 VA = P1 + S1 * (D1 - R1): IF VA < 1 THEN VA = 1
2120 VB = P2 + S1 * (D2 - R2): IF VB < 1 THEN VB = 1
2130  IF CO$ = "T" THEN VC = P3 - S2 * (N2 - 128):VD
 = P4 - S2 * (N3 - 128)
2140  IF CO$ = "D" THEN VC = P3 - S3 * V1:VD
 = P4 - S3 * V2
2150  IF VC < 1 THEN VC = 1
```

```
2160  IF VD < 1 THEN VD = 1
2170  IF VA > 191 THEN VA = 191

2180  IF VB > 191 THEN VB = 191
2190  IF VC > 191 THEN VC = 191
2200  IF VD > 191 THEN VD = 191
2210  HPLOT NN,VA
2220  HPLOT NN,VB
2230  HPLOT NN,VC
2240  HPLOT NN,VD
2250 NN = NN + 1
2260  IF NN > 279 THEN N = NP - 1
2270  NEXT N
2280 SL = OS
2290  GET A$: GOTO 610
2300  HGR
2310  POKE  - 16297,0: POKE  - 16304,0: POKE
  - 16302,0
2320  IF CO$ = "0" THEN  GOTO 2370
2330  HPLOT 0,0 TO 278,0 TO 278,191
 TO 0,191 TO 0,0
2340  HPLOT XB - 5,YB TO XB + 5,YB:
 HPLOT XB,YB - 5 TO XB,YB + 5
2350  HCOLOR= 7:UU = 280 / UX:UZ = 190 / UW
2360  IF R1 < 0 THEN R1 = X1:R2 = X2
2370  FOR I = 1 TO NP
2380  GOSUB 170
2390  IF R1 = 0 THEN R1 = D1:R2 = D2
2400 XX = C1 * (D1 - R1) + C2 * (D2 - R2)
2410 YY =  - (C3 * (D1 - R1) + C4 * (D2 - R2))
2414 KZ = XX
2415 XX = XX *  COS (TH * PI / 180) - YY *
 SIN (TH * PI / 180)
2416 YY = KZ *  SIN (TH * PI / 180) + YY *
 COS (TH * PI / 180)
2417  RETURN
2420 VA = XB + UU * XX:VB = YB - UZ * YY
2430  IF VA < 0 THEN VA = 0
2440  IF VB < 0 THEN VB = 0
```

```
2450  IF VA > 279 THEN VA = 279
2460  IF VB > 191 THEN VB = 191
2470  IF I = 1 THEN  HPLOT VA,VB
2480  IF ST = 1 THEN  HPLOT  TO VA,VB
2490  IF ST = 0 THEN  HPLOT VA,VB
2500  NEXT
2510  GET A$: GOTO 610
2520  REM
2530  TEXT : HTAB 1: VTAB 23: CALL  - 868:
 HTAB 9: PRINT "";
2540 EL =  PEEK (218) + 256 *  PEEK (219):
 EN =  PEEK (222)
2550  IF EN = 6 THEN  PRINT "CAN'T FIND FILE
 ";NA$;:NA$ = "":: GOTO 2570
2560  PRINT "ERROR ";EN;" AT LINE ";EL;
2570  HTAB 39: GET A$: GOTO 610
2580  PRINT PL$;" (";PV;") : ";: INPUT "";X$:
 IF X$ <  > "" THEN PV =  VAL (X$)
2590  RETURN
3000  HTAB 5: PRINT "RAW";: HTAB 12: PRINT
 "CENTERED;: HTAB 23: PRINT "FROMMAP";: HTAB 35:
 PRINT "X - TRACK"
3002  PRINT "======================================="
3005 X =  PEEK (KS)
3010 I = 0
3020 I = I + 1: IF I > NP THEN  GOTO 3500
3030  GOSUB 120

3035 CXL = XL - IC
3050 FT = APS * 6000 / 3600 * (NP - I) * 1.1952
3060  IF CXL <  =  - 85 THEN XDG =  - 2.3 + .46
 / 22 * (CXL + 85)
3070  IF  - 85 < CXL AND CXL <  =  - 63 THEN XDG
 =  - 1.84 + .46 / 21 * (CXL + 63)
3080  IF  - 63 < CXL AND CXL <  =  - 45 THEN XDG
 =  - 1.38 + .46 / 18 * (CXL + 45)
3090  IF  - 45 < CXL AND CXL <  =  - 28 THEN XDG
 =  - .92 + .46 / 17 * (CXL + 28)
3100  IF  - 28 < CXL AND CXL <  =  - 13 THEN XDG
```

```
= - .46 + .46 / 15 * (CXL + 13)
3110  IF  - 13 < CXL AND CXL < 0 THEN XDG = .46
 / 14 * CXL
3120  IF CXL = 0 THEN XDG = 0
3130  IF 0 < CXL AND CXL < 14 THEN XDG = .46 /
 14 * CXL
3140  IF 14 <  = CXL AND CXL < 28 THEN XDG =
 .46 + .46 / 14 * (CXL - 14)
3150  IF 28 <  = CXL AND CXL < 45 THEN XDG =
 .92 + .46 / 17 * (CXL - 28)
3160  IF 45 <  = CXL AND CXL < 60 THEN XDG =
 1.38 + .46 / 15 * (CXL - 45)
3170  IF 60 <  = CXL AND CXL < 79 THEN XDG =
 1.84 + .46 / 19 * (CXL - 60)
3180  IF 79 <  = CXL THEN XDG = 2.3 + .46 /
 20 * (CXL - 79)
3200 RXDG = XDG * PI / 180
3210 XT = (FT + DLA) *  TAN (RXDG)
3220  RETURN
3400  PRINT I;: HTAB 5: PRINT XL;: HTAB 12: PRINT
