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SAMSO TR 71-190

2

FINAL REPORT

SYSTEM 621B USER EQUIPMENT DEFINITION AND EXPERIMENT PROGRAM FOR THE U. S. ARMY

PHASE I

See 1473

Space and Missile Systems Organization
SAMSO (XLRO) AFSC
Los Angeles, California 90045

3 September 1971

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3 September 1971

[redacted]

~~(GAC No~~. 621B-AFR)

[redacted]

FOREWORD

This report contains the findings of a program titled, "System 621B User Equipment Definition and Experiment for the U. S. Army". The work was accomplished by Grumman Aerospace Corporation (GAC) at Bethpage, New York and the Hazeltine Corporation (HC) at Greenlawn, New York and complies with all requirements of Contract Number F04701-71-C-0176 and Amendment Numbers P00003 and P00008.

The report is published in one volume and the Grumman Report Number is 621B-AFR. The United States Air Force Report Number is SAMSO-TR 71-190.

This report discusses the results of a Phase I study directed to preparing a field test plan for a System 621B Single Channel User Receiver and to performing sufficient design tasks to allow immediate procurement and execution of the test program.

Grumman wishes to acknowledge the assistance of Messrs. M. Miller and S. Pomerantz of USASATCOM, and the members of SAMSO and the Aerospace Corporation.

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Publication approval of this technical report does not constitute Air Force approval of the report's findings or conclusions. It is published only for exchange and stimulation of ideas.

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ABSTRACT

In order to solidify confidence in the predicted performance of the System 621B receiver, this report outlines the tradeoffs that were performed to determine the best field test, for the U.S. Army, of a representative single-channel receiver which would use a helicopter as a test vehicle. Options have been defined including a choice of single-channel receivers and the addition of a real time navigation capability. The details of the design and test plan for the selected field test are given, as well as the requirement for the test range. This effort was done in sufficient range and depth to allow the immediate initiation of the test hardware procurement and/or fabrication.

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1. INTRODUCTION

This report describes a program to test the suitability of the System 621B navigation system for use by land, sea and air vehicles of the United States Army. Among the Army functions for which such accurate position-fixing, navigation and survey data may be required are:

- Tactical and strategic electronic warfare
- Airborne operations
- Ground reconaissance, mounted and manpack
- Topographic survey
- Riverine operations
- Target and weapon system location - fire control
- Special applications - non-tactical
  - Range instrumentation
  - Geodetic
  - Photogrammetric

It has been shown, based upon analytic data (Reference 2), that System 621B may be able to satisfy many of the position-fixing, navigation and survey accuracy requirements implicit in these functions. The test program is intended to demonstrate and verify some of the analysis contained in Reference 2.

All these functions imply that the Army may employ a large number of System 621B user equipments. It is therefore imperative that the System 621B user equipment for the Army be as cost-effective as possible. A one-protected-channel receiver is the basic element which may meet this criterion and Army requirements. Alternate methods of achieving single-channel receiver operation for the test program are outlined.

The system will be tested with a helicopter as the ground and airborne receiver test bed. Ground and ballon transmitters will be used to simulate satellite operation. To minimize cost, it is desirable that the single-channel receiver be tested immediately following the test of the four-channel receiver at White Sands. The test set-ups will be almost identical. No hardware changes in the transmitters or their associated equipment and only minor changes - relocation of the balloon antenna and replacement of its hemispherical antenna by a shaped beam antenna - in the area navigation test will be required.

2. OBJECTIVES

The System 621B navigation system, consisting of four satellite transmitters, ground station, and a user receiver/computer, can provide three-dimensional position and velocity data to its users. The system capabilities will be demonstrated using three ground transmitters to simulate three of the satellites and a balloon-borne or ground-based transmitter to simulate the fourth, depending on the particular test. A four-channel receiver will be aboard an NC-135 aircraft, the data from which shall be recorded for later processing at a ground facility. This test program is scheduled for the White Sands Missile Range during the period of November 1971 through March 1972.

The test configuration for the Army is similar, except for the replacement of the four-channel receiver in the NC-135 aircraft by a one-channel receiver in a UH-1H helicopter. This modification is highly desirable in the operational system to reduce receiver cost and thereby permit widespread use of the system by Army vehicles. The single-channel receiver will be aboard a helicopter and the data from the receiver will be recorded for post-flight processing at a ground-based facility. On-board real-time computation, as in an operational system, could be implemented for these tests. Since the other elements of the system are essentially unchanged, almost identical test set-ups can be used for both systems. Therefore, to minimize test costs, it is recommended that the one-channel receiver be tested using the test set-up and personnel planned for the SAMSO NC-135 tests. It is estimated that field installation, checkout and flight testing will require about four months.

The primary objective is the evaluation of the real-time data derived from the Flight Test Program. A listing of the objectives is given in Table 2-1. However, in addition to the preparation for the field tests, there are analytical results required to support the field test. These are described throughout this report. They include:

- Preparation of software to evaluate field test data
- Analytical evaluation of the effects on the amplitude and phase of the incoming signal due to rotor modulation. A Fourier analysis of the rotor modulated wave will be accomplished in order to evaluate effects on the receiver
- Determination of the errors due to multipath from a refined modeling of ground roughness, and ground reflection coefficient for the flight paths and the tie down configurations
- Evaluation of multipath from the rotor at low grazing angles
- Evaluation of antenna vibration effects on the receiver

Table 2-1 Demonstration Objectives

PRIMARY OBJECTIVES

1. Determine accuracy of a single channel receiver in area navigation
2. Determine accuracy of single channel receiver in ILS
3. Determine accuracy of a single channel receiver and cycle rate at low signal levels for ground based users
4. Determine rotor modulation effects
5. Determine ground multipath effects

SECONDARY OBJECTIVES

1. Determine code and carrier rate aiding requirements
2. Determine accuracy of a single channel receiver with and without doppler information
3. Determine acceptable antenna locations
4. Determine reacquisition and channel sequencing capability

TERTIARY OBJECTIVES

1. Provide data to compare single channel performance versus NC-135A tests with 4 channel receiver
2. Determine vibration and acoustic effect on accuracy and sequencing
3. Evaluate real time computer workload for code and carrier aiding (Option III)
4. Determine data sample rate requirement for receipt of satellite ephemerides modulation

3. TECHNICAL APPROACH

The objective of this program is to demonstrate the ability of System 621B to meet U.S. Army position-fixing, navigation and survey requirements. This is to be achieved by utilizing a single channel receiver installed in a helicopter and operated over a ground-based transmitter configuration similar to the SAMSO deployment. It is anticipated that this proposed Army test program can be performed basically using the transmitter configuration that will be set up for the SAMSO ILS tests. This test configuration uses three ground-based transmitters and one balloon-borne transmitter, and is to be performed at the Northrup strip at the White Sands Missile Range. The SAMSO ILS tests are the last tests to be run in the SAMSO series and the Army tests can be performed immediately following the SAMSO ILS tests with the same transmitter configuration (Figure 3-1). No hardware changes will be required in the transmitters or transmitter associated equipment (antennas, MCS, etc.). Some minor changes to the ILS configuration will be required for the area navigation test. These include the removal and relocation of the balloom transmitter and antenna to a specific ground location (Figure 3-2) and if necessary the replacement of the ILS antennas (hemispherical) by the shaped beam antennas that SAMSO will use for the NC-135 Phase II area navigation test. Both changes are straightforward and require no new hardware. A single aircraft antenna will be used in four helicopter locations to perform all tests (Figure 3-3).

3.1 TIE DOWN TESTS

These use the same transmitter configuration as the SAMSO ILS test. The helicopter is tied down to the pad located 500 ft from the MCS van and the following tests are performed:

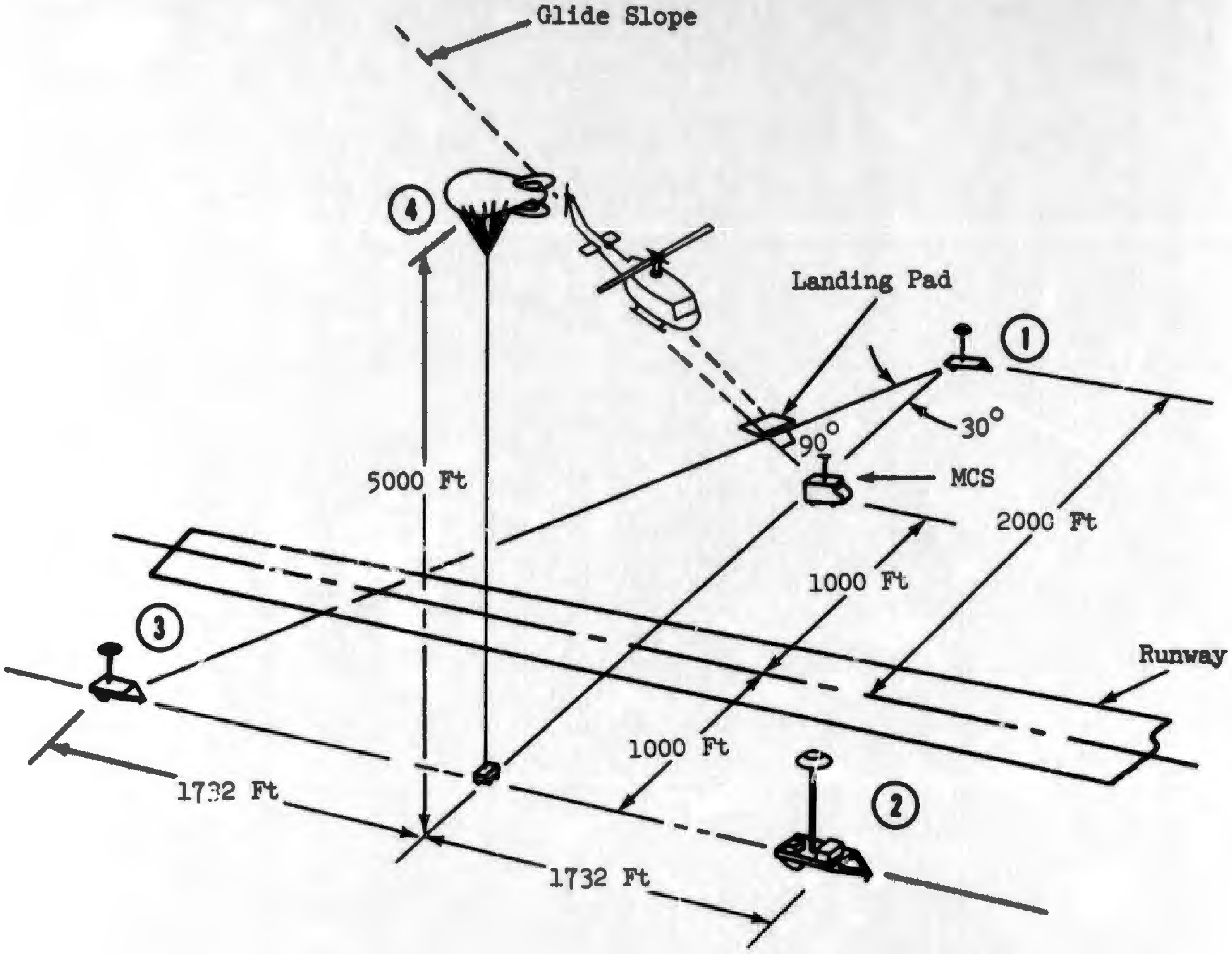


Figure 3-1 Helicopter ILS and Tiedown Transmitter Configuration

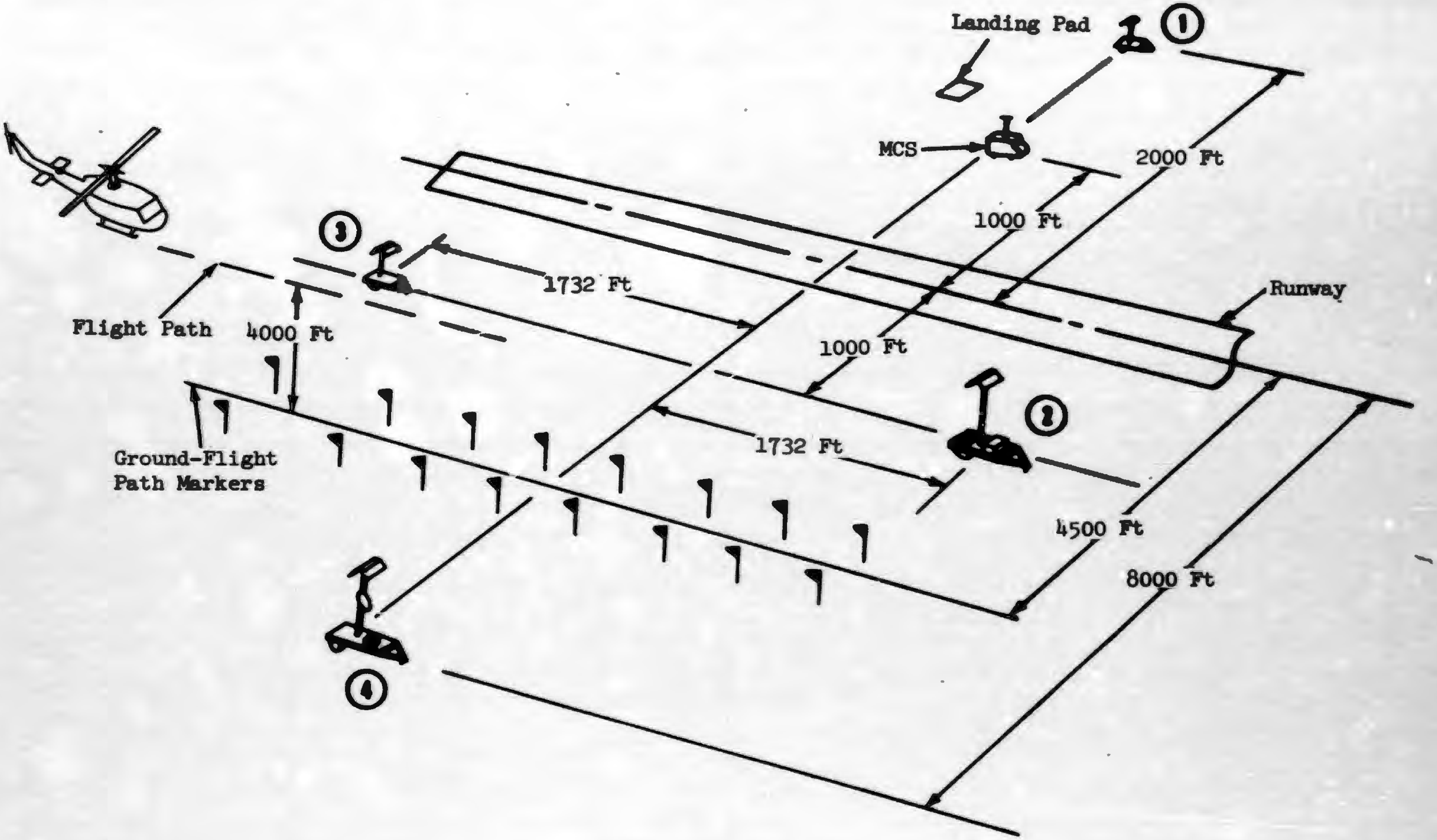


Figure 3-2 Helicopter Area Navigation Transmitter Configuration

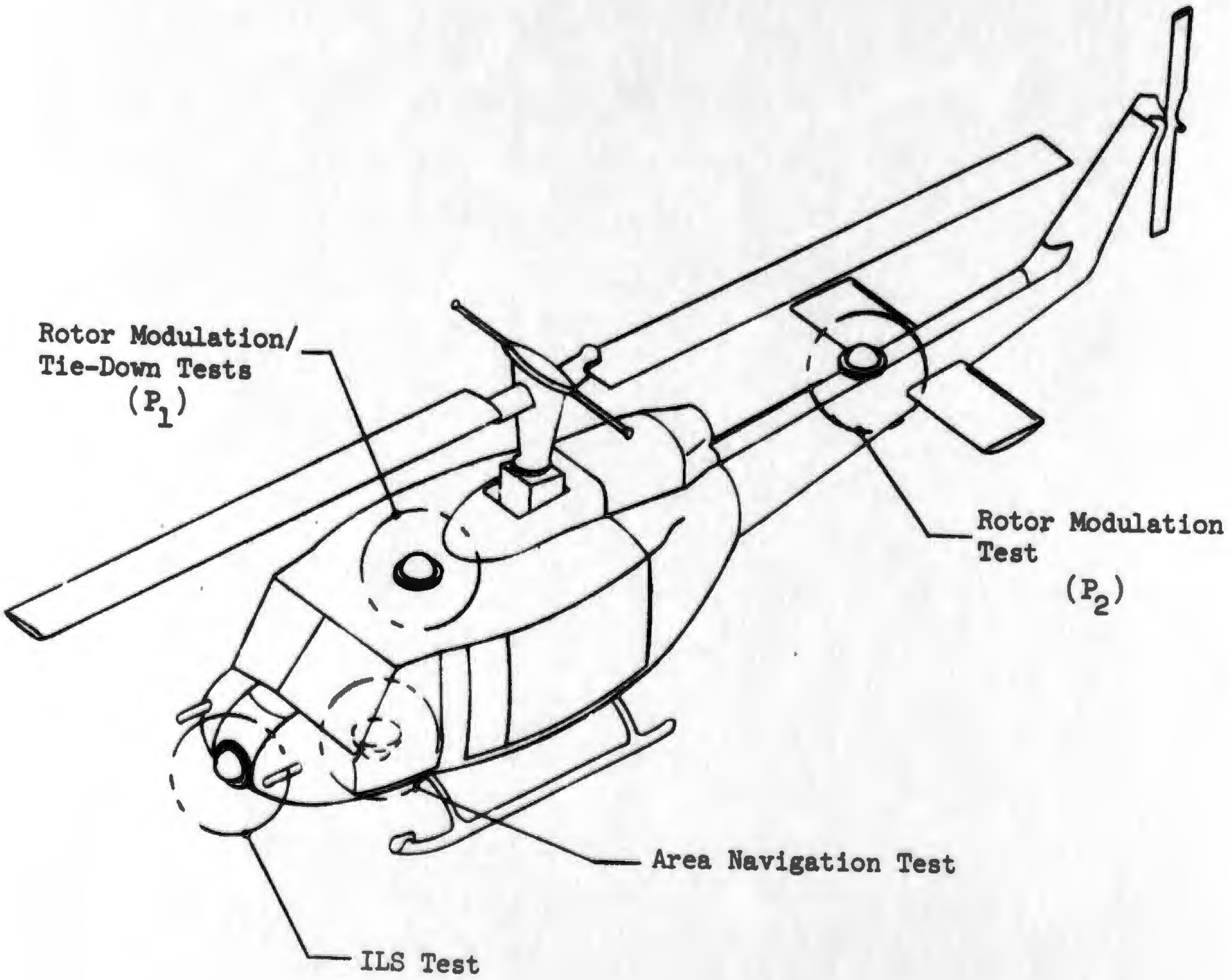


Figure 3-3 Antenna Locations

- Rotor Modulation - This test utilizes a top mounted antenna at two locations which observes the balloon transmitter through the rotor. In the tie down condition, the rotor can be run at zero and at flight speed, and the effect of rotor modulation and multipath can be ascertained. Various rotor reflection angles can be achieved by lowering the balloon.

- Baseline Receiver Accuracy and Survey - With the helicopter tied down at a known point, its position, as determined from measurements, can be compared to the known location. This will provide a very accurate reference with which to compare System 621B in terms of land navigation and survey requirements. Further, a comparison of this data with that of MCS (at a known location with respect to the helicopter tie down point) will indicate, very accurately, the relative navigation capabilities of System 621B. In the relative navigation test, the MCS can be utilized as a user, since the transmitter biases will drop out of the relative navigation equations.