 CXL;: HTAB 23: PRINT FT;: HTAB 35: PRINT XT
3480  IF  PEEK (KB) > 128 THEN  GOTO 3500
3490  GOTO 3020
3500  GET A$: GOTO 610
4000  HGR
4010  POKE  - 16297,0: POKE  - 16304,0: POKE
  - 16302,0
4020  HPLOT 0,0 TO 278,0 TO 278,191 TO
 0,191 TO 0,0
4030  HPLOT XB - 21,YB - 6 TO XB - 21,YB + 6 TO
 XB + 21,YB + 6 TO XB + 21,YB - 6
4040  HCOLOR= 7
4050 WU = 280 / WW
4055 ZU = 190 / ZZ
4060  FOR I = 1 TO NP
4070  GOSUB 185
4080  GOSUB 3035
4090 PXT = XB + WU * XT
4100 PFT = YB + ZU * FT
```

```
4105  IF I = 1 THEN  GOTO 4128
4106  IF I = 2 THEN  GOTO 4128
4109  IF ST = 0 THEN  GOTO 4122
4110  IF ST = 1 THEN  GOTO 4111
4111  IF I = 3 THEN  GOTO 4122
4118  HPLOT  TO PXT,PFT
4120  GOTO 4128
4122  HPLOT PXT,PFT
4128  NEXT
4130  GET A$: GOTO 610
4500  HOME
4501  PR# 1
4503  PRINT  CHR$ (9);"10L"

4504  IF I > 1 THEN  GOTO 4506
4505  PRINT "This is the data for "F$
4506  PRINT "#";: HTAB 17: PRINT "LOCALIZER";:
 HTAB 30: PRINT "LORAN";: HTAB 40: PRINT "DIFFERENCE"
4507  PRINT "PNT";: HTAB 17: PRINT "ANGLE";: HTAB
 30: PRINT "ANGLE";: HTAB 40: PRINT "LOC-LORAN"
4508 A1 = 0:X1 = 0:Y1 = 0:Q1 = 0
4509  FOR I = 1 TO NP
4510  GOSUB 3030
4520  GOSUB 2380
4525 YY = YY - 7950 / 3.28
4530 XS =  -  ATN (XX / YY)
4540 XS = XS * 180 / PI
4550 DX = XS - XDG
4552 STRING$ =  STR$ (XDG)
4553 LING$ =  STR$ (XS)
4554 DING$ =  STR$ (DX)
4560  PRINT I;: HTAB 17: PRINT  LEFT$ (STRING$,5)
 ;: HTAB 30: PRINT  LEFT$ (LING$,5);: HTAB 40:
 PRINT  LEFT$ (DING$,5)
4561  IF I = 1 THEN  GOTO 4565
4562  IF I = 2 THEN  GOTO 4565
4563 A1 = A1 + DX
4565 LL = LL + SL
4570  NEXT
```

```
4575 LL = LA
4580 X1 = A1 / (NP - 2)
4600  FOR I = 1 TO NP
4610  GOSUB 3030
4620  GOSUB 2380
4630  IF I = 1 THEN  GOTO 4705
4640  IF I = 2 THEN  GOTO 4705
4650 YY = YY - 7950 / 3.28
4660 XS =  -  ATN (XX / YY)
4670 XS = XS * 180 / PI
4680 DX = XS - XDG
4690 Y1 = DX - X1:Q1 = Q1 + (Y1 * Y1)
4705 LL = LL + SL
4710  NEXT
4715 SD =  SQR (Q1 / (NP - 2))
4720  PRINT "AVERAGE ERROR ANGLE = ";X1
4730  PRINT "STANDARD DEVIATION = ";SD
4750  PR# 0
4760  GET A$: GOTO 610
```

Appendix C

FLIGHT TEST PALLET

This appendix gives detailed construction parameters of the flight test pallet, lists the airplane weight and balance calculations, and shows the FAA paperwork required to take the pallet aloft.

C.1 PALLET CONSTRUCTION

The pallet is constructed of .063 inch, 5052 sheet aluminum (ultimate sheer strength is 18 ksi, yield strength is 13 ksi, and ultimate tensile strength is 28 ksi), one inch diameter 2024-T35 aluminum rods (ultimate shear strength is 41 ksi, yield strength is 47 ksi and ultimate tensile strength is 68 ksi), 1/4 x 1 x 1 inch 6061-T6 angle aluminum (ultimate shear strength is 30 ksi, yield strength is 40 ksi, ultimate tensile strength is 45 ksi), and 3/8 inch diameter threaded steel rods.

The six legs of the pallet are made of the 2024 aluminum rods and are attached to an angle alumimum base frame by 3/8 inch diameter steel sheet metal screws. The top part of the pallet is essentially eight separate equipment compartments welded together by the Laboratory for Nuclear Science at MIT. This framework of compartments is in turn welded to an aluminum shelf which is bolted to the angle aluminum base frame by four 1/4 inch aircraft grade bolts. The basic configuration is shown in figure 4-5 of chapter 4.

C.2 PALLET WEIGHT AND BALANCE

The weight and balance measurements for the pallet are as follows:

1) Impact foam, wires, nylon, misc.	5.00 lbs
2) LORAN-C receiver	8.75 lbs
3) Two gel cells	36.00 lbs
4) Inverter	10.25 lbs
5) Monitor	21.00 lbs
6) Apple II+	12.00 lbs
7) Disk II	4.50 lbs
8) A/D converter	1.00 lbs
9) VOR receiver	6.50 lbs
10) VOR head	3.00 lbs
11) Pallet	29.00 lbs
12) Total weight	137.50 lbs

The center of mass is 18.125 inches from the rear of the pallet.

C.3 AIRPLANE WEIGHT AND BALANCE

The loading and center of gravity for the airplane system are as follows:

	WEIGHT (lbs)	ARM (in)	MOMENT (in-lbs)
Empty Weight	1385.25	83.4	115980
Oil	11	32	325
Fuel	306	94.8	29009
Pilot	155	90.6	14043
Co-pilot	205	90.6	18573
Pallet	137.5	112.9	15528
Operator	164	126	20664
Rear Tie Downs	0.5	131	65
Front Tie Downs	0.42	98	41
Longerons	4	131.4	534
Cross Spar	1.3	159.4	214
TOTAL	2372.1 lbs		214902 in-lbs

CG = 90.60 in. Aft limit at 2372.1 lbs is 92.49 inches and foreward limit is 88.70 inches.

Same situation as above with empty fuel tanks:

TOTAL	2066.1 lbs	185894 in-lbs

CG = 89.97 in. Aft limit at 2066.1 lbs is 92.34 inches and foreward limit is 83.81 inches.

Full fuel tanks, no co-pilot:

TOTAL	2167.1 lbs	196329 in-lbs

CG = 90.60 in. Aft limit at 2167.1 lbs is 92.4 inches and foreward limit is 85.58 inches.

Empty fuel tanks, no co-pilot:

TOTAL	1861.1 lbs	167321 in-lbs

CG = 89.90 in. Aft imit at 1861.1 lbs is 92.22 inches and foreward limit is 79.64 inches.

Full fuel tanks, co-pilot and operator reversed:

TOTAL	2372.1	216353 in-lbs

CG = 91.21 in. Aft limit at 2372.1 lbs is 92.49 inches and foreward limit is 88.70 inches.

C.4 EQUIPMENT TIE DOWN

Each piece of equipment is held to the pallet and prevented from movement in any direction by a number of means. Figure C-1 shows the pallet with equipment tie downs. Each of the equipment tie down strategies are explained below.

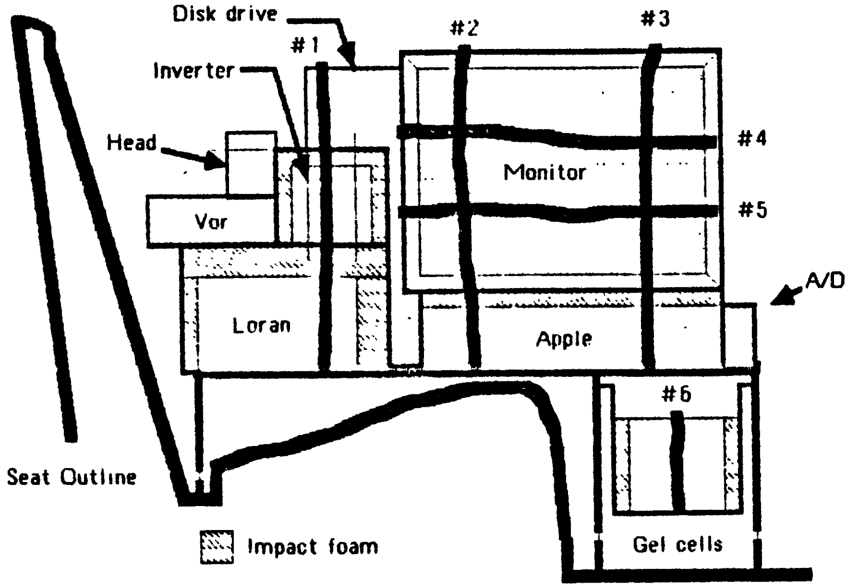

Figure C.1: Equipment Tie Downs

1) Gel cells. The gel cells (2) are padded fore and aft by impact foam. Movement is prevented fore and aft by the pallet, and movement side to side and up is prevented by 0.5 inch wide nylon webbing secured by a buckle. The tensile strength of the nylon and buckle are presented later in this appendix.

2) Apple II+. The Apple is padded above by a 0.5 inch thick sheet of impact foam. Movement fore, aft, up, and left (into airframe) is prevented by the pallet, and movement right (into Flight Test Engineer) is prevented by restraints two and three.

3) Monitor. The monitor is padded fore, aft, and above by no less than two inches of impact foam. Movement fore, aft, up, and left is prevented by the pallet. Movement right is prevented by restraints four and five (primary) and restraints two and three (secondary).

4) Disk drive. Movement fore and aft is prevented by the pallet. Movement left is prevented by velcro attachment to pallet and restraint number one. Movement right is prevented by velcro, restraint one, and by a 3/8 inch diameter steel rod run through two levels of the pallet.