- Signal Levels - For this test, transmitter signal levels will be varied to ascertain effects on receiver cycling time and performance.

3.2 ILS TEST

This uses the same transmitter configuration as the tie down tests. The helicopter will use a nose mounted antenna and will land at the pad located 500 ft from the MCS van. The ILS profiles selected insure that all transmitters remain forward of the helicopter until touchdown. Data will be evaluated for ILS applicability and also compared with the MCS data to evaluate applicability of system to a relative ILS problem (helicopter landing at a point whose coordinates have been deduced from another System 621B receiver).

3.3 AREA NAVIGATION

This test will require a slight change in the ILS transmitter configuration. For this test the balloon transmitter and antenna will be removed from the balloon and located at a specific ground location. The helicopter will then overfly the transmitters in a prescribed manner. This test will indicate the area navigation capability of the one channel receiver. Moderate helicopter flight profiles will be used.

A power variation analysis has indicated a variation in received power of from -137 dbm to -127 dbm (see Figure 5-27) over the optimum GDOP region. The minimum signal level is encountered at a distance of 4500 ft along the flight path and increases to -135 dbm at 4000 ft. The variation in power level of from -135 dbm to -127 dbm along the course will have the effect of improved accuracy at the higher signal levels. For Option I (Section 8), the receiver can meet a measurement error of $\sigma_R = 7$ ft at -135 dbm, so that no major problems are anticipated. However, if during the flight test program it is found that this signal level is marginal, then the ILS antenna will be replaced by the SAMSO area navigation shaped beam antenna which will reduce this variation from -132 dbm to -128 dbm. This is a simple replacement.

4. ASSUMPTIONS AND GROUND RULES

1. Field tests with the Army supplied helicopter will commence upon completion of NC-135 tests and continue for four months. Ten weeks of the four months will be allocated to modification, installation and checkout and the remaining six weeks for flight test. See schedule in letter of transmittal.

2. SAMSO Phase II equipment shall be made available for use in the helicopter program immediately upon completion of the final NC-135 flight, as required. GAC personnel will perform the necessary modifications and/or installations in the helicopter on site. Flight recorder shall be provided GFE by the Air Force.

3. Modification and installation of antennas, equipment racks and cables will be performed at Holloman by GAC/HC with the exception of the UH-1H helicopter nose door which shall be provided by the U.S. Army to GAC for modification.

4. The installation effort will be a one-time installation.

5. Modifications, fabrications and installation of equipment shall be accomplished by engineering drawings and technical writings.

6. The balloon used for the NC-135 ILS tests shall be made available for Army tests 1 and 2.

7. The field test will be performed at Holloman AFB and WSMR.

8. The Army will provide the helicopter and flight crews.

9. The Army will perform preflight and post flight checks and maintenance of helicopter.

10. WSMR services required by the program will be provided GFE upon Air Force request. This will include providing the installation and site surveys for the transmitters, but WSMR will have technical assistance from Grumman Aerospace Corporation and Hazeltine Corporation.

11. The 6600 computer facilities at Kirtland AFB, will be made available for any on-site data reduction.

12. Constant-receiver-power flight profiles shall be a goal but not a requirement, thereby allowing use of SAMSO transmitter antennas.

13. Existing ground test equipment from the NC-135 tests will be utilized.

14. The Army will provide a suitable helicopter inverter, and installation instructions.

15. WSMR will provide a helicopter landing pad at Northrup strip.

5. SYSTEMS ANALYSIS

This section addresses the system aspects of the field test demonstration as outlined in Section 3. In this category are the following topics:

- Single-channel receiver performance
- Selection of the ILS transmitter configuration and navigation performance
- Selection of the Area Navigation transmitter configuration and navigation performance
- Data reduction
- Analysis of Rotor Modulation effects
- Multipath
- Received power computation for tie-down
- Helicopter performance

5.1 SYSTEM ACCURACY REQUIREMENT, MEASUREMENT ERROR AND CYCLE TIME

In single-channel operation a receiver will lock on a channel, remain locked long enough to obtain a meaningful measure of pseudo-range and pseudo-doppler, break lock and then begin search for the acquisition of the next channel. The accuracy of the overall system will depend on both the measurement accuracy per channel and the time required for acquisition. The uncertainty in vehicle dynamics will have greater effect as the time between updates increases. The system accuracy requirement will therefore place an upper bound on the cycle time. Similarly, the system accuracy is a direct function of the quality of the measurement and therefore system specifications will place an upper bound on measurement accuracy.

An analytic expression is now derived which relates system accuracy requirement to measurement accuracy requirement and cycle time.

It is assumed that position and velocity are updated between measurements by

$$\bar{Y}(t_n + \Delta T) = \bar{Y}(t_n) + \bar{V}\Delta T \qquad (5\text{-}1)$$

$$\bar{V}(t_n + \Delta T) = \bar{V}(t_n) \qquad (5\text{-}2)$$

where t_n is the time of the last update and ΔT is the time interval between updates.

The errors in equation (5-1) and (5-2) are due to errors in the initial conditions and errors due to unmodeled accelerations.

$$\delta Y_i(t) = \delta Y_i(t_n) + \Delta T\, \delta V_i(t_n) + \int_0^t ds \int_0^s a_i(\tau)\, d\tau$$

$$\delta V_i(t) = \delta V_i(t_n) + \int_0^t a_i(\tau)\, d\tau$$

A worst case bound on δY_i and δV_i is obtained by assuming worst case measurement errors to be $3\sigma_R$ and $3\sigma_{\dot{R}}$ respectively and assuming constant acceleration a_i, then for δY

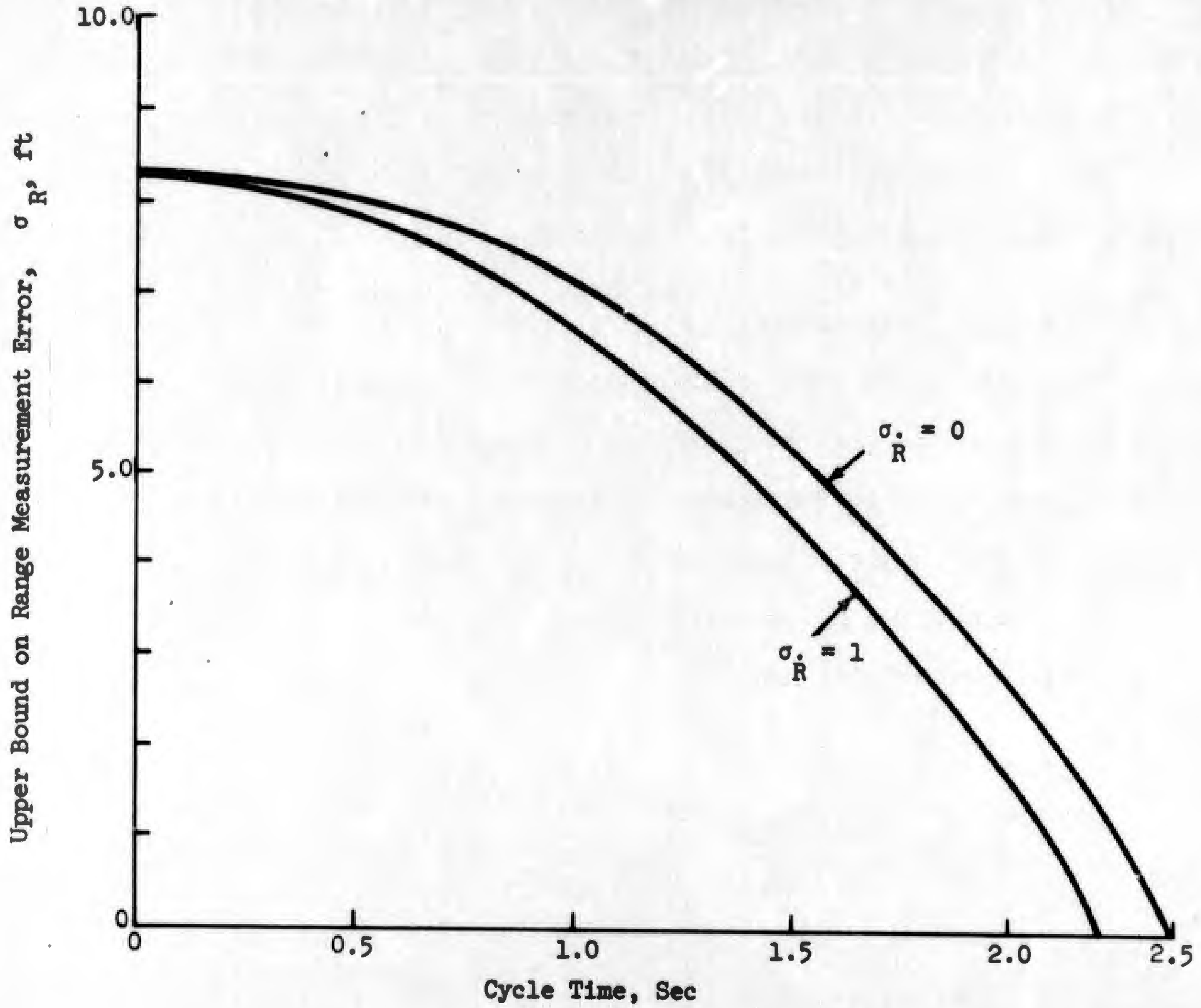
$$|\delta Y_i(t)| \le (GDOP_i)[3\sigma_R + (3\sigma_{\dot{R}})\Delta T] + \frac{1}{2} a_i(\Delta T^2) \qquad (5\text{-}3)$$

and $\delta \dot{Y}_i$

$$|\delta \dot{Y}_i| \le (GDOP_i)[3\sigma_{\dot{R}}] + a_i \Delta T \qquad (5\text{-}4)$$

where $GDOP_i$ is an appropriate GDOP constant which relates the measurement error to the error in the desired output quantity. A typical application of equations (5-3) and (5-4) is shown in Figure 5-1. For this curve the following system requirements are displayed.

- Maximum position error is required to be less than 50 ft
- Maximum acceleration = ½ G = 16 ft/sec² (Ref. 9)
  These requirements may be representative of formation flying with 100 ft displacement between vehicles
- $GDOP_i = 2$
  The curve shows the required pseudo-range accuracy plotted versus the cycle time so that the system requirement is met. Note that cycle time is the time for the receiver to acquire all four channels;



Maximum Acceleration = 1/2g
Maximum Position Error = 50 Ft

Figure 5-1 Upper Bound on Range Measurement Error, σ_R, to Maintain Position Accuracy within 50 ft it is normally four times the increment between successive measurements

We observe that $\sigma_{\dot{R}}$, the doppler error has relatively minor impact on position accuracy over the range

$$0 < \sigma_{\dot{R}} < 1 \text{ ft/sec}$$

We observe that a σ_R of 8.5 ft would be required, even if instantaneous cycle time were possible; that the measurement error must get better as cycle time increases. When cycle time exceeds 2.5 seconds we observe that the system specification cannot be satisfied with even perfect measurements.

From the curve, a reasonable design point might be $\sigma_R = 5.0$ ft; cycle time = 1.0 seconds. It is pointed out in Section 9.1 that the Option II (single channel) digital receiver can provide $\sigma_r \leq 5.0$ ft at a signal level of -140 dbm at an update rate of five (5) samples per second. The Option I receiver (modified SAMSO four-channel receiver) however, will provide $\sigma_r \leq 5.0$ ft at a signal level of -130 dbm at a cycle time of one (1) second. The error increases to $\sigma_r = 7$ ft at a worst case signal level of -135 dbm.

5.2 SELECTION OF THE ILS TRANSMITTER CONFIGURATION

In order to construct an ILS transmitter configuration, several constraints associated with the problem must be accounted for. Since these constraints may degrade the navigation solution, the question may be asked, "by how much". In its work for SAMSO, Grumman Aerospace Corporation has derived the optimum or "ideal" ILS configuration solution. This derivation is given in Appendix A. As a result of this derivation the selection of the ILS configuration can be achieved by direct reasoning.

The design procedure consisted of the following steps:

- Derive the ideal configuration which yields the minimum altitude and sink rate error at a critical landing point, generally the flare point, or for the case of the helicopter, the landing point
- Taking into account the practical constraints of the problem, perturb the ideal by the minimum amount necessary to satisfy these constraints and derive a recommended configuration
- Demonstrate that the degradation in accuracy using the recommended configuration is negligibly degraded from that of the ideal

5.2.1 The Ideal Solution

Appendix A demonstrates that an ideal ILS configuration for the flight test program is composed of three ground transmitters forming an equilateral triangle centered about the critical point (landing point) and a balloon-based transmitter directly above the critical point. This conclusion was based on the following assumptions:

- Three transmitters are constrained to be on the ground
- The fourth transmitter can be in a balloon whose maximum altitude is fixed (e.g., 5000 ft)
- There are no balloon ephemeris errors

- The pseudo-range and pseudo-range-rate measurement errors are independent random variables with zero mean and standard deviations of σ_R and $\sigma_{\dot{R}}$ respectively
- The navigation algorithm makes no attempt to utilize a-priori estimate of vehicle position and velocity
- The algorithm does estimate pseudo-range bias and bias rate sufficiently well to make the system appear to be a pure range and range rate system. Computer simulation, to be discussed later, will verify that this assumption is indeed valid

Subject to the assumptions listed, the ideal solution yields the minimum altitude and sink rate error at the critical point; these values are:

$$E[\delta z^2] = \sigma_R^2 \qquad (5\text{-}5)$$

$$E[\delta \dot{z}^2] = \sigma_{\dot{R}}^2 \qquad (5\text{-}6)$$

or that the minimum altitude and sink rate errors are equal to the measurement errors.

In Appendix A it is shown that the ideal procedure to eliminate the effect of balloon ephemeris errors is to have the MCS located at the landing pad, as shown in Figure 5-2.

If the last assumption is valid, Appendix B shows that there is no effect at the critical point due to balloon ephemeris errors.

5.2.2 The Practical Solution

The method of selection of a recommended ILS configuration is to attempt to approach, as closely as possible, the ideal solution. Taking into account the following practical considerations:

- It is highly desirable to maintain the transmitter and MCS locations from Phase II. In the configuration from the Phase II flight test program, the MCS will be 500 ft from the center of the ground triangle, as shown in Figure 5-3

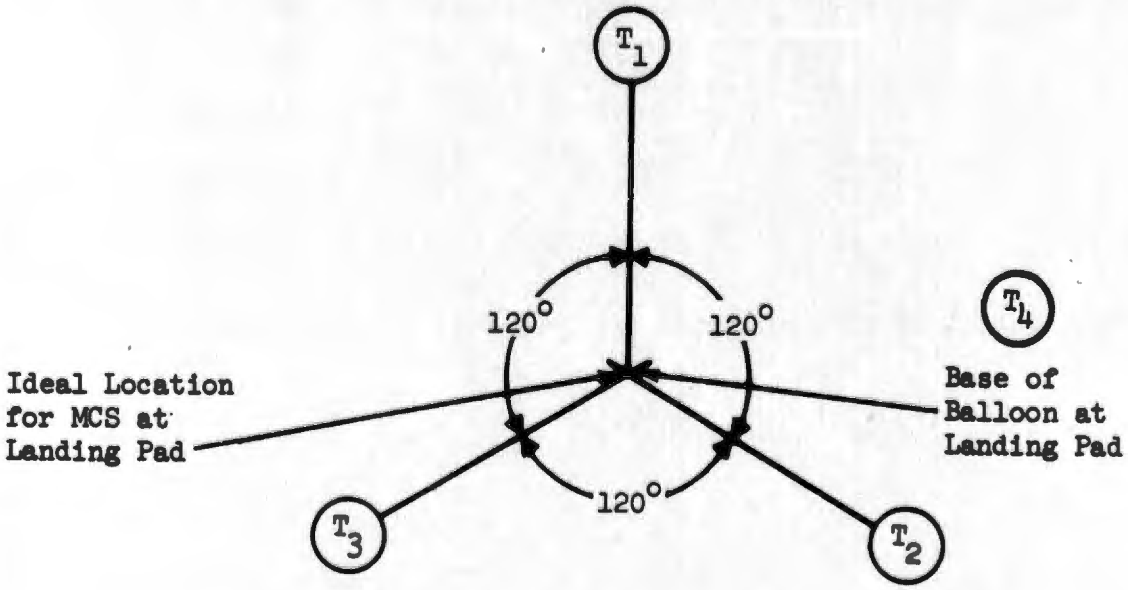


Figure 5-2 Ideal ILS Location for Three Ground Transmitters, One Balloon Transmitter and MCS

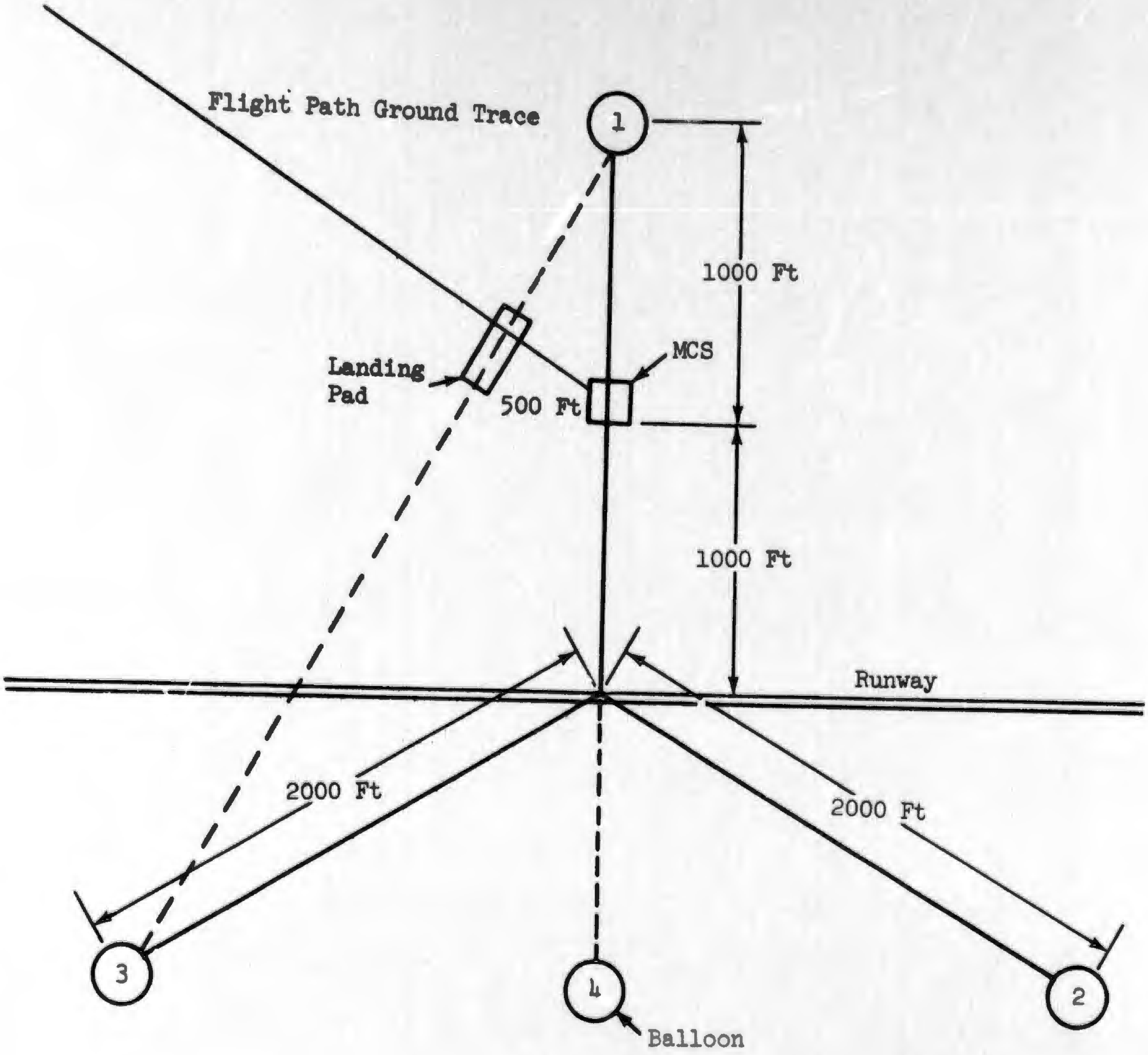


Figure 5-3 Practical ILS Configuration

- The base of the balloon will be located 1,000 ft from the center of the runway

- In order to maintain antenna/transmitter line of sight with a single antenna located in the nose of the helicopter, it is important to keep all transmitters nominally in front of the helicopter as it approaches. This dictates that the landing pad not be located closer to the MCS than on a line connecting transmitters 1 and 3 as shown in Figure 5-3

- The approach of the helicopter need not be along the center of the runway but it should be reasonably close so that WSMR tracking equipment will be acceptable without relocations

- The fact that the test under discussion uses a single-channel mechanization requires that a-priori estimate of position and velocity be incorporated into the navigation algorithm. Nominal values associated with the test locale will be used i.e. best guess.