5) Inverter. The inverter is padded fore, aft and above by impact foam. Movement fore and aft is prevented by the pallet. Movement left is prevented by restraint one. Movement right is prevented by restraint one and two steel rods run through two levels of the pallet.

6) VOR head. Movement fore, aft, up and left is prevented by the pallet.

Movement right is prevented by a steel rod run through two sections of the pallet.

7) VOR receiver. Movement fore, aft, and up is prevented by the pallet. Movement side to side is prevented by sheet metal screw attachment to pallet through standard screw bracket in rear of receiver frame.

8) LORAN-C receiver. The LORAN is padded fore, aft and up is prevented by the pallet. Movement left is prevented by restraint number one. Movement right is prevented by restraint one and by a 1 x 1 inch aluminum L bracket secured to the pallet by sheet metal screws.

9) A/D converter is contained in its own aluminum box and attached to pallet by sheet metal screws.

C.5 PALLET TIE DOWN

The pallet rests on the six legs which in turn rest on hard points on the plane's frame and floor. It is secured to the plane by a system of seven aluminum spars. The pallet bottom is secured at four points to seatbelt hardpoints by 1/8 x 1 x 1 inch, 6063-T5 angle aluminum (ultimate shear strength is 17 ksi, yield strength is 21 ksi, ultimate tensile strength is 27 ksi). The smallest cross-section subject to shear loads is 1/8 x 1/4 inches or .03125 square inches and will withstasnd a shear load of 531.25 pounds. Figure C-2 shows the location of these spars.

The pallet top (top of monitor section) is secured by two longerons to

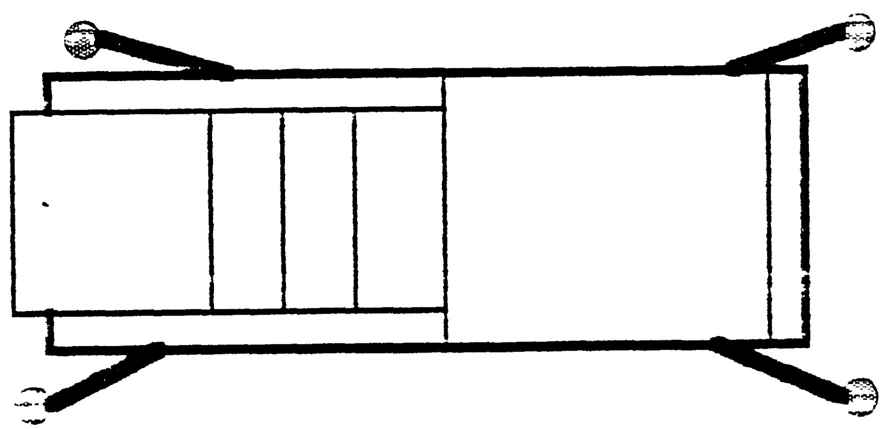

Figure C.2: Pallet Bottom Tie Down Spars

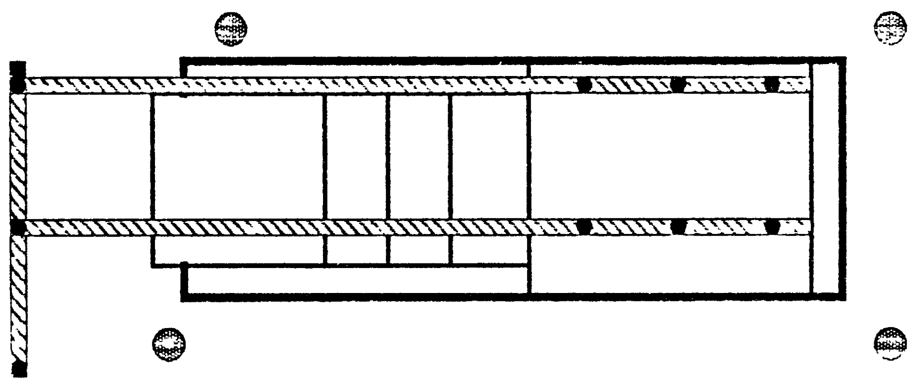

Figure C.3: Pallet Longerons and Cross Spar

a cross spar bolted to the rear passenger shoulder harness hardpoints. The longerons are 1/8 x 1.5 x 1.5 inch, 6063-T5 angle aluminum. The cross section subject to tensile loads is 1/8 x 1.5 inches or .1879 square inches and will withstand a tensile load of 5073.3 pounds.

The cross spar is 1/8 x 2 x 2 inches, 6061-T6 angle aluminum (ultimate shear strength is 30 ksi, yield strength is 40 ksi, ultimate tensile strength is 45 ksi). The smallest section subject to shear loads is 1/8 x 5/16 inches or .1641 square inches and will withstand a shear load of 4921.9 pounds. Figure C-3 shows the longerons and cross spar.

C.5.1 Nylon Webbing

The nylon webbing is 0.5 inch wide and used primarily as mountain climbing gear. A length of this webbing was loaded on a Materials Testing System Tensile Machine as the Technology Laboratory for Advanced Composites (TELAC) at MIT and subjected to a five inch ramp stroke in two seconds. The nylon broke at 1436.25 pounds. A graph of this test is shown in figure C-4 and is labled as try #2. Try #1 shows a similar test with a one inch stroke. The nylon stretched the full one inch without breaking.