A configuration is now recommended (Figure 5-3) which requires no movement of transmitters or MCS from the NC-135 ILS test configuration. To satisfy the antenna pointing problem the landing pad is moved 500 ft from the MCS and the approaching ground trace makes a 30° angle with the runway. The glide slope can be defined by using the lens system, also used in the NC-135 tests. See Section 6.3 for details of the lens system.

The results of a covariance analysis and simulations are presented in Figures 5-4 through 17 to demonstrate that the resultant configuration causes negligible accuracy degradation from the ideal. The results were derived on the basis of an 8 state Kalman filter which is described in Section 5.4. The landing profile is given in Figure 5-18.

Computer runs are presented for receiver cycle times of 0.8 sec and 1.6 sec respectively (.2 sec and .4 sec between measurements) for the recommended configuration. Balloon altitude is 5000 ft and balloon ephemeris errors of 5 ft and 5 ft/sec were assumed. Measurement errors of 5 ft and .5 ft/sec were also assumed.

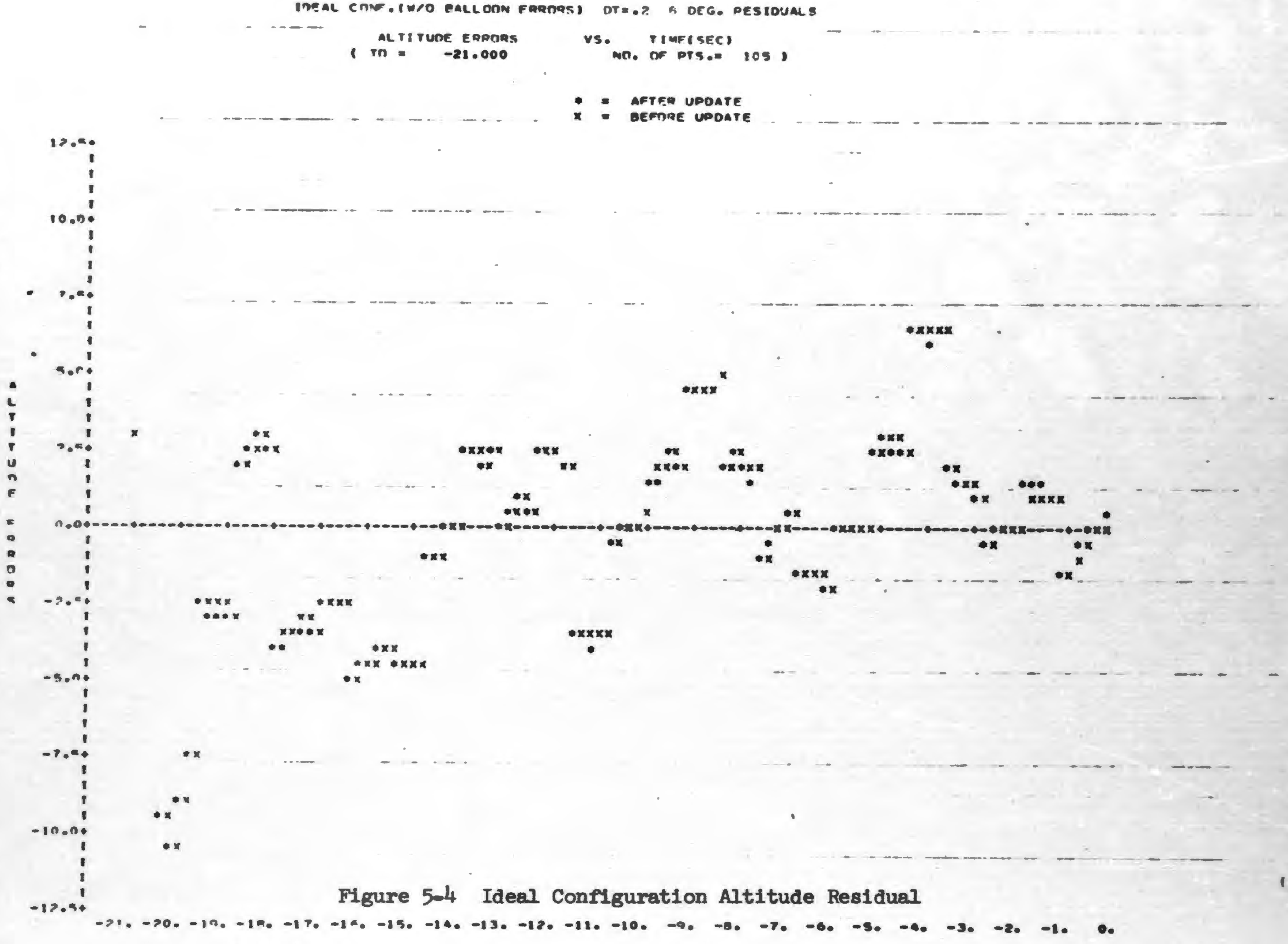


Figure 5-4 Ideal Configuration Altitude Residual

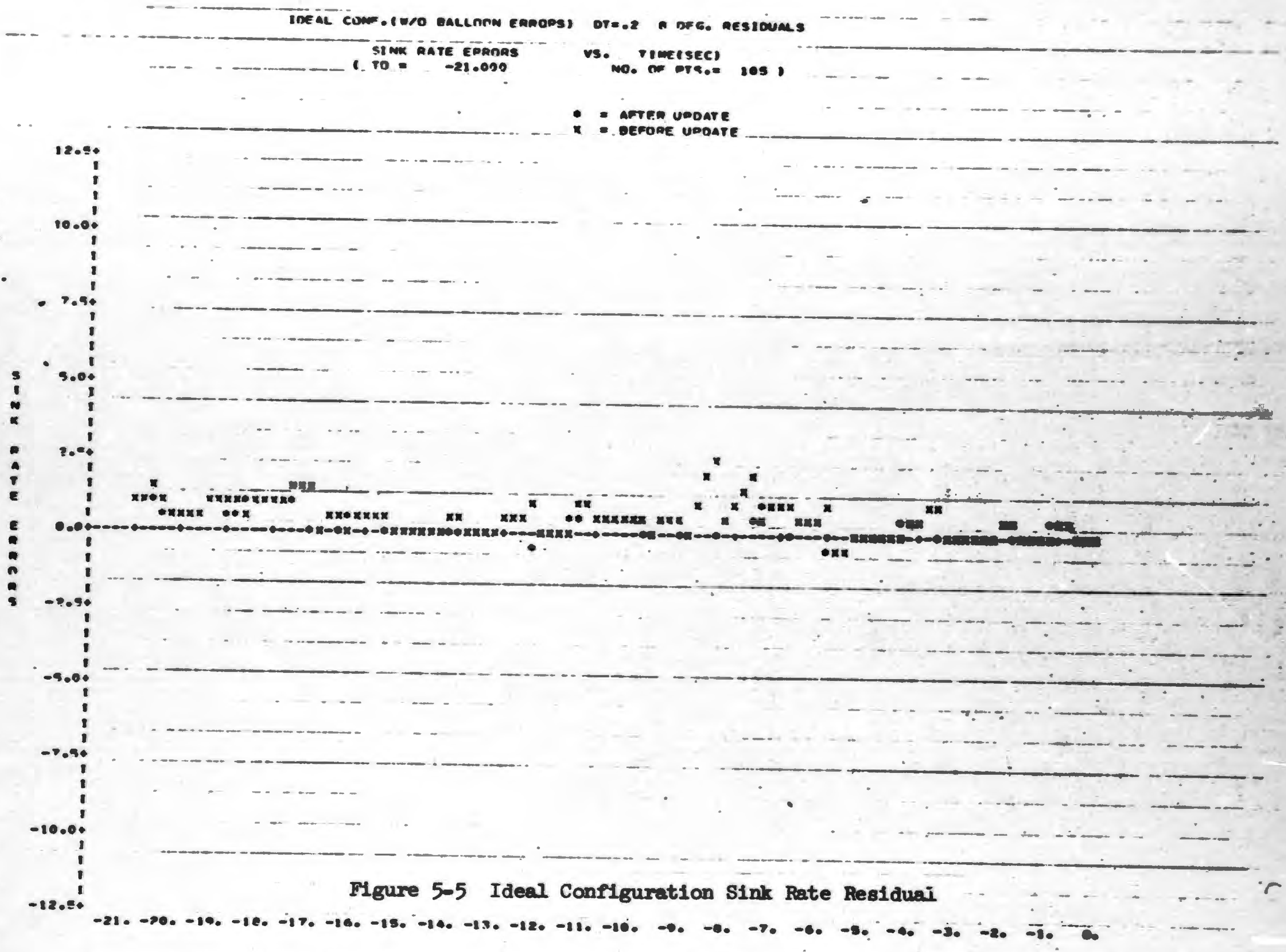


Figure 5-5 Ideal Configuration Sink Rate Residual

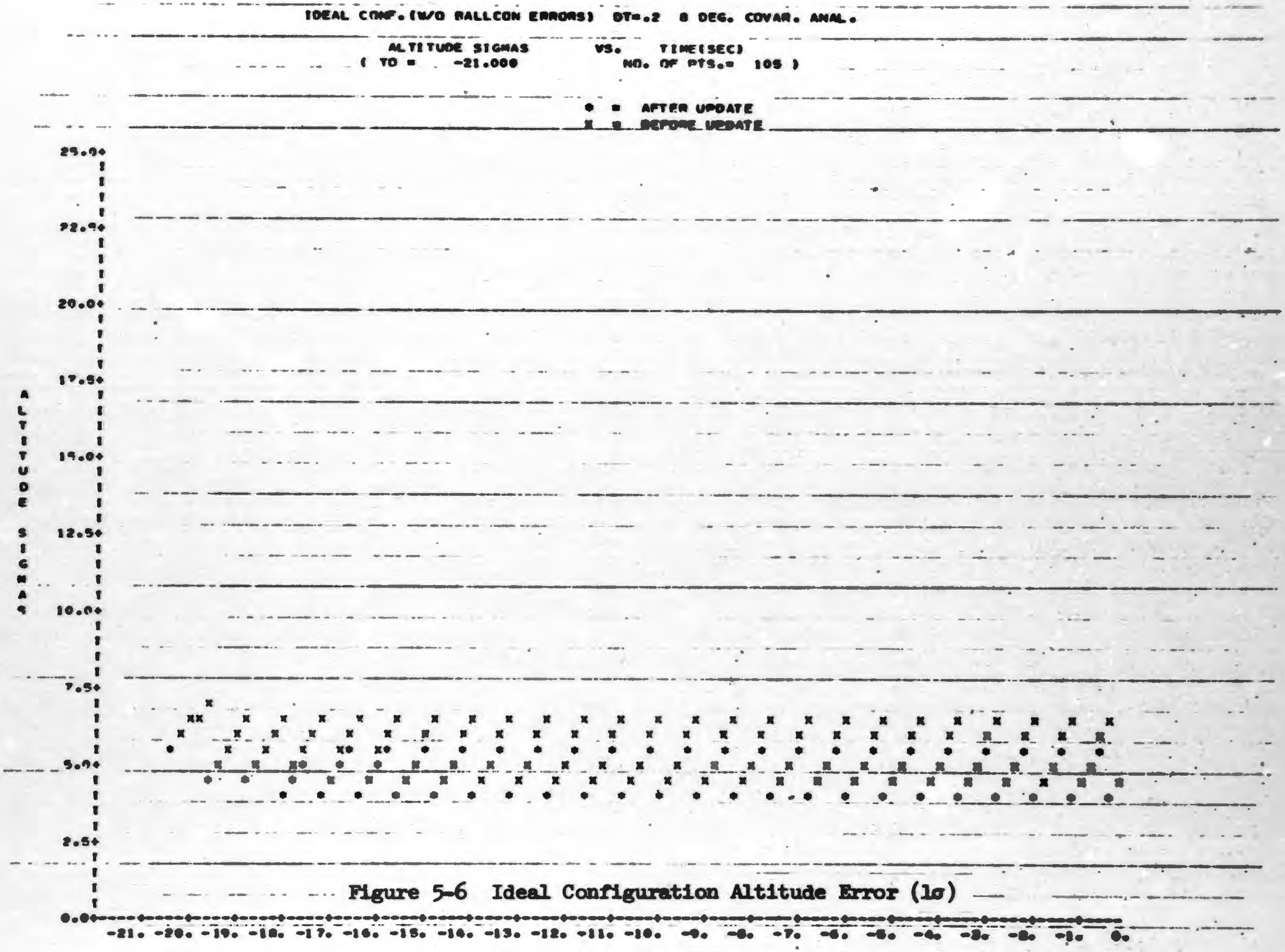


Figure 5-6 Ideal Configuration Altitude Error (1σ)

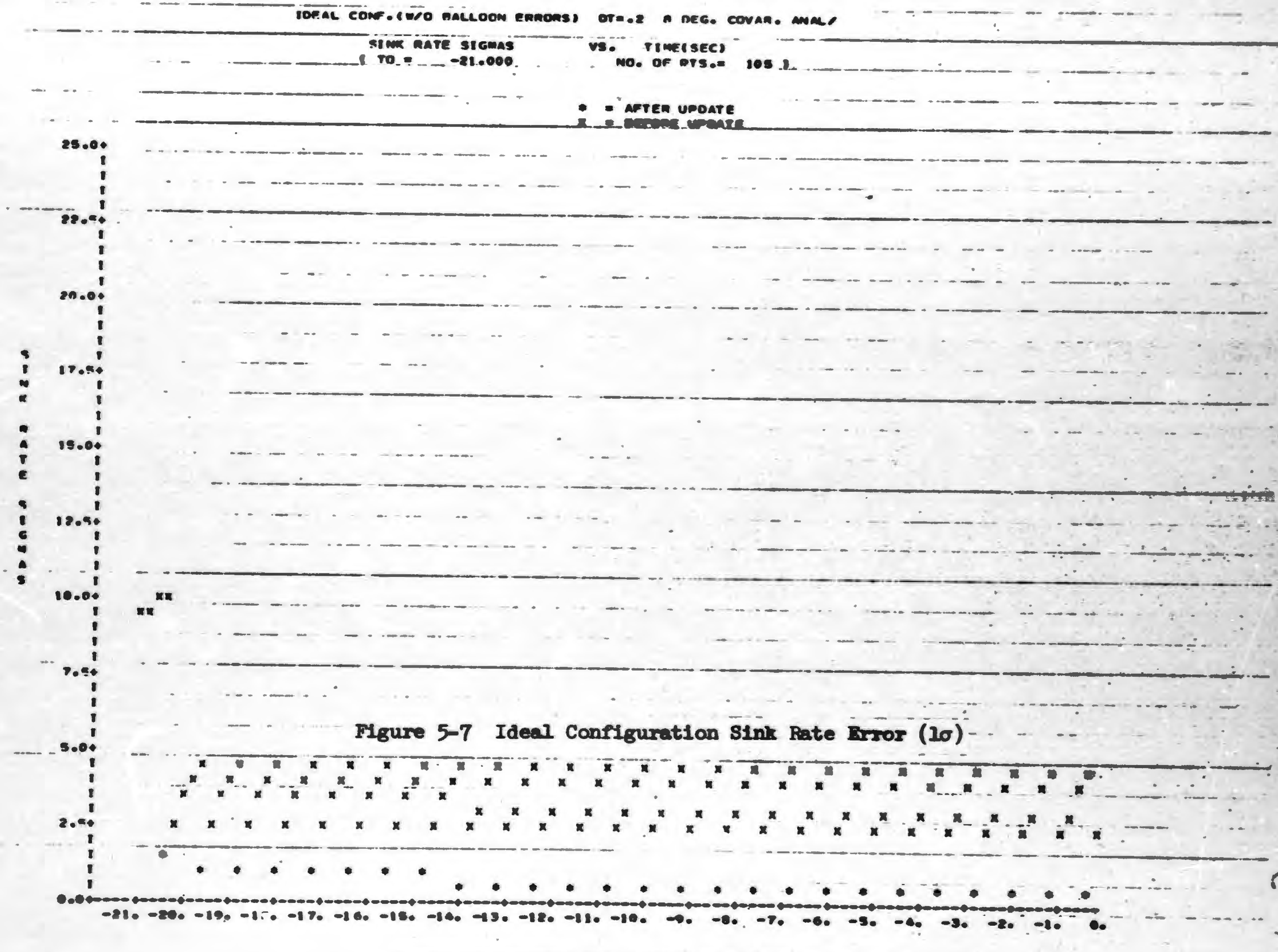


Figure 5-7 Ideal Configuration Sink Rate Error (1σ)

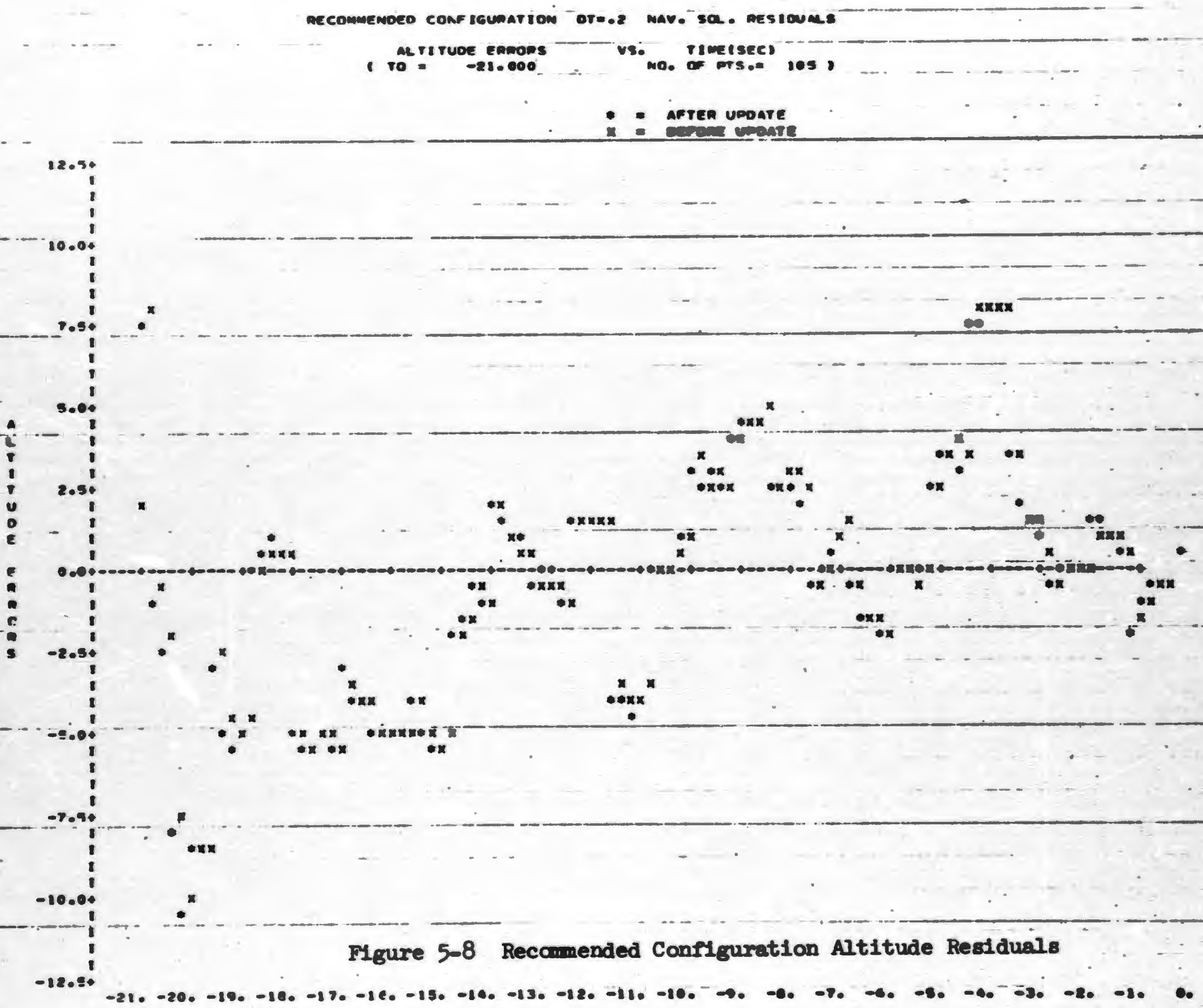


Figure 5-8 Recommended Configuration Altitude Residuals

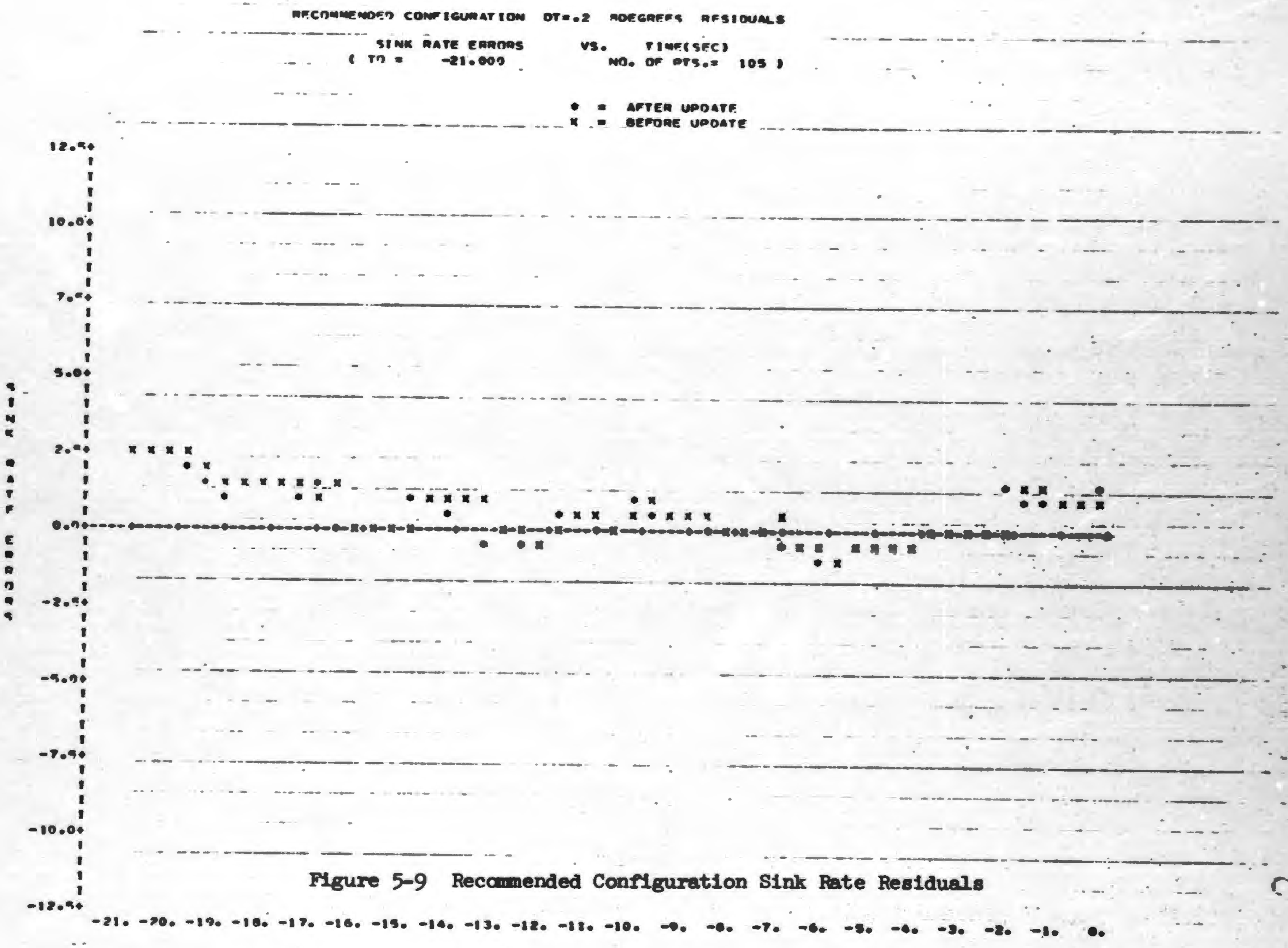


Figure 5-9 Recommended Configuration Sink Rate Residuals

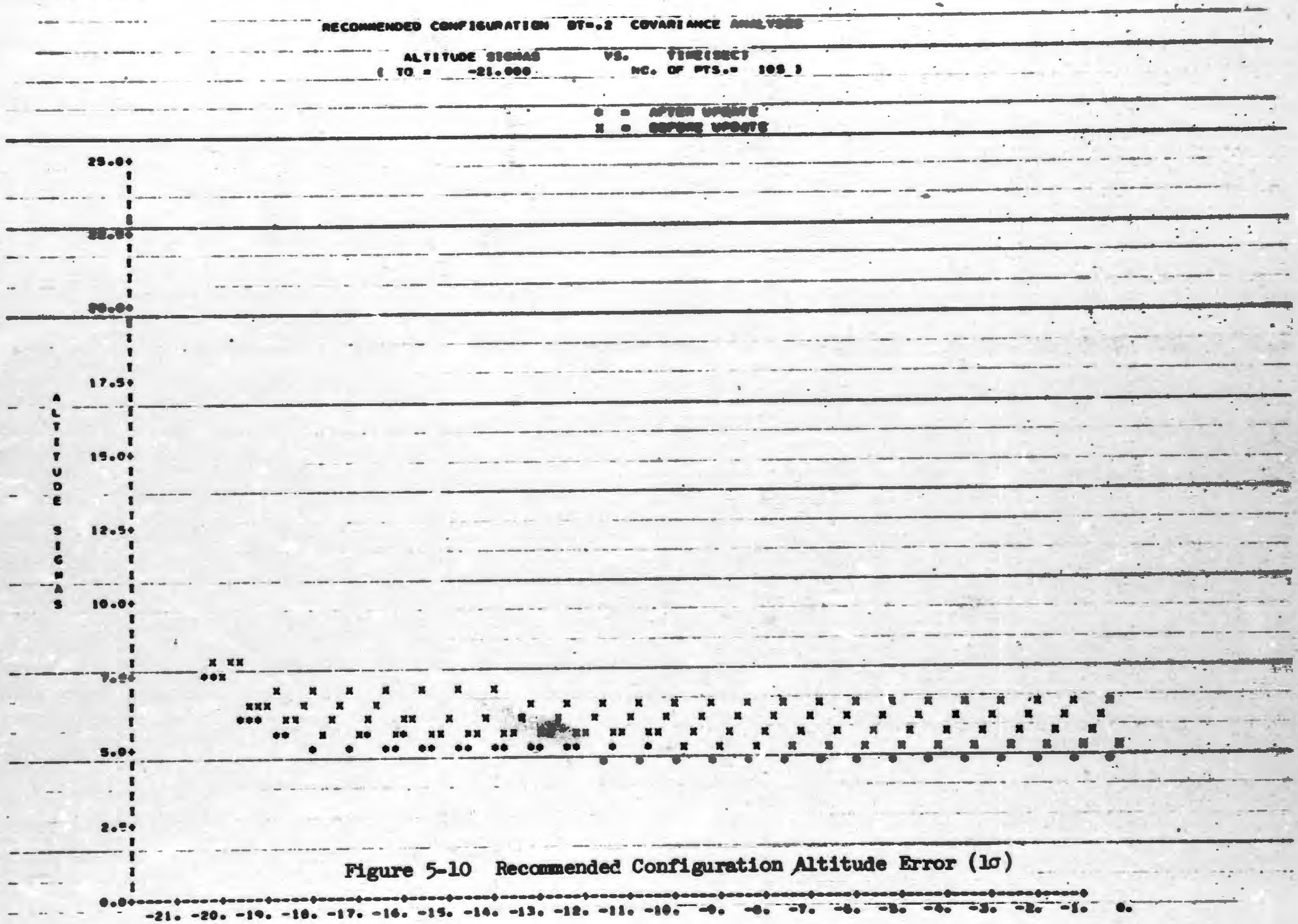


Figure 5-10 Recommended Configuration Altitude Error (1σ)

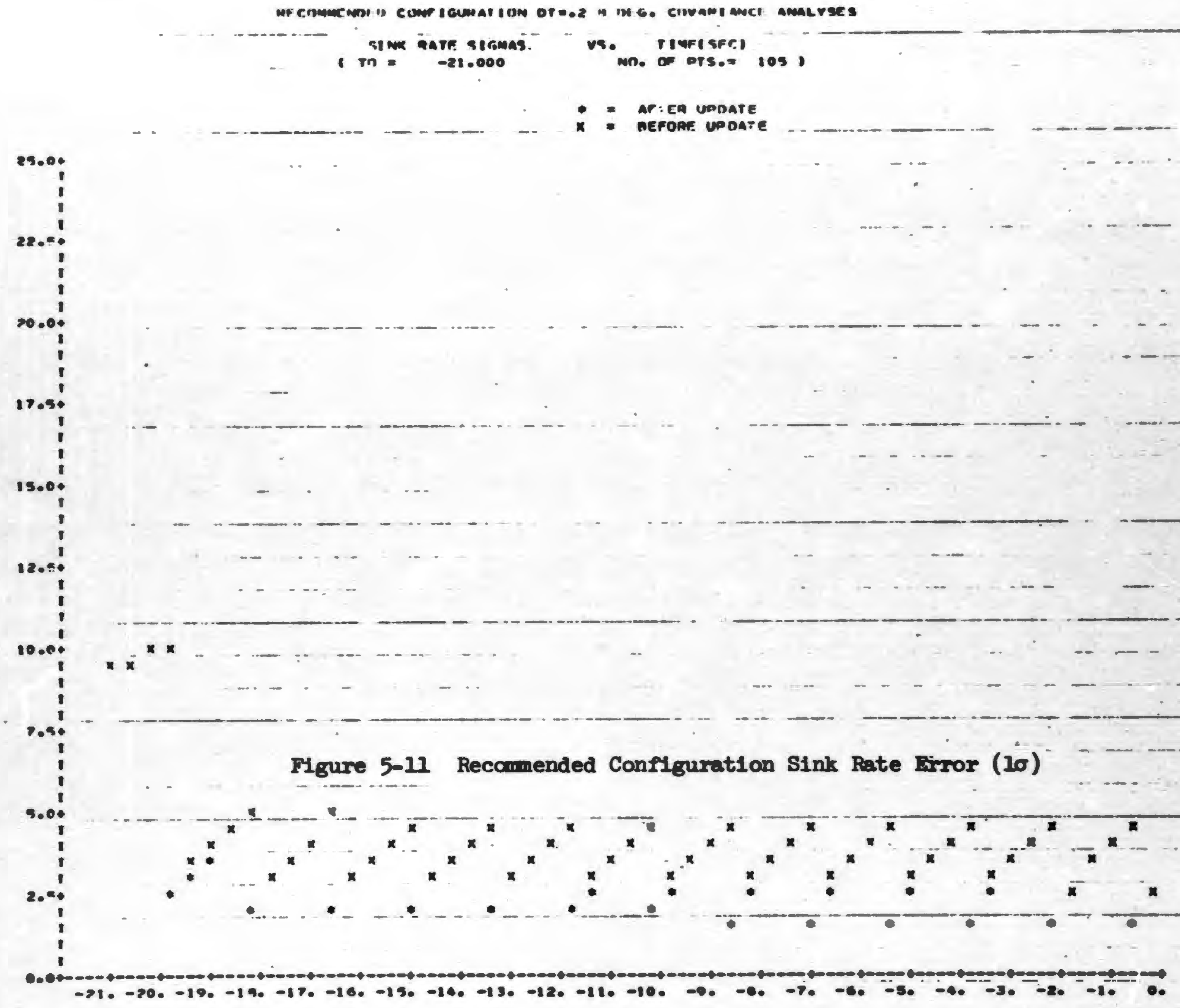


Figure 5-11 Recommended Configuration Sink Rate Error (1σ)

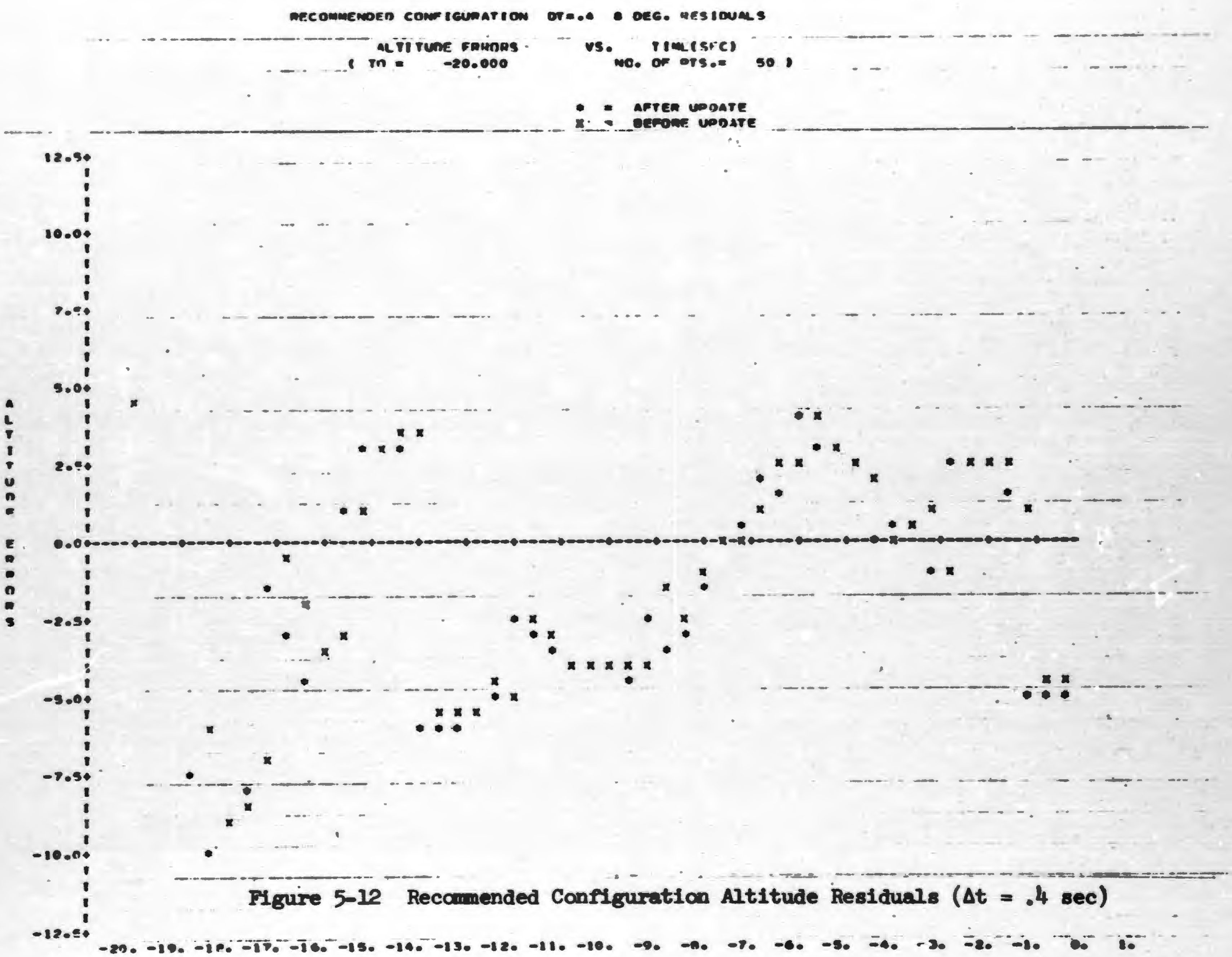


Figure 5-12 Recommended Configuration Altitude Residuals (Δt = .4 sec)

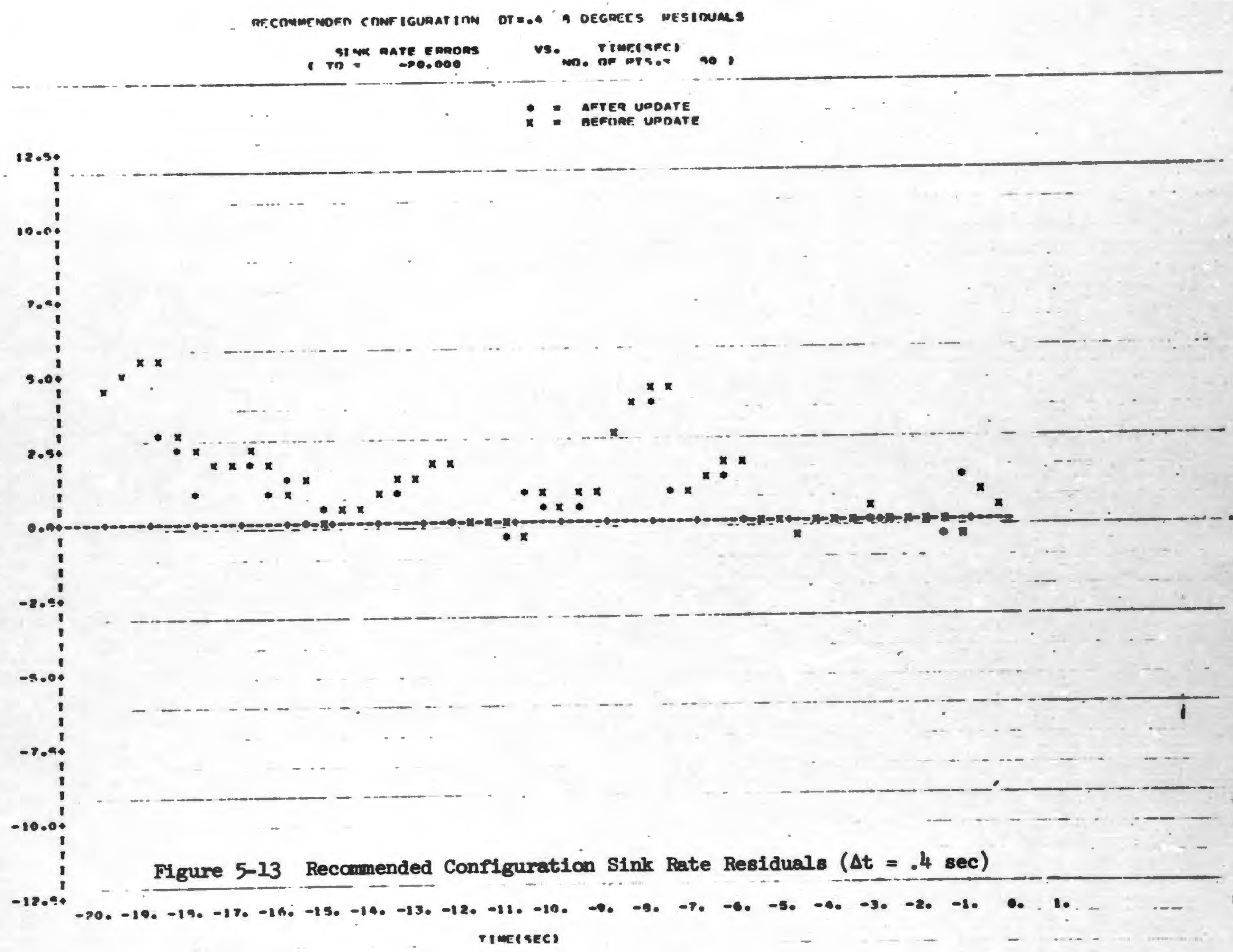


Figure 5-13 Recommended Configuration Sink Rate Residuals (Δt = .4 sec)