C.5.2 Equipment Buckles

The nylon restraints for the equipment are held together by means of buckles, also used as mountain climbing gear. A sample buckle was loaded on an MTS tensile machine and loaded to failure. It failed at 219.84 pounds. Figure C-5 shows a graph of this test.

C.6 INSTALLATION INSTRUCTIONS

This section lists the installation procedure for the pallet.

1) Remove cushions from backs of rear two seats.

2) Position pallet bottom on seat behind pilot's seat and secure to plane with four spars.

3) Place rear seat foam cushion along seat back.

4) Slide gel cells into box, pack with foam, and secure with restraint

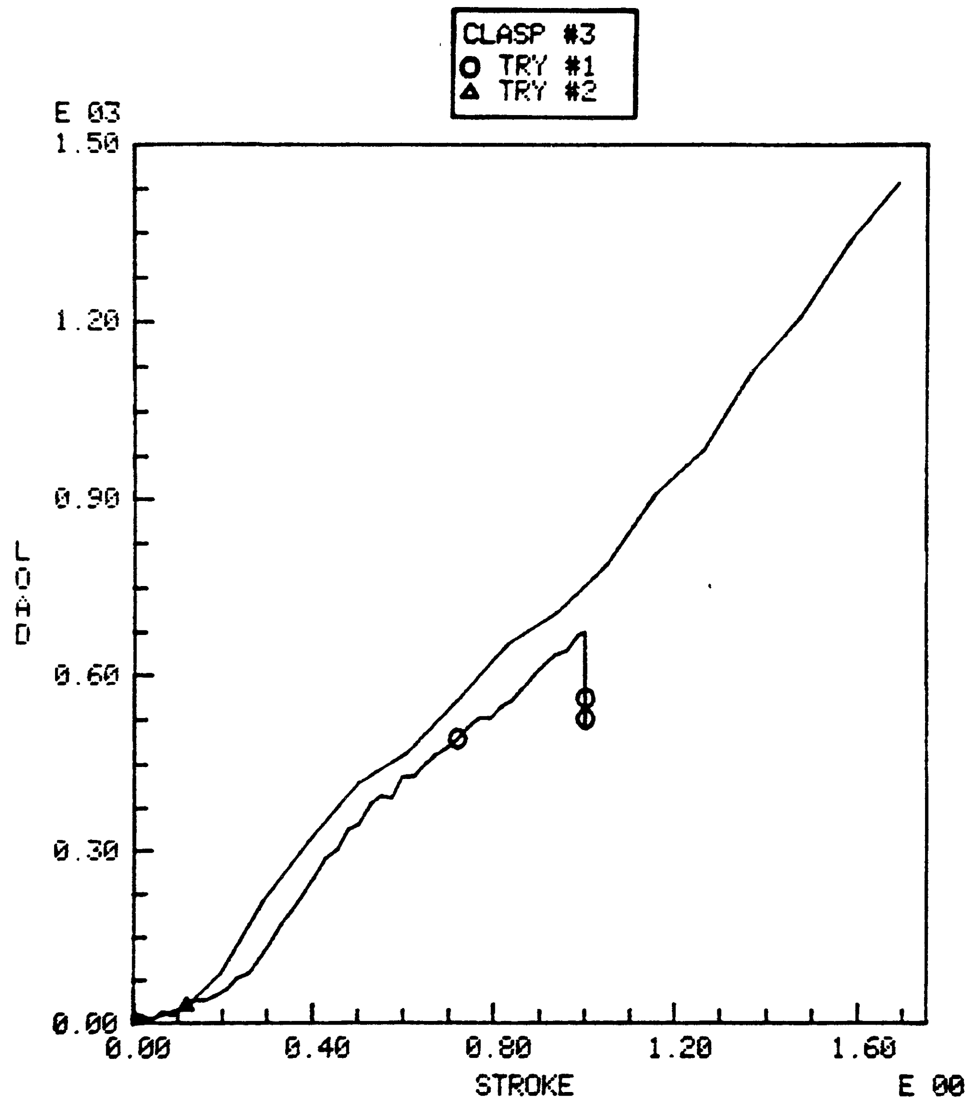

Figure C.4: Nylon Webbing Strength Test

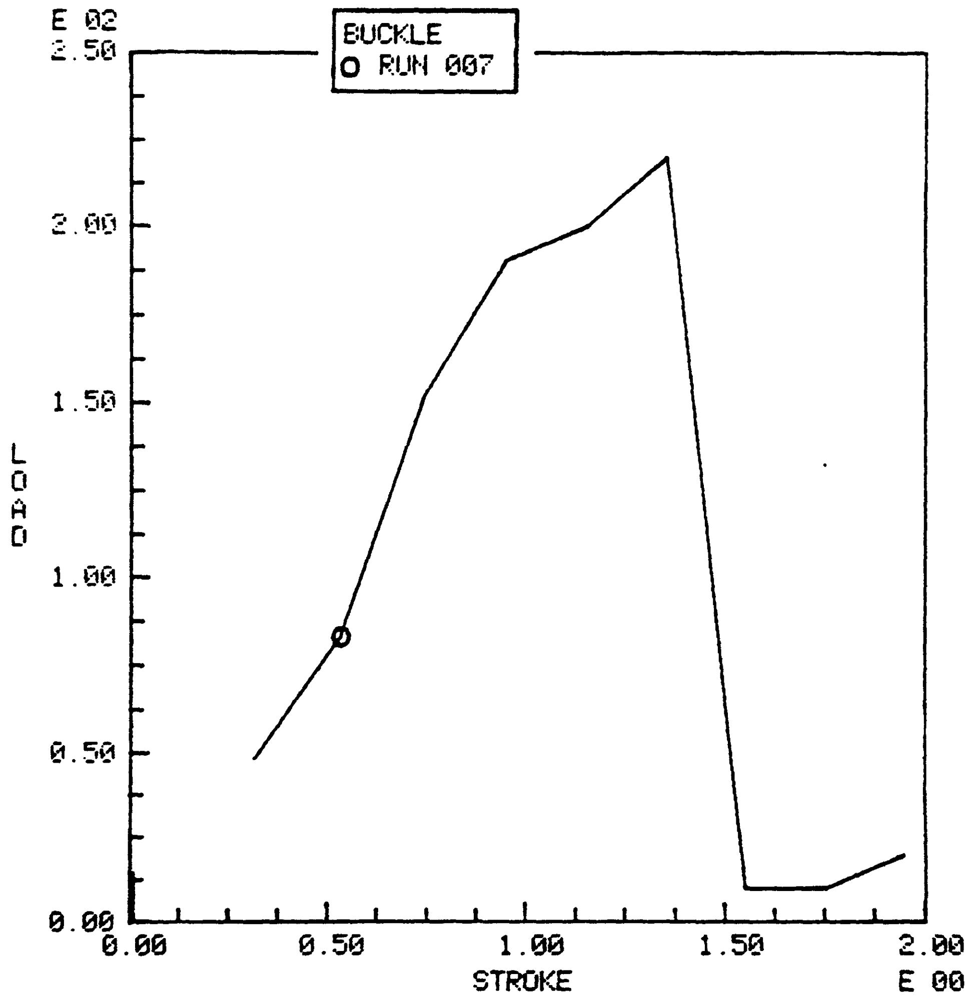

Figure C.5: Equipment Buckle Strength Test number six.

5) Place pallet top in rear of plane along plane centerline.

6) Attach A/D box to pallet top.

7) Place monitor in box, run power cord out side, run data line out cord hole and back through rear hole in Apple section.

8) Place LORAN in box, run data out line through rear hole in Apple section.

9) Put disk drive on seat behind pallet and run ribbon cable through rear hole in Apple section.

10) Hook A/D card ribbon cable into Apple slot #7, connect disk drive, monitor, and LORAN to proper inputs. Make sure Apple is switched on.

11) Slide Apple back into pallet and attach Apple power cord.

12) Place disk drive in box.

13) Move pallet over onto left seat and into final position. Bolt top of pallet to bottom. Replace right rear seat back cushion.

14) Slide inverter into box.

15) Slide VOR transceiver into box and secure with machine screw.

16) Slide VOR head into box.

17) Attach cables to rear of VOR transceiver, run output to VOR head and A/D converter.

18) Hook VOR and LORAN to respective antennas.

19) Attach longerons to cross spar and to monitor top. Tighten all

bolts.

20) Pack monitor with foam and place cover on box.

21) Connect LORAN and VOR to power buss on top of monitor box, making sure to ground LORAN.

22) Connect inverter and gel cell to buss, set rear breaker then set front breaker. Turn on inverter. Plug in monitor, then the Apple.