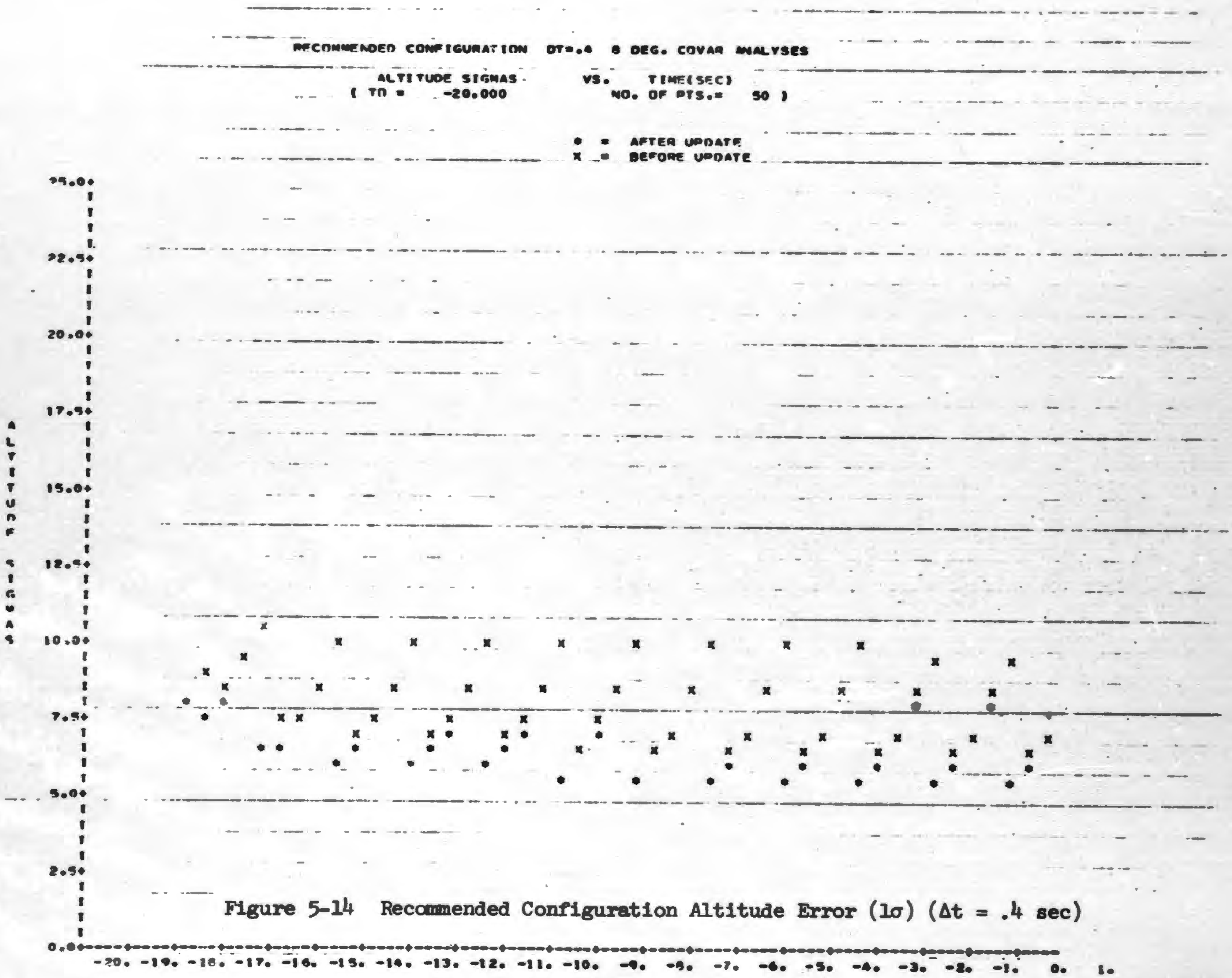


Figure 5-14 Recommended Configuration Altitude Error (1σ) (Δt = .4 sec)

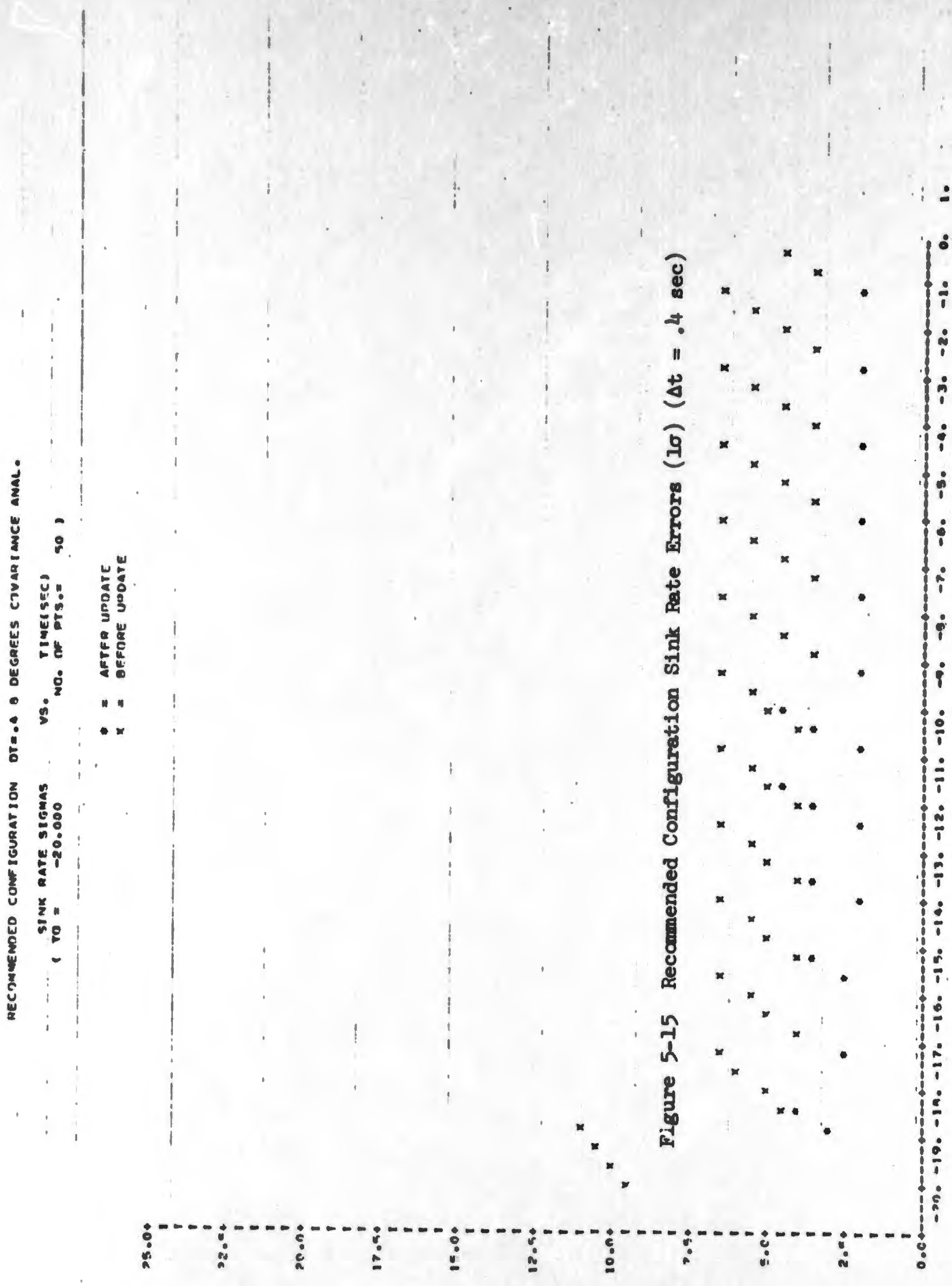


Figure 5-15 Recommended Configuration Sink Rate Errors (1σ) (Δt = .4 sec)

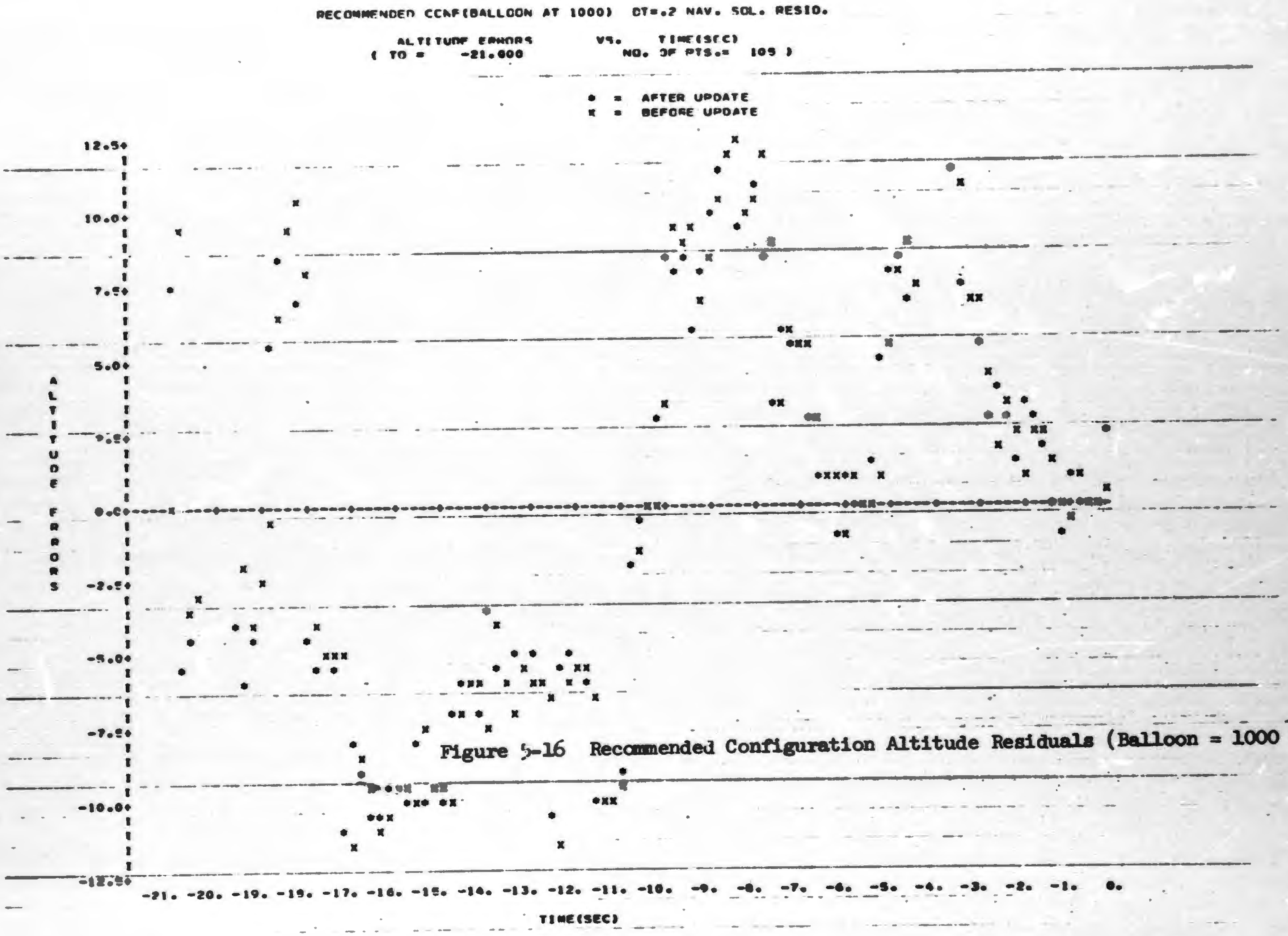


Figure 5-16 Recommended Configuration Altitude Residuals (Balloon = 1000 ft)

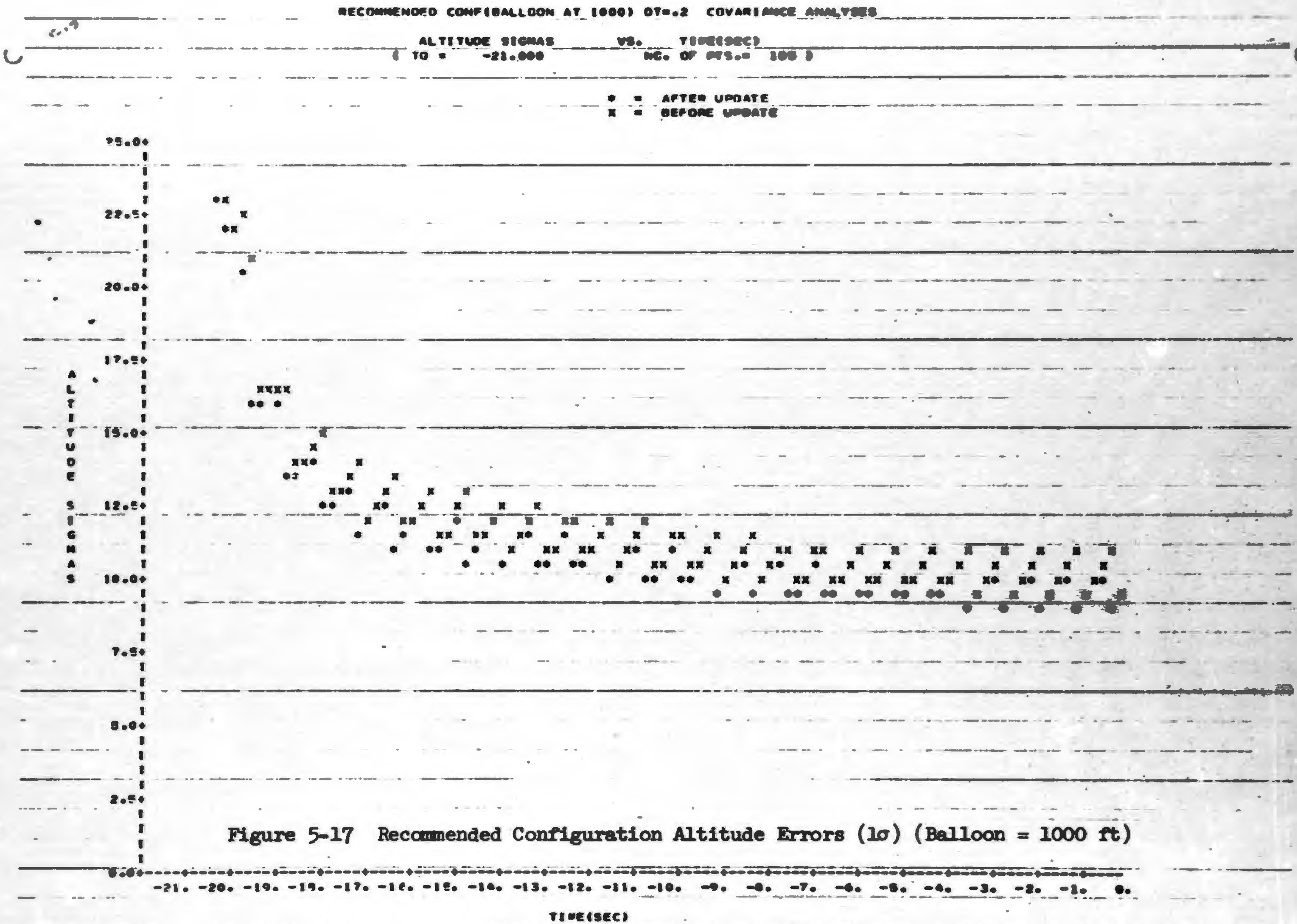


Figure 5-17 Recommended Configuration Altitude Errors (1σ) (Balloon = 1000 ft)

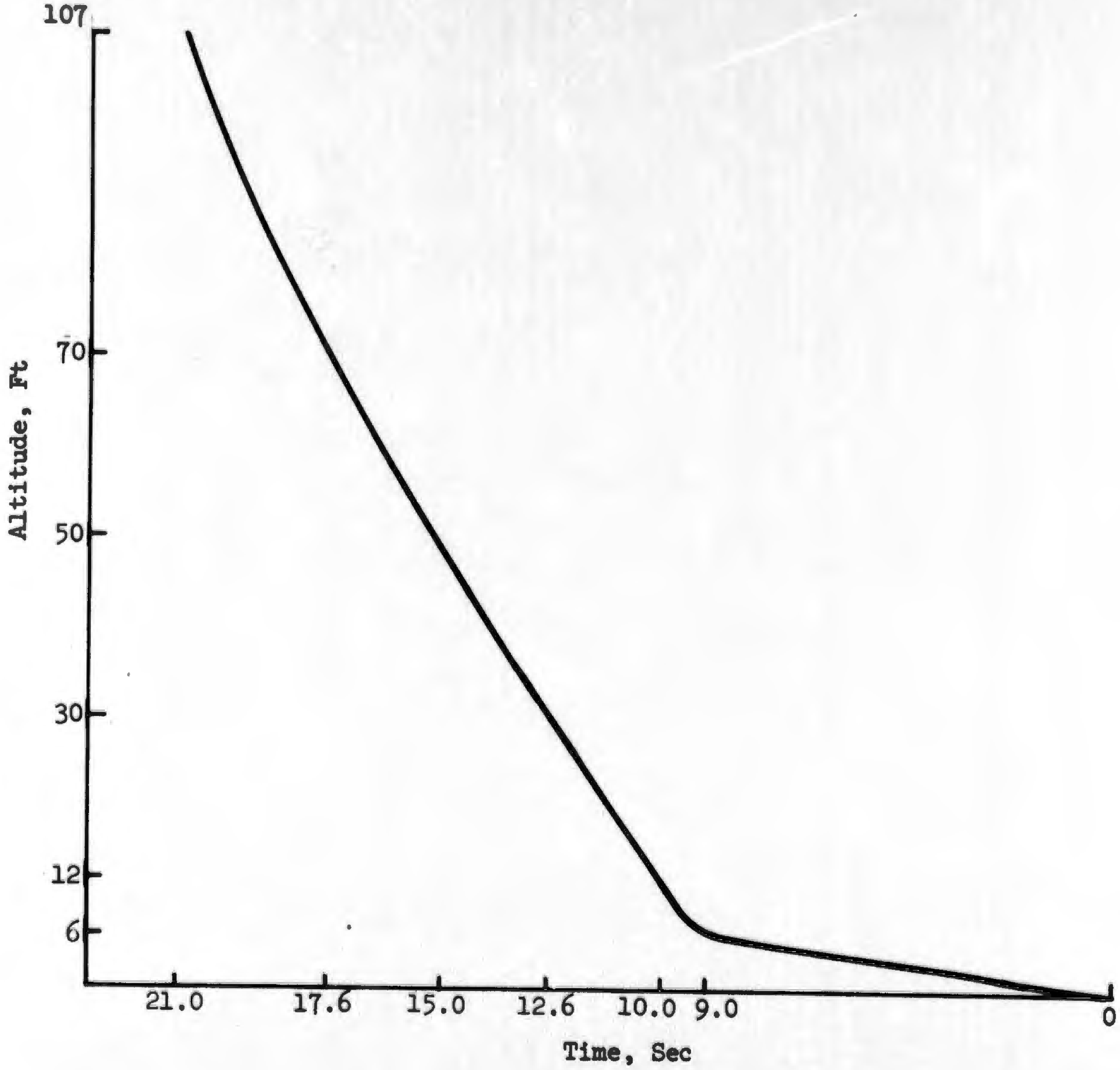


Figure 5-18 Helicopter Landing Profile

Figures 5-4 and 5-5 are a plot of the residuals for the ideal case for measurement updates of .2 sec. These residuals are the difference between the actual helicopter parameter (altitude or sink rate), and the corresponding navigation solution at each measurement time. It can be seen that the altitude and sink rate residuals fall within the measurement errors of 5 ft and .5 ft/sec as indicated by the analytically derived results, equation 5-5 and 5-6. It should be noted that no balloon ephemeris errors were assumed for the ideal runs.