23) Once all connections are correct, disengage rear and front breakers.

24) Secure monitor with restraints four and five.

25) Pack Apple with foam, secure with restraints two and three.

26) Pack inverter with foam.

27) Install steel rod restraints for inverter (2 rods) and VOR head.

28) Pack LORAN with foam.

29) Place and secure restraint one.

30) Adjust and tighten all pallet restraints as necessary.

31) Installation complete.

32) Turn all equipment on and test again before taxi and/or takeoff.

C.7 REMOVAL INSTRUCTIONS

Removal of pallet and equipment will be accomplished essentially in reverse order of installation. The first step will be to turn off equipment and disconnect gel cell, followed by the installation instructions in reverse order, modified as necessary for convienence.

C.8 FAA PAPERWORK AND APPROVAL

This section contains the FAA paperwork and FAA approval that was sought and obtained before and flying could be done with the pallet installation. The report mentioned at the end of Form 337, Flight Test Pallet Tie Down Strategy and Installation Instructions has been ommitted in its original form. This appendix contains all of the information contained in that report.

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

MAJOR REPAIR AND ALTERATION
(Airframe, Powerplant, Propeller, or Appliance)

Form Approved Budget Bureau No. 04–R060 1

FOR FAA USE ONLY

OFFICE IDENTIFICATION

INSTRUCTIONS: Print or type all entries. See FAR 43.9, FAR 43 Appendix B, and AC 43.9-1 (or subsequent revision thereof) for instructions and disposition of this form.

1. AIRCRAFT	MAKE: Gulfstream American	MODEL: AA-5B
	SERIAL NO: AA5B-0231	NATIONALITY AND REGISTRATION MARK: N74452
2. OWNER	NAME (As shown on registration certificate): Lyman R. Hazleton, Jr.	ADDRESS (As shown on registration certificate): 6530 S.W. 144 St. Miami, Fla. 33158

3. FOR FAA USE ONLY

The data identified herein compl[illegible] applicable airworthiness require[illegible] approved only for the above [illegible] subject to conformity [illegible] by a person authorized in FAR-[illegible].