Figures 5-6 and 7 are plots of the results of covariance analysis based on the ideal configuration with balloon ephemeris errors, and again the one sigma values, after update, fall within the measurement errors. The excursion can be seen by comparing the results before and after a measurement update.

The corresponding results for the recommended configuration is plotted in Figures 5-8 through 11. A comparison of these results with those of the ideal indicated no significant degradation.

The analysis was repeated for cycle times of 1.6 seconds (.4 seconds between measurement), for the recommended configuration. The results are plotted in Figures 5-12 through 15. Comparison of these results with those of the recommended configuration with .8 seconds cycle time indicates some degradation. However, the results are still reasonable for the ILS.

Figures 5-16 and 17 are the results of a repeat of the analysis for the recommended configuration with .8 second cycle time and the balloon lowered to 1000 ft. This will be required in order to perform an ILS test, for comparison purposes, which avoids rotor modulation of the balloon borne transmitter signal. Comparison of this data with Figure 5-8 and 5-10, where the balloon is at 5000 ft indicates that the errors have approximately doubled. However, the results still are more than adequate for a Category II landing as defined by International Civil Aviation Organization (ICAD).

The results tabulated in Table 5-1 were derived from simulation of single passes and covariance analysis which used pessimistic values for vehicle dynamic forcing noise. The conclusions to be drawn from these results are that the approach is feasible in that the accuracy yields performance which is not significantly degraded from the ideal.

5.2.3 Discussion of the Analysis Results

Since the Kalman Filter assumed pessimistic values for driving function noise, the covariance analysis results tend to be pessimistic. By comparison to the scatter plots of simulated residuals, it can be noted that the covariance seems closer to a worst case bound than standard deviation. This approach is necessary because of the non-Gaussian nature of vehicle dynamics.

It also should be noted that covariance plots are shown for the system both prior to and after update. Also it will be observed that the curves are cyclic corresponding to the single-channel nature of the system. Results are best after update from the balloon transmission and degrade progressively until the next balloon data is received. This result is expected since the plots are of altitude and altitude sink rate, both of which are almost solely dependent on the balloon update.

5.2.4 Calibration Link

A definitive description of the calibration/monitor link is given in Reference 1. A short description is given here for convenience. The monitor link will not change from the configuration set up for the SAMSO NC-135 ILS Tests. This configuration will be used throughout the Army tests.

Each transmitter is free running and the calibration receiver (four channels) located in the Mobile Calibration Station (MCS) records time and frequency of the transmission of the four transmitters. It should be noted that the stability of the oscillators is five parts in 10^{10} in 24 hours, so that the relative stability between the various oscillators is quite good.

The data recorded by the MCS is utilized to calculate the time bias between transmitters to allow for data reduction of the airborne receiver. This approach is adequate for a non-real time navigation system. Should real time capability be desired, these time biases would have to be transmitted to the helicopter.

Table 5-1 Simulation Results

	Altitude Error		Sink Rate Error	
	Cov Anal 1σ	Max Residual	Cov Anal 1σ	Max Residual
Recommend Config T = 0.8 sec	6.0	8.0	4.0	1.5
T = 1.6 sec	7.5	5.0	5.7	1.8
Ideal Config T = 0.8 sec	5.7	4.7	4.0	0.85

5.3 SELECTION OF THE AREA NAVIGATION TRANSMITTER CONFIGURATION

Four geometries were identified as potential candidates for the area navigation transmitter configuration for the army helicopter test. Of these four, the "elongated diamond" (Figure 3-2) is recommended as the configuration which best satisfies the combined conditions of GDOP simulation, power profile, line of sight, number of data points per pass and minimization of implementation costs, This configuration is the same as the transmitter configuration for the ILS with the exception that the balloon transmitter (4) is relocated to a ground location.

5.3.1 Configuration Tradeoff Analysis

The logic of selection for the Area Navigation test for the army helicopter demonstration is philosophically identical to that of the basic phase II four-channel receiver demonstration. The objective is to simulate as realistically as possible the GDOP's, power levels, and operational characteristics of an operational 621B satellite system subject to the constraints imposed by the flight test equipment.

The GDOP's expected in an operational system are discussed quite extensively in Reference (1). A summary of the significant GDOP's are shown here in Table 5-2.

The power levels of the signal seen by a System 621B receiver in an operational environment is assumed to be nominally -123 dbm. Under fringe conditions -140 dbm may be of interest. In order to simulate an operational environment, the power levels should be constant for a given flight. Power levels directly affect measurement accuracy and cycle time, and within limits, power levels should be constant during the flight test. It is therefore desirable to design a transmitter geometry to simulate these conditions for as large a set of data points as possible, subject to the following constraints.

Table 5-2 Operational GDOP's

		Static			Dynamic	
		CEP	ALT	TIME	CEP	ALT
Rotating "Y"	Equatorial	2	6	6	2	1
	CONUS	4-5	5-4	6	2	1
Eggbeater	Equatorial	1	3	2	*	*
	CONUS	1	3	2	*	*

* Not known

- The helicopter shall not exceed an altitude of 9000 ft above sea level (5000 ft above WSMR ground level)
- The helicopter's inability to maintain a straight flight path trajectory at low speeds directly affects the time over a usable GDOP region per run. Thus a minimum indicated airspeed of 60 kts was assumed
- Acceptable line of sight from the four transmitters to the helicopter receiver shall be maintained throughout the pass
- Each transmitter must be monitored by the MCS
- It is desirable to minimize the movement or modification of existing equipment. (The ILS test of Phase II will immediately precede Army single-channel receiver test.)

The Symmetric "Y". Analogous to Phase II, the direct solution for the transmitter configuration for the helicopter application is a symmetric "Y", scaled down from the Phase II configuration. For a helicopter maximum altitude of 5000 ft AGL, the recommended symmetric "Y" has legs of equal length of 3400 ft, and equal angles of 120 degrees between the legs.

With this configuration, when the helicopter flies directly over the center transmitter, the angles to the transmitters are identical to those seen by a user at the equator under a 30° inclination rotating "Y". It has been shown in Reference (1) that this geometry gives a precise simulation of the equatorial region and reasonably simulates CONUS for off center trajectories. This configuration has two significant weaknesses.

- All transmitters would require relocation
- The time over the prime GDOP region is too small (less than 1/2 mile or 30 seconds)

Alternate Configurations. Consistent with the goal of minimizing the number of transmitters moved, the site selection is based on the three ground transmitters remaining from the Phase II ILS test. The fourth transmitter location, which is that of the balloon, was exhaustively varied along an axis of symmetry.

Figure 5-19 shows that placement of only the balloon transmitter can create the elongated "Y", small symmetric "Y" and the elongated diamond configuration. The three circles represent the three fixed transmitters. They form an equilateral triangle with sides of 3464 ft. The MCS (depicted by the block) is 1000 ft from the topmost (as seen from the diagram) transmitter and on the symmetric axis.

By moving the fourth transmitter location in the positive direction we create elongated "Y"'s; by moving it in the negative direction we create elongated diamonds. By placing it in the center we create a small symmetric Y. GDOP contours were generated at regular intervals. These three configurations, along with the optimum large symmetric "Y", are compared in the tradeoff matrix of Table 5-3. The results indicate that the elongated diamond is best overall. The GDOP's for this configuration are 2-4, 7, 5 for static CEP, static altitude and time bias respectively. These compare favorably with the operational GDOP's given in Table 5-2. Further, this configuration provides a good corridor with good length, where the GDOP's are essentially constant. This configuration is therefore recommended.

5.3.2 GDOP Contours for the Recommended Configuration

The computer print-outs given in Figures 5-20 through 5-26 show GDOP contours for the elongated diamond. The GDOP contours are represented by maps of hexadecimal numbers, 0_{16} to A_{16}, over a region 12,300 ft by 1,845 ft. Each hexadecimal number has been rounded off from the actual GDOP value for the center of the subregion calculated as follows:

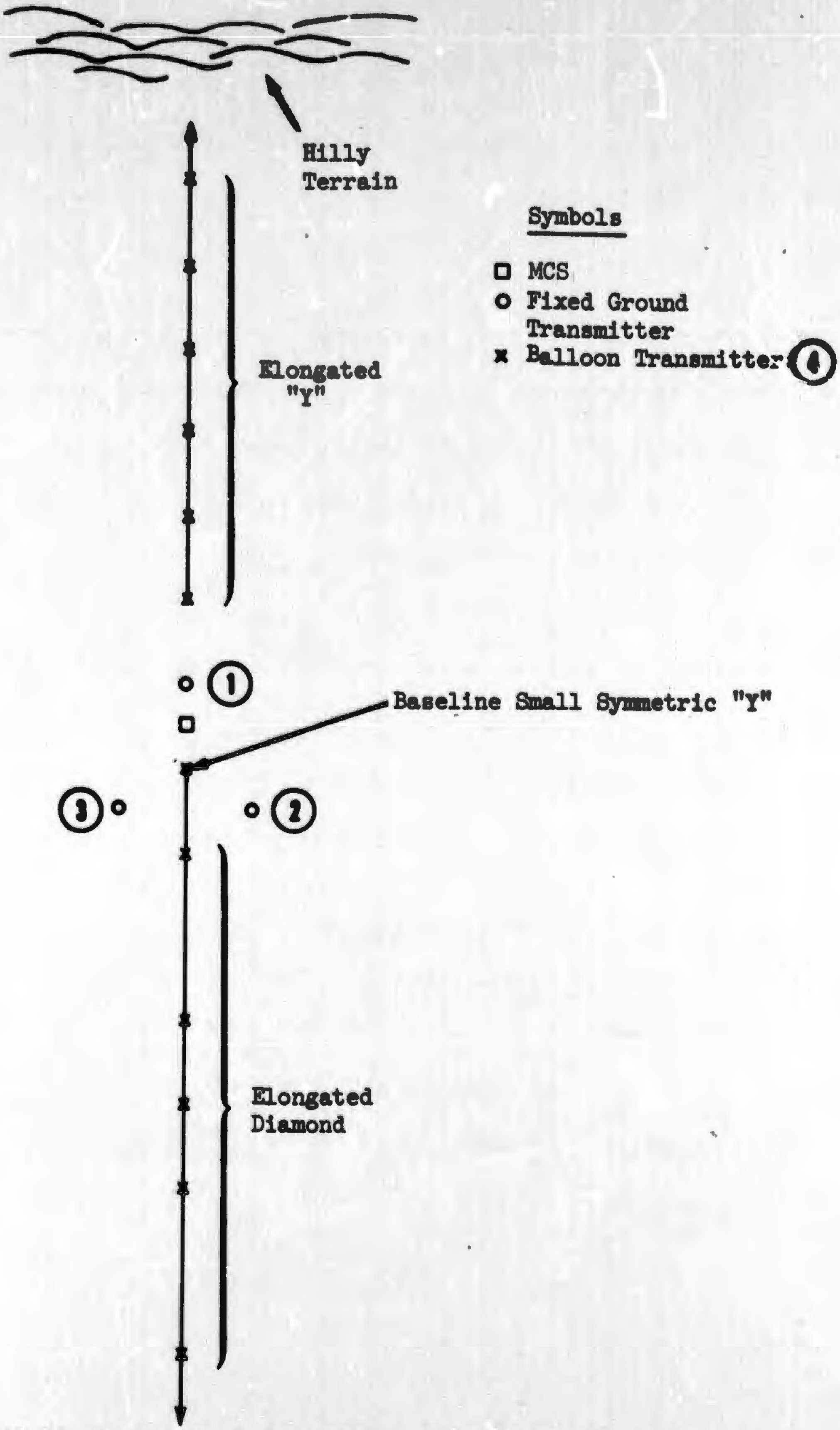


Figure 5-19 Movement of the Balloon Transmitter Along the Symmetric Axis Yields Three Candidate Configurations

Table 5-3 Comparison of Each Transmitter Configuration

	Small Symmetric "Y"	Larger Symmetric "Y"	Elongated "Y"	Elongated Diamond
Simulate Realistic GDOP's	Good	Good	Fair	Fair
Length of Good GDOP Region (Ft)	Poor 3000	Poor 4500	Good 9000	Best 12,000
Maintain Nearly Constant Power Levels received by Helicopter from all Transmitters	Poor	Poor	Good	Best
Line of Sight Maintained between Helicopter Receiver and Transmitters	Yes	Yes	Yes	Yes
Adequate Line of Sight between MCS and Transmitters	Yes	Yes	Yes	Yes
Minimize Relocation of Transmitters	Yes	No (Requires relocation of all transmitters)	Limited by hilly region for setting balloon transmitter	Yes

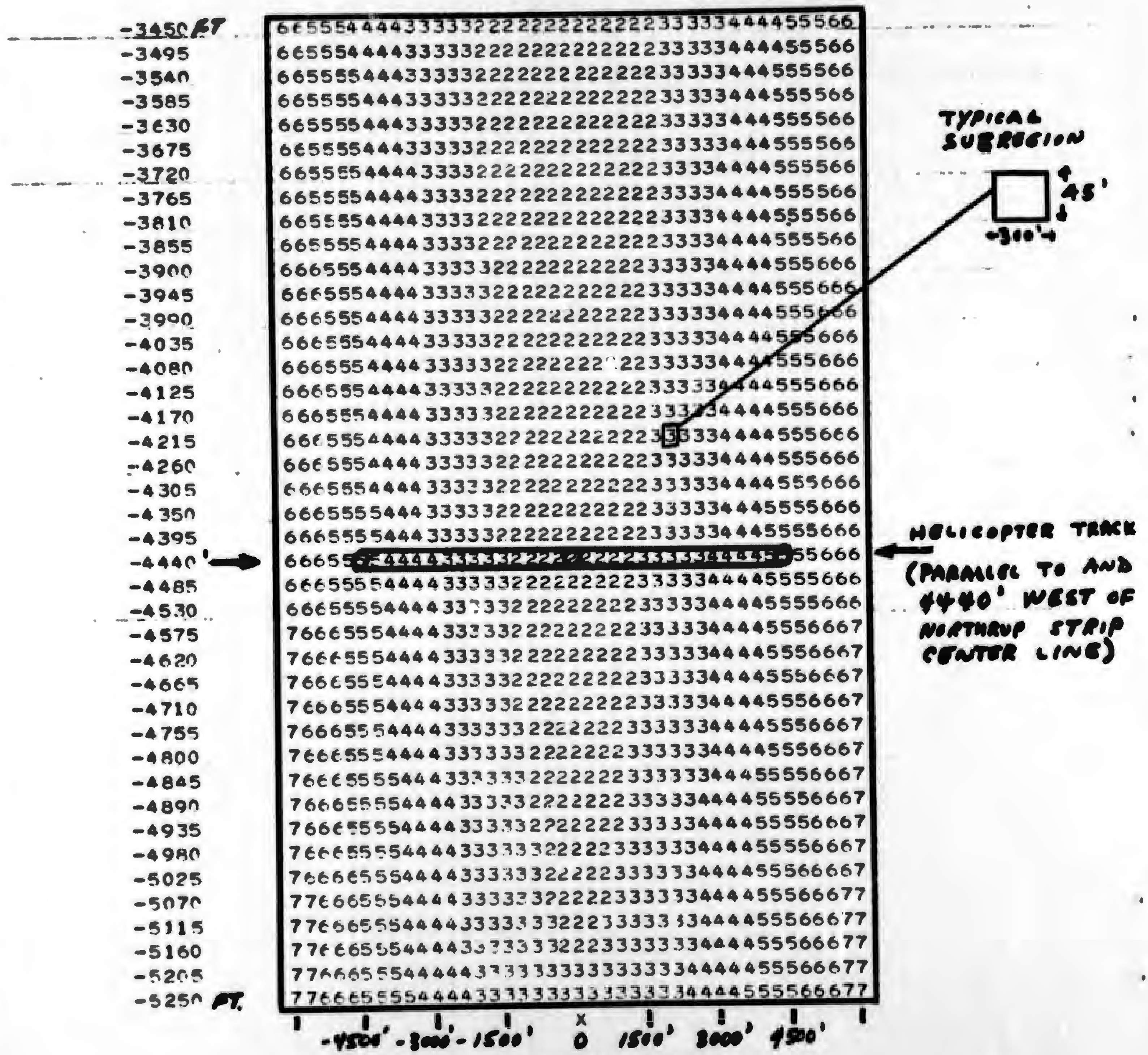
```
CONTOURS PLOTTED IN X-Y PLANE

        0.0          0.0     -1732.000     1732.000
  -8000.000     2000.000     -1000.000    -1000.000
     10.000       10.000        10.000       10.000

HELICOPTER ALT=  4000.00

IGDOP=   1      STATIC CEP GDOP
```

NOTE: This map REPRESENTS A HORIZONTAL PLANE AT 4000 FT AGL



```
-3450 FT  66555444433333222222222222233333444455566
-3495     66555444433333222222222222233333444455566
-3540     66555544433333222222222222233333444555566
-3585     66555544433333222222222222233333444555566
-3630     66555544433333222222222222233333444555566
-3675     66555544433333222222222222233333444555566
-3720     66555544443333222222222222233334444555566
-3765     66555544443333222222222222233334444555566
-3810     66555544443333222222222222233334444555566
-3855     66555544443333222222222222233334444555566
-3900     66655544443333322222222222333334444555666
-3945     66655544443333322222222222333334444555666
-3990     66655544443333322222222222333334444555666
-4035     66655544443333322222222222333334444555666
-4080     66655544443333322222222222333334444555666
-4125     66655544443333322222222222333334444555666
-4170     66655544443333322222222222333334444555666
-4215     66655544443333322222222222333334444555666
-4260     66655544443333322222222222333334444555666
-4305     66655544443333322222222222333334444555666
-4350     66655554443333322222222222333334445555666
-4395     66655554443333322222222222333334445555666
-4440     66655[illegible]55666
-4485     66655554444333332222222223333344445555666
-4530     66655554444333332222222223333344445555666
-4575     76665554444333332222222223333344445556667
-4620     76665554444333332222222223333344445556667
-4665     76665554444333332222222223333344445556667
-4710     76665554444333332222222223333344445556667
-4755     76665554444333333222222233333344445556667
-4800     76665554444333333222222233333344445556667
-4845     76665555444333333222222233333344455556667
-4890     76665555444433333222222233333444455556667
-4935     76665555444433333222222233333444455556667
-4980     76665555444433333322222333333444455556667
-5025     76666555444433333322222333333444455566667
-5070     77666555544443333322222333334444555566677
-5115     77666555544443333332223333334444555566677
-5160     77666555544443333332223333334444555566677
-5205     77666555544443333333333333334444555566677
-5250 FT  77666655554444333333333333344445555666677
```

Figure 5-20 Static CEP GDOP

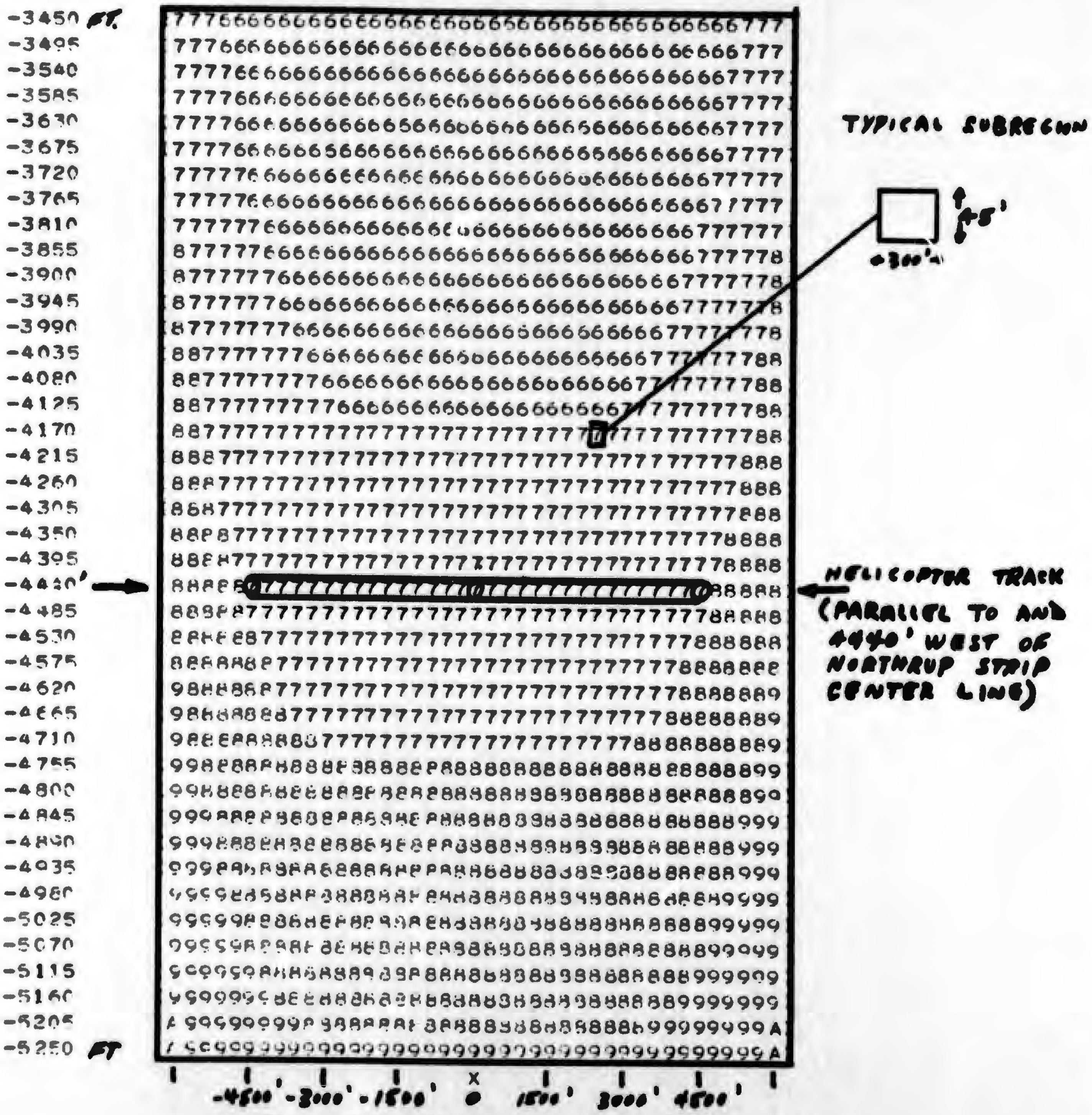
```
CONTOURS PLOTTED IN X-Y PLANE

      0.0          0.0      -1732.000     1732.000
  -8000.000     2000.000    -1000.000    -1000.000
     10.000       10.000       10.000       10.000

          ALT=  4000.00


IGDOP=    2       STATIC ALT GDOP
```

NOTE: THIS MAP REPRESENTS A HORIZONTAL PLANE AT 4000' AGL



TYPICAL SUBREGION

HELICOPTER TRACK (PARALLEL TO AND 4440' WEST OF NORTHRUP STRIP CENTER LINE)

Figure 5-21 Static Altitude GDOP

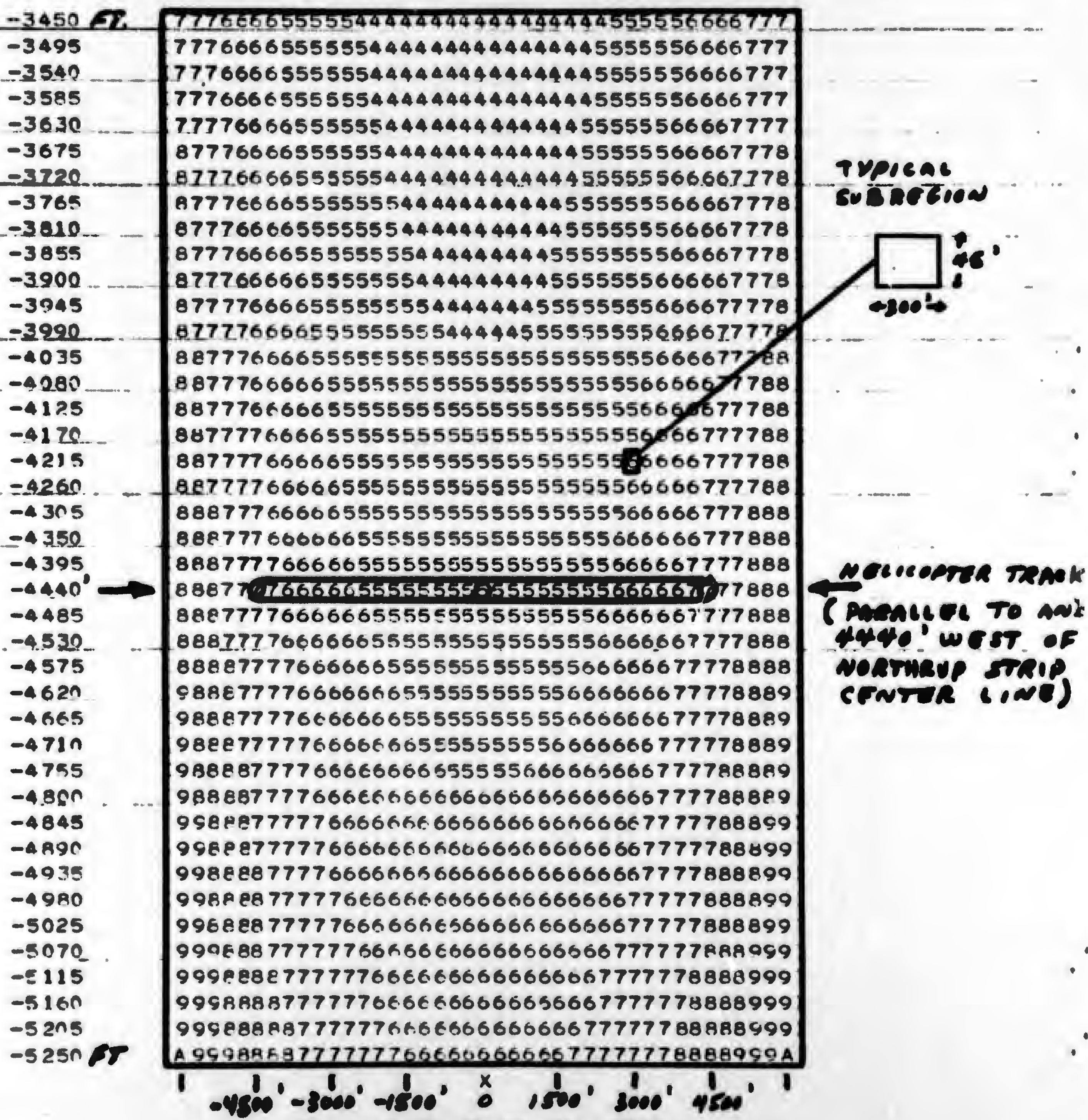
```
CONTOURS PLOTTED IN X-Y PLANE

     0.0           0.0         -1732.000      1732.000
 -8000.000      2000.000      -1000.000     -1000.000
    10.000        10.000         10.000        10.000

         ALT=  4000.00
```

NOTE: THIS MAP REPRESENTS
A HORIZONTAL PLANE
AT 4000' AGL

```
 IGDOP=    3      STATIC BIAS GDOP
```



```
   -3450 FT.  777666655555544444444444444444445555556666777
   -3495      777666655555544444444444444444445555556666777
   -3540      777666655555544444444444444444445555556666777
   -3585      777666655555544444444444444444445555556666777
   -3630      777766665555554444444444444444455555566667777
   -3675      877766665555554444444444444444455555566667778
   -3720      877766665555554444444444444444455555566667778
   -3765      877766665555555444444444444444555555566667778
   -3810      877766665555555544444444444445555555566667778
   -3855      877766665555555554444444444455555555566667778
   -3900      877766666555555554444444444555555555666667778
   -3945      877776666555555555444444445555555555666677778
   -3990      877776666555555555554444445555555555666677778
   -4035      887776666655555555555555555555555556666677788
   -4080      887776666655555555555555555555555556666677788
   -4125      887776666655555555555555555555555556666677788
   -4170      887777666655555555555555555555555556666777788
   -4215      887777666665555555555555555555555566666777788
   -4260      887777666665555555555555555555555566666777788
   -4305      888777666665555555555555555555555566666777888
   -4350      888777666666555555555555555555555666666777888
   -4395      888777766666555555555555555555555666667777888
   -4440'  →  888777766666655555555555555555556666667777888  ←
   -4485      888777766666655555555555555555556666667777888
   -4530      888777766666665555555555555555566666667777888
   -4575      888877777666666555555555555555666666777778888
   -4620      988877777666666655555555555555666666677778889
   -4665      988877777666666665555555555556666666677778889
   -4710      988877777766666665555555555556666666777778889
   -4755      988887777666666666555555556666666667777788889
   -4800      988887777666666666666666666666666667777788889
   -4845      998887777766666666666666666666666677777788899
   -4890      998887777766666666666666666666666667777788899
   -4935      998888777766666666666666666666666677777888899
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   -5070      999888777777666666666666666666666777777888999
   -5115      999888877777666666666666666666667777778888999
   -5160      999888877777766666666666666666677777778888999
   -5205      999888887777776666666666666666677777788888999
   -5250 FT   A99988887777777666666666666666777777788889 99A
```
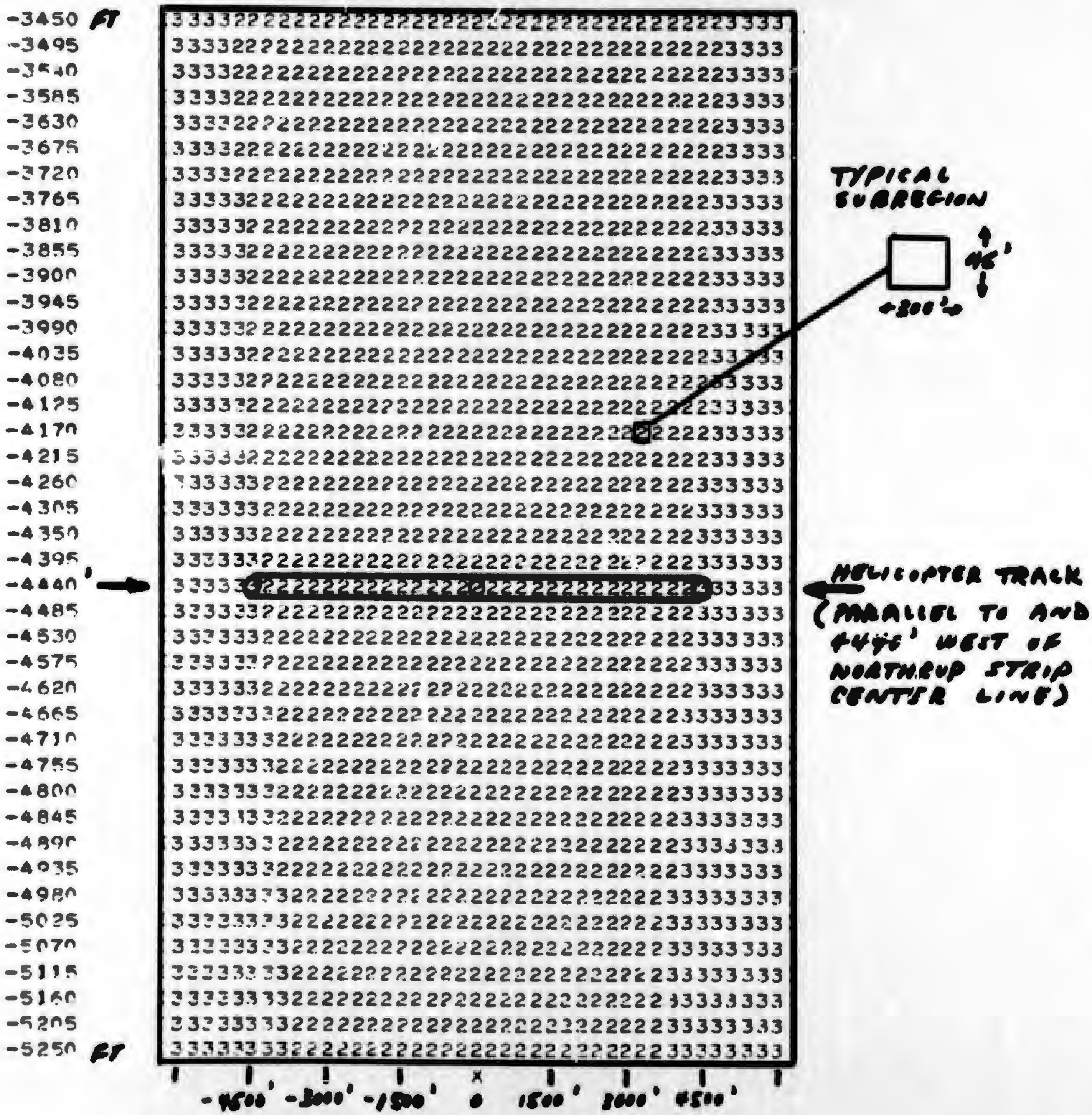

Figure 5-22 Static Bias GDOP

```
CONTOURS PLOTTED IN X-Y PLANE

       0.0          0.0      -1732.000      1732.000
   -8000.000     2000.000    -1000.000     -1000.000
      10.000       10.000       10.000        10.000

         ALT=   4000.00

 IGDOP=    4      DYNAMIC CEP GDOP
```

NOTE: THIS MAP REPRESENTS A HORIZONTAL PLANE AT 4000FT AGL



TYPICAL SUBREGION

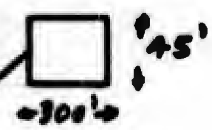
HELICOPTER TRACK (PARALLEL TO AND 4440' WEST OF NORTHRUP STRIP CENTER LINE)

Figure 5-23 Dynamic CEP GDOP

```
CONTOURS PLOTTED IN X-Y PLANE

     0.0             0.0        -1732.000      1732.000
 -8000.000       2000.000      -1000.000     -1000.000
    10.000          10.000         10.000        10.000

          ALT=  4000.00

 IGDOP=    5      DYNAMIC ALT GDOP

   -3450 FT  544433322222111111111111111112222233334445
   -3495     54443332222211111111111111111222223334445
   -3540     54443332222211111111111111111222223334445
   -3585     54443332222211111111111111111222223334445
   -3630     54443332222211111111111111111222223334445
   -3675     54443333222211111111111111111222233334445
   -3720     54443333222211111111111111111222233334445
   -3765     54443333222221111111111111112222233334445
   -3810     54443333222221111111111111112222233334445
   -3855     54443333222221111111111111112222233334445
   -3900     54443333222221111111111111112222233334445
   -3945     54443333222221111111111111112222233334445
   -3990     54443333222221111111111111112222233334445
   -4035     54443333222221111111111111112222233334445
   -4080     54443333222221111111111111112222233334445
   -4125     54443333222221111111111111112222233334445
   -4170     54443333222221111111111111112222233334445
   -4215     54443333222221111111111111112222233334445
   -4260     54443333222221111111111111112222233334445
   -4305     54443333222221111111111111112222233334445
   -4350     54444333222221111111111111112222233344445
   -4395     54444333222221111111111111112222233344445
   -4440     55444333222221111111111111112222233344455
   -4485     55444333222221111111111111112222233344455
   -4530     55444333222221111111111111112222233344455
   -4575     55444333222221111111111111112222233344455
   -4620     55444333322221111111111111112222333344455
   -4665     55444333322221111111111111112222333344455
   -4710     55444333322222111111111111122222333344455
   -4755     55444333322222111111111111122222333344455
   -4800     55444333322222111111111111122222333344455
   -4845     55444333322222111111111111122222333344455
   -4890     55444333322222111111111111122222333344455
   -4935     55444333322222111111111111122222333344455
   -4980     55444333322222111111111111122222333344455
   -5025     55444333322222111111111111122222333344455
   -5070     55444333322222111111111111122222333344455
   -5115     55444333322222111111111111122222333344455
   -5160     55444333322222111111111111122222333344455
   -5205     55444333322222111111111111122222333344455
   -5250 FT  55444333322222111111111111122222333344455
                                  X
           -4500' -3000' -1500'   0    1500' 3000' 4500'
```