APPROVING INSPECTOR [signature]
DATE 04/04/85

4. UNIT IDENTIFICATION				5. TYPE	
UNIT	MAKE	MODEL	SERIAL NO.	REPAIR	ALTERATION
AIRFRAME	••••••••• (As described in item 1 above) •••••••••				XX
POWERPLANT					
PROPELLER					
APPLIANCE	TYPE / MANUFACTURER				

6. CONFORMITY STATEMENT

A. AGENCY'S NAME AND ADDRESS	B. KIND OF AGENCY	C. CERTIFICATE NO.
Robert J. Carrison 57 Littleton Rd. Chelmsford, Ma. 01824	X U.S. CERTIFICATED MECHANIC FOREIGN CERTIFICATED MECHANIC CERTIFICATED REPAIR STATION MANUFACTURER	A&P 476225855

D. I certify that the repair and or alteration made to the unit(s) identified in item 4 above and described on the reverse or attachments hereto have been made in accordance with the requirements of Part 43 of the U.S. Federal Aviation Regulations and that the information furnished herein is true and correct to the best of my knowledge.

DATE	SIGNATURE OF AUTHORIZED INDIVIDUAL
29 March 1985	[signature]

7. APPROVAL FOR RETURN TO SERVICE

Pursuant to the authority given persons specified below, the unit identified in item 4 was inspected in the manner prescribed by the Administrator of the Federal Aviation Administration and is ☒ APPROVED ☐ REJECTED

BY				
	FAA FLT STANDARDS INSPECTOR	MANUFACTURER	X INSPECTION AUTHORIZATION	OTHER (Specify)
	FAA DESIGNEE	REPAIR STATION	CANADIAN DEPARTMENT OF TRANSPORT INSPECTOR OF AIRCRAFT	

DATE OF APPROVAL OR REJECTION	CERTIFICATE OR DESIGNATION NO.	SIGNATURE OF AUTHORIZED INDIVIDUAL
4-5-85	264053974 A&P IA	[signature]

FAA Form 337 (7-67) ☆ U S Government Printing Office 1977—772-646/141 (8320)

Figure C.6: FAA Form 337, Side One

NOTICE

Weight and balance or operating limitation changes shall be entered in the appropriate aircraft record. An alteration must be compatible with all previous alterations to assure continued conformity with the applicable airworthiness requirements.

8. **DESCRIPTION OF WORK ACCOMPLISHED** *(If more space is required, attach additional sheets. Identify with aircraft nationality and registration mark and date work completed.)*

All work described below was performed on 25 March 1985

1.0 Pallet designed to hold equipment made of .063 inch, 5052 sheet aluminum was installed at station 113. It rests on 1 inch diameter, 2024-T351 aluminum rods, and is secured to the airplane by a system of seven spars. Four 1/8"x1"x1" angle aluminum spars attach the bottom of the pallet to four seatbelt hardpoints. Two 1/8"x1.5"x1.5" angle aluminum longerons attach the top of the pallet to a cross-spar in the rear of the plane. All six of these ties are made of 6063-T5 aluminum. The cross-spar is made of 6061-T6, 1/8"x2"x2" angle aluminum and is secured to the rear passenger shoulder harness hardpoints.

2.0 A Micrologic ML-3000 LORAN-C receiver was installed at station 125. It is secured to the pallet (1.0) by 1/2" nylon webbing and a 1/4"x1"x1" section of angle aluminum. Impact foam surrounds the receiver on three sides.

3.0 Two Powersonic 12 volt DC gel cells were installed at station 108. They are secured to the pallet (1.0) by nylon webbing. They are padded on two sides by impact foam.

4.0 A Micronic DC to AC power inverter was installed at station 123. It is secured to the pallet (1.0) by nylon webbing and two 3/8" steel rod restraints. It is padded on three sides by impact foam.

5.0 A computer monitor was installed at station 111. It is secured to the pallet (1.0) by four nylon webbing restraints. It is padded on three sides by impact foam.

6.0 An Apple II+ computer was installed at station 111. It is secured to the pallet (1.0) by nylon webbing restraints.

7.0 An Apple II disk drive was installed at station 123. It is secured to the pallet (1.0) by nylon webbing and a 3/8" steel rod restraint.

8.0 An Apple A/D card was installed at station 104. It is secured to the pallet (1.0) by two steel sheet metal screws.

9.0 A King KX-175B transceiver was installed at station 127. It is secured to the pallet (1.0) by means of a screw through standard bracket on rear of frame.

10.0 A King VOR head was installed at station 126. It is secured to the pallet (1.0) by means of a 3/8" steel rod restraint.

11.0 All electrical connections have been made with 16 gauge, nylon insulated wire to a central 12 volt bus located on top of the pallet. Two 10 amp circuit breakers have been introduced to the system as a safety precaution.

12.0 Additional information and detailed parameters are provided in the attached document, Flight Test Pallet Tie Down Strategy and Installation Instructions.

13.0 Airplane weight and balance is contained in the document.

☒ ADDITIONAL SHEETS ARE ATTACHED

Figure C.7: FAA Form 337, Side Two

Document was not available at time of publication.

Figure C.8: Application for Airworthiness Certificate, Side One

UNITED STATES OF AMERICA

DEPARTMENT OF TRANSPORTATION — FEDERAL AVIATION ADMINISTRATION

SPECIAL AIRWORTHINESS CERTIFICATE

A	CLASSIFICATION:	Restricted		
	PURPOSE:	Electronic Equipment/ Research		
B	MANU-FACTURER	NAME N/A		
		ADDRESS N/A		
C	FLIGHT	FROM N/A		
		TO N/A		
D	N— 74452		SERIAL NO.	AA5B-0231
	BUILDER	Grumman American	MODEL	AA-5B
E	DATE OF ISSUANCE	04-05-85	EXPIRY	N/A
	OPERATING LIMITATIONS DATED	04-05-85	ARE PART OF THIS CERTIFICATE	
	SIGNATURE OF FAA REPRESENTATIVE	C.H. Davison	DESIGNATION OR OFFICE NO.	NE-FSDO-61

Any alteration, reproduction, or misuse of this certificate may be punishable by a fine not exceeding $1,000 or imprisonment not exceeding 3 years, or both. THIS CERTIFICATE MUST BE DISPLAYED IN THE AIRCRAFT IN ACCORDANCE WITH APPLICABLE FEDERAL AVIATION REGULATIONS.

FAA FORM 8130-7 (3-69) SUPERSEDES FAA FORMS 1362-B; 8100-3; 8130-5 *SEE REVERSE SIDE*

A	This airworthiness certificate is issued under the authority of the Federal Aviation Act of 1958 and the Federal Aviation Regulations (FAR).
B	This airworthiness certificate authorizes the manufacturer named on the reverse side to conduct production flight tests, and only production flight tests, of aircraft registered in his name. No person may conduct production flight tests under this certificate: (1) Carrying persons or property for compensation or hire; and/or (2) Carrying persons not essential to the purpose of the flight.
C	This airworthiness certificate authorizes the flight specified on the reverse side for the purpose shown in Block A.
D	This airworthiness certificate certifies that, as of the date of issuance, the aircraft to which issued has been inspected and found to meet the requirements of the applicable FAR. The aircraft does not meet the requirements of the applicable comprehensive and detailed airworthiness code as provided by Annex 8 to the Convention On International Civil Aviation. No person may operate the aircraft described on the reverse side: (1) except in accordance with the applicable FAR and in accordance with conditions and limitations which may be prescribed by the Administrator as part of this certificate; (2) over any foreign country without the special permission of that country.
E	Unless sooner surrendered, suspended, or revoked, this airworthiness certificate is effective for the duration and under the conditions prescribed in FAR Part 21, Section 21.181 or 21.217.

Figure C.9: Restricted Airworthiness Certificate

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

Aircraft: Grumman American   Model: AA-5B

Registration No.: N74452   Serial No.: AA5B-0231

OPERATING LIMITATIONS, RESTRICTED CATEGORY, ELECTRONIC EQUIPMENT RESEARCH

1. This aircraft is certificated in the restricted category for the purpose of electronic equipment research.

2. This aircraft shall be operated in accordance with FAR 91.39 and the following terms and conditions.

   a. Operation over densely populated areas is authorized provided the requirements of FAR 91.79 are met, considering the performance characteristics of this aircraft, as equipped for the special purpose, and considering power-on and power-off performance.

   b. Operations conducted near a busy airport where passenger transport operations are conducted shall be coordinated with the air traffic service facility (Center, FSS, or Tower) having cognizance over the area in which the research operation is to be conducted. Operations shall be routed to remain clear of transport passenger operations.

3. Takeoffs and landings shall be made to provide the least possible exposure to persons and property on the surface.

4. Any major alteration to this aircraft will invalidate the attached restricted category airworthiness certificate. No further operation of this aircraft under the terms of this certificate may be conducted unless further operation is authorized by an FAA General Aviation Airworthiness Inspector.

5. This aircraft shall be inspected before and after each flight by the pilot-in-command or by a certificated mechanic with at least an airframe rating for security of electronic equipment and evidence of cracks or other indications of wear or damage.

6. Research electronic equipment must be monitored for interference with the aircraft's navigation and communication equipment.

7. The electronic equipment must be installed and/or removed by a certificated mechanic with at least an airframe rating. Each installation or removal shall be recorded in the airframe log for this aircraft, and it shall be performed in accordance with removal and reinstallation instructions which are part of FAA 337 dated 4-5-85 for this aircraft.

Figure C.10: Limitations on Restricted Aircraft Operation, Page One

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8. This restricted category airworthiness certificate and these special operating limitations shall remain in effect when any portion of the special purpose equipment is installed and until surrendered, suspended, or revoked.

9. These special operating limitations may be amended by application for an issuance of a new special airworthiness certificate, restricted category.

10. Flight operations in restricted category must be conducted by a pilot holding at least a ~~commercial~~ pilot certificate with airplane ~~multi~~- engine land rating who meets the recent flight experience requirements of FAR 61.57(d) with respect to this make and model of aircraft.

DATE: 04-05-85

C.H. Davison
NE-FSDO-61

Figure C.11: Limitations on Restricted Aircraft Operation, Page Two

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