NOTE: THIS MAP REPRESENTS A HORIZONTAL PLANE AT 4400' AGL

TYPICAL SUBREGION



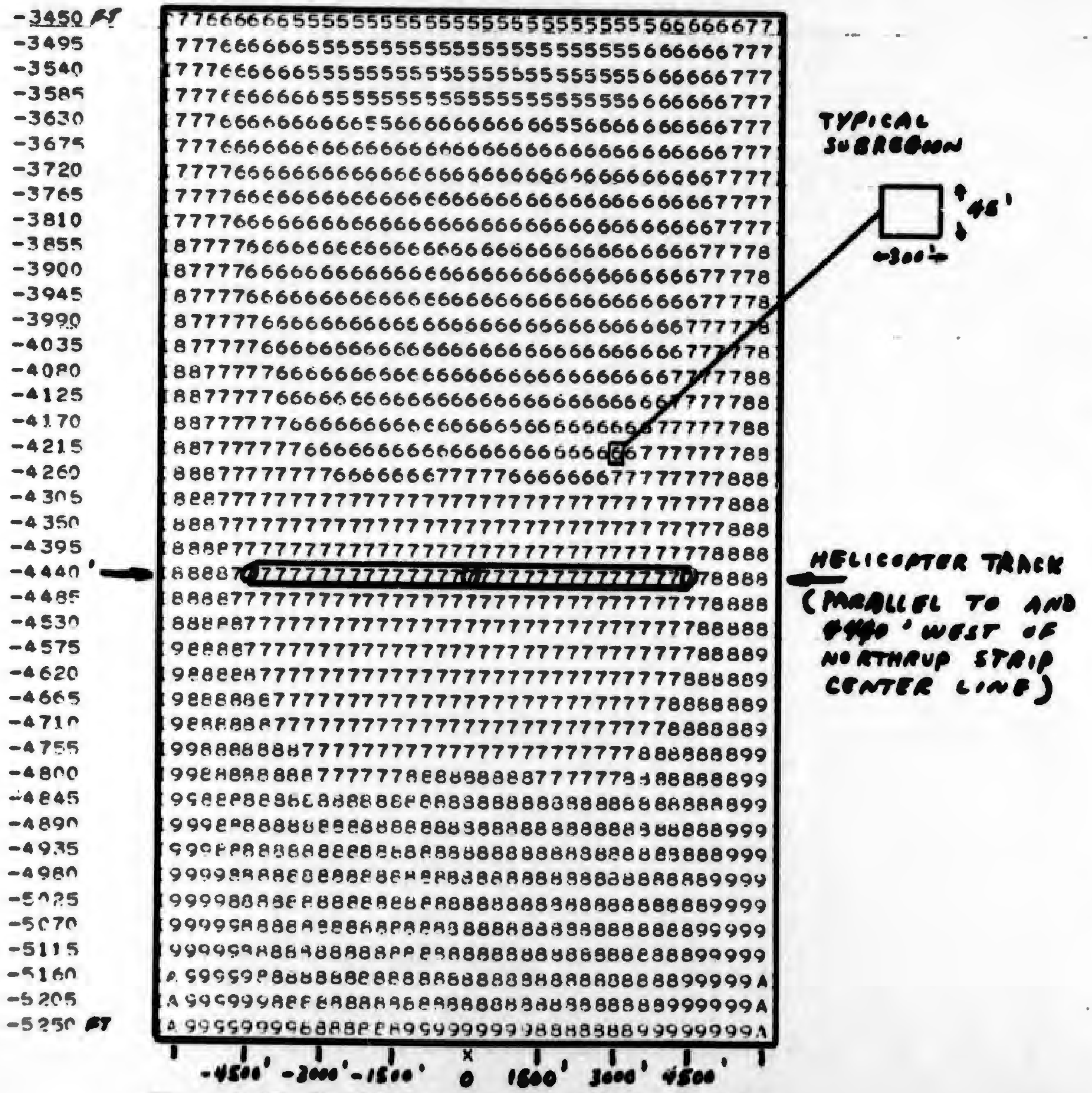
HELICOPTER TRACK (PARALLEL TO AND 4440' WEST OF NORTHRUP STRIP CENTER LINE)

Figure 5-24 Dynamic Altitude GDOP

```
CONTOURS PLOTTED IN X-Y PLANE

      0.0            0.0       -1732.000      1732.000
  -8000.000       2000.000     -1000.000     -1000.000
     10.000         10.000        10.000        10.000

          ALT=  3500.00
```

NOTE: THIS MAP REPRESENTS A HORIZONTAL PLANE AT 3500 FT. AGL

```
IGDOP=    2       STATIC ALT GDOP
```



```
-3450 FT  77666666555555555555555555555555566666677
-3495     77766666655555555555555555555555666666777
-3540     77766666655555555555555555555555666666777
-3585     77766666665555555555555555555556666666777
-3630     77766666666665566666666666556666666666777
-3675     77766666666666666666666666666666666666777
-3720     77776666666666666666666666666666666667777
-3765     77776666666666666666666666666666666667777
-3810     77776666666666666666666666666666666667777
-3855     87777666666666666666666666666666666677778
-3900     87777666666666666666666666666666666677778
-3945     87777666666666666666666666666666666677778
-3990     87777766666666666666666666666666666777778
-4035     87777766666666666666666666666666666777778
-4080     88777776666666666666666666666666667777788
-4125     88777776666666666666666666666666677777788
-4170     88777777666666666666666666666666777777788
-4215     88777777766666666666666666666667777777788
-4260     88877777776666666777776666666677777777888
-4305     88877777777777777777777777777777777777888
-4350     88877777777777777777777777777777777777888
-4395     88887777777777777777777777777777777778888
-4440     88887777777777777777777777777777777778888
-4485     88887777777777777777777777777777777778888
-4530     88888777777777777777777777777777777788888
-4575     98888777777777777777777777777777777788889
-4620     98888877777777777777777777777777777888889
-4665     98888887777777777777777777777777777888889
-4710     98888887777777777777777777777777778888889
-4755     99888888877777777777777777777777888888899
-4800     99888888887777778888888887777778888888899
-4845     99888888888888888888888888888888888888899
-4890     99988888888888888888888888888888888888999
-4935     99988888888888888888888888888888888888999
-4980     99998888888888888888888888888888888889999
-5025     99998888888888888888888888888888888889999
-5070     99999888888888888888888888888888888899999
-5115     99999988888888888888888888888888888999999
-5160     A9999988888888888888888888888888888899999A
-5205     A999999888888888888888888888888888999999A
-5250 FT  A999999996888888999999998888888999999999A
```

TYPICAL SUBREGION

HELICOPTER TRACK (PARALLEL TO AND 4440' WEST OF NORTHRUP STRIP CENTER LINE)

Figure 5-25 Static Altitude GDOP (Alt = 3500 ft)

```
CONTOURS PLOTTED IN X-Y PLANE

      0.0            0.0        -1732.000      1732.000
  -8000.000       2000.000      -1000.000     -1000.000
     10.000         10.000         10.000        10.000

           ALT=  4500.00

IGDOP=   2      STATIC ALT GDOP
```

NOTE: THIS MAP REPRESENTS A HORIZONTAL PLANE AT 4500FT AGL

```
     -3450 FT  77777666666666666666666666666666666677777
     -3495     77777666666666666666666666666666666677777
     -3540     77777766666666666666666666666666666777777
     -3585     77777766666666666666666666666666666777777
     -3630     77777776666666666666666666666666667777777
     -3675     87777777666666666666666666666666677777778
     -3720     87777777766666666666666666666666777777778
     -3765     87777777776666666666666666666667777777778
     -3810     87777777777666666666666666666677777777778
     -3855     88777777777766666666666666666777777777788
     -3900     88777777777777766666666666777777777777788
     -3945     88777777777777777777777777777777777777788
     -3990     88877777777777777777777777777777777777888
     -4035     88877777777777777777777777777777777777888
     -4080     88877777777777777777777777777777777777888
     -4125     88887777777777777777777777777777777778888
     -4170     88887777777777777777777777777777777778888
     -4215     88887777777777777777777777777777777778888
     -4260     88888777777777777777777777777777777788888
     -4305     88888877777777777777777777777777777888888
     -4350     88888877777777777777777777777777777888888
     -4395     88888887777777777777777777777777778888888
     -4440     88888888777777777777777777777777788888888
     -4485     98888888877777777777777777777777888888889
     -4530     98888888887777777777777777777778888888889
     -4575     98888888888887777777777777778888888888889
     -4620     99888888888888888888888888888888888888899
     -4665     99888888888888888888888888888888888888899
     -4710     99988888888888888888888888888888888888999
     -4755     99988888888888888888888888888888888888999
     -4800     99988888888888888888888888888888888888999
     -4845     99998888888888888888888888888888888889999
     -4890     99999888888888888888888888888888888899999
     -4935     99999888888888888888888888888888888899999
     -4980     99999988888888888888888888888888888999999
     -5025     99999998888888888888888888888888888999999
     -5070     99999999888888888888888888888888899999999
     -5115     99999999999888888888888888888899999999999
     -5160     A999999999999999999999999999999999999999A
     -5205     A999999999999999999999999999999999999999A
     -5250 FT  AA9999999999999999999999999999999999999AA
```

TYPICAL SUBREGION

HELICOPTER TRACK (PARALLEL TO AND 4440' WEST OF NORTHRUP STRIP CENTER LINE)

-4500' -3000' -1500' 0 1500' 3000' 4500'

Figure 5-26 Static Altitude GDOP (Alt = 4500 ft)

$$\text{CEP GDOP} = \frac{\text{CEP } x, y}{\sigma_r}$$

$$\text{Altitude GDOP} = \frac{\sigma_z}{\sigma_r}$$

$$\text{Bias GDOP} = \frac{\sigma_b}{\sigma_r}$$

Where σ_r is the standard deviation of each of the range measurements.

The subregion for each number is an area 300 ft (in the direction of the helicopter track) by 45 ft (in the direction perpendicular to the helicopter track). The GDOP maps represent a horizontal plane at the altitude indicated. The arrows point to the helicopter track which has a good GDOP length of 9000 ft. These contours also indicate that the helicopter flight path may vary up to ± 200 ft from nominal and still remain in a constant GDOP area.

Figures 5-25 and 5-26 printouts show the static altitude GDOP for helicopter altitudes of 3500 and 4500 ft, respectively. These contours are representative of the other 4 GDOP's and demonstrate that the helicopter can afford to vary from the 4000 ft nominal altitude without affecting the GDOP's in the ± 200 ft corridor.

5.3.3 Power Variation Analysis

During an area navigation pass the power received from each transmitter, P, is dependent on the receivers, range, and line of sight angle, to that transmitter.

$$P = \frac{K G_T(\theta, \phi) \; G_R(\theta, \phi)}{\gamma^2}$$

where K = a constant proportional to the desired transmitter power

G_T = the transmitter antenna gain as a function of the line of sight angles θ and ϕ

G_R = the receiver antenna gain

γ = the distance between receiver and transmitter

If the ILS hemispherical antennas are used for the area navigation test, when both the helicopter and transmitter antenna are identical. Therefore

$$G_T = G_R = G$$

and the power becomes

$$P = \frac{K G^2}{\gamma^2}$$

In decibels,

$$P_{db} = 10 \log_{10} P = 10 \log K + 20 \log G - 20 \log \gamma$$

Figure 5-27 shows received power, P, in dbm for each of the four transmitters during the helicopter pass. The transmitter power is slightly larger for transmitters (1) and (4) to compensate for their larger transmitting distance.

Although the analysis of Section 9.1 indicates that the Option I receiver can maintain track on all four sequenced channels at signal levels greater than -135 dbm, the large variation of ±5 db may result in marginal operation at the extremes of the flight paths. If this is the case, the NC-135, Phase II, area navigation antennas will be used in place of the ILS transmitter antenna only for the area navigation tests.

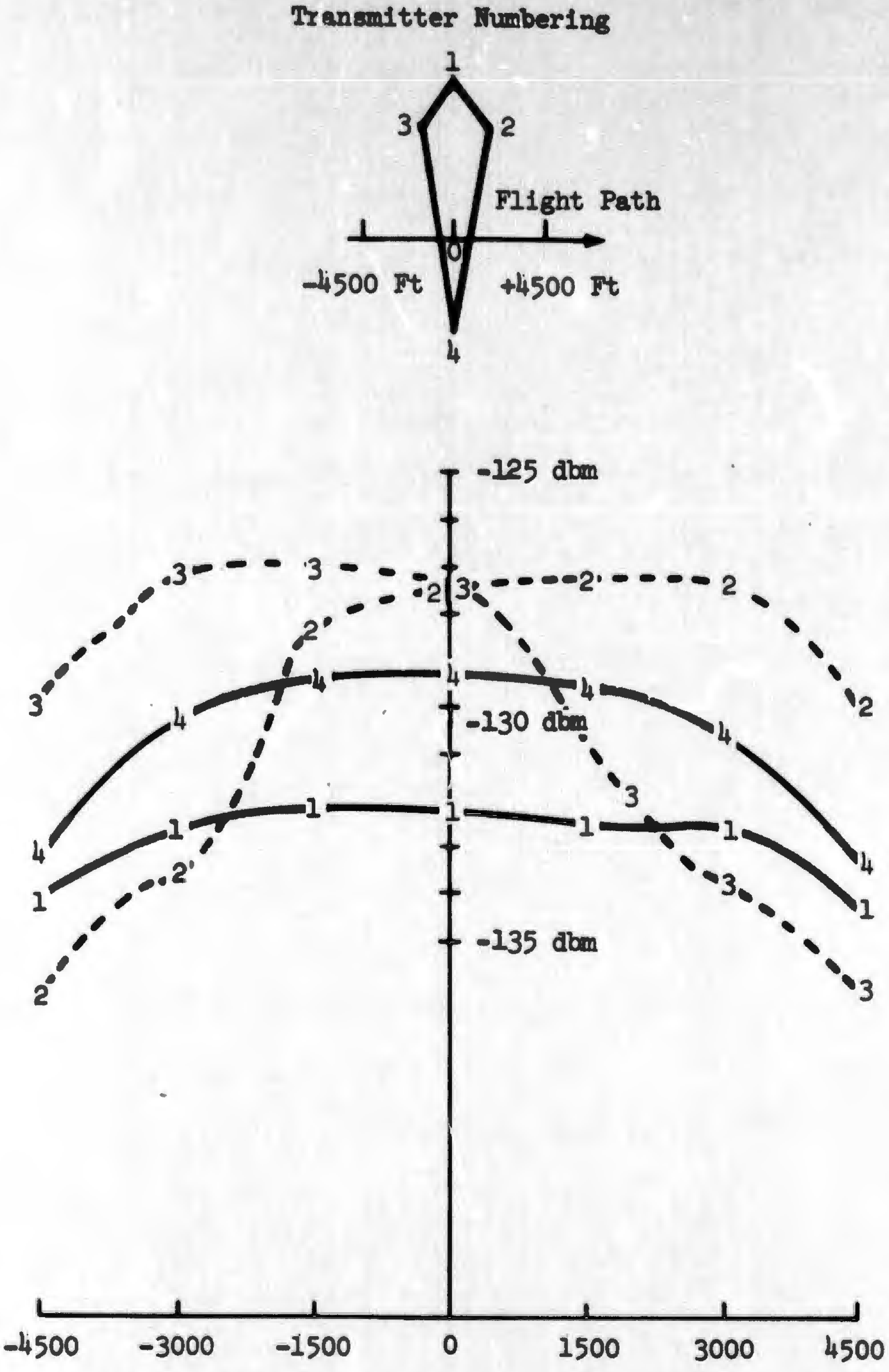


Figure 5-27 Power Level vs Helicopter Position

These antennas have been designed to compensate for space loss and antenna gain variation. The resulting power variation at the helicopter receiver should then be less than ±2 db. See Section 9.5 for antenna details. The Option II receiver will have the capability to operate at the signal levels of about -140 dbm, so that the antenna will not need to be changed.

5.3.4 Area Navigation Performance Analysis

The 8-state Kalman Filter described in Section 5.4 was used to evaluate area navigation performance. The recommended elongated diamond configuration was used with .8 second receiver cycle time and measurement errors of 5 ft and .5 ft/sec. The filter was modeled to anticipate a ±0.5 g maneuver at any time. Figure 5-28 through 5-30 are the results prior to and after the imposition of a 0.5 g turn which occurred at time t = 0 and continued throughout the remaining time. Straight line constant velocity flight was imposed prior to the maneuver at t = 0.

Figures 5-28 and 5-29 are the residual plots and Figure 5-30 is the covariance result from Kalman filter. The results are for the Y axis, the axis which connects transmitters 1 and 4 in Figure 5-19 and undergoes the large acceleration. Since the filter has been modeled to anticipate a 0.5 g maneuver, the covariance result, Figure 5-30, did not change from a one sigma value of 3 ft after update and throughout the flight. The corresponding performance indicated in the residual state of position and velocity, Figures 5-28 and 5-29, demonstrates navigation performance within 10 ft and 5 ft/sec respectively after imposition of the acceleration. These errors include both a bias and a random component. The deterministic component, (peak = 3.2 ft/sec) is caused by the helicopter acceleration and is the result of using a constant value of velocity between measurement intervals in the navigation solution.

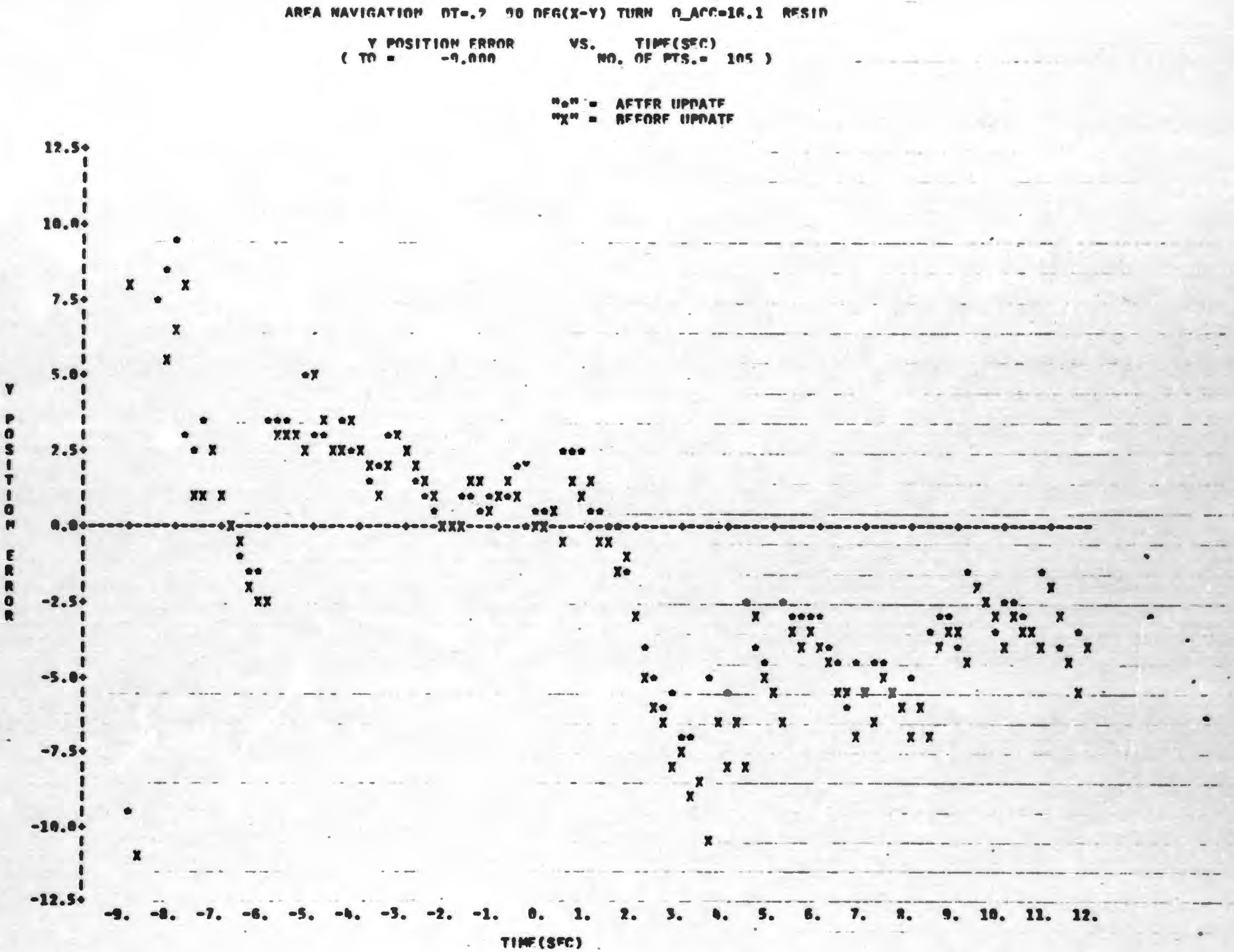


Figure 5-28 Area Navigation Position Residuals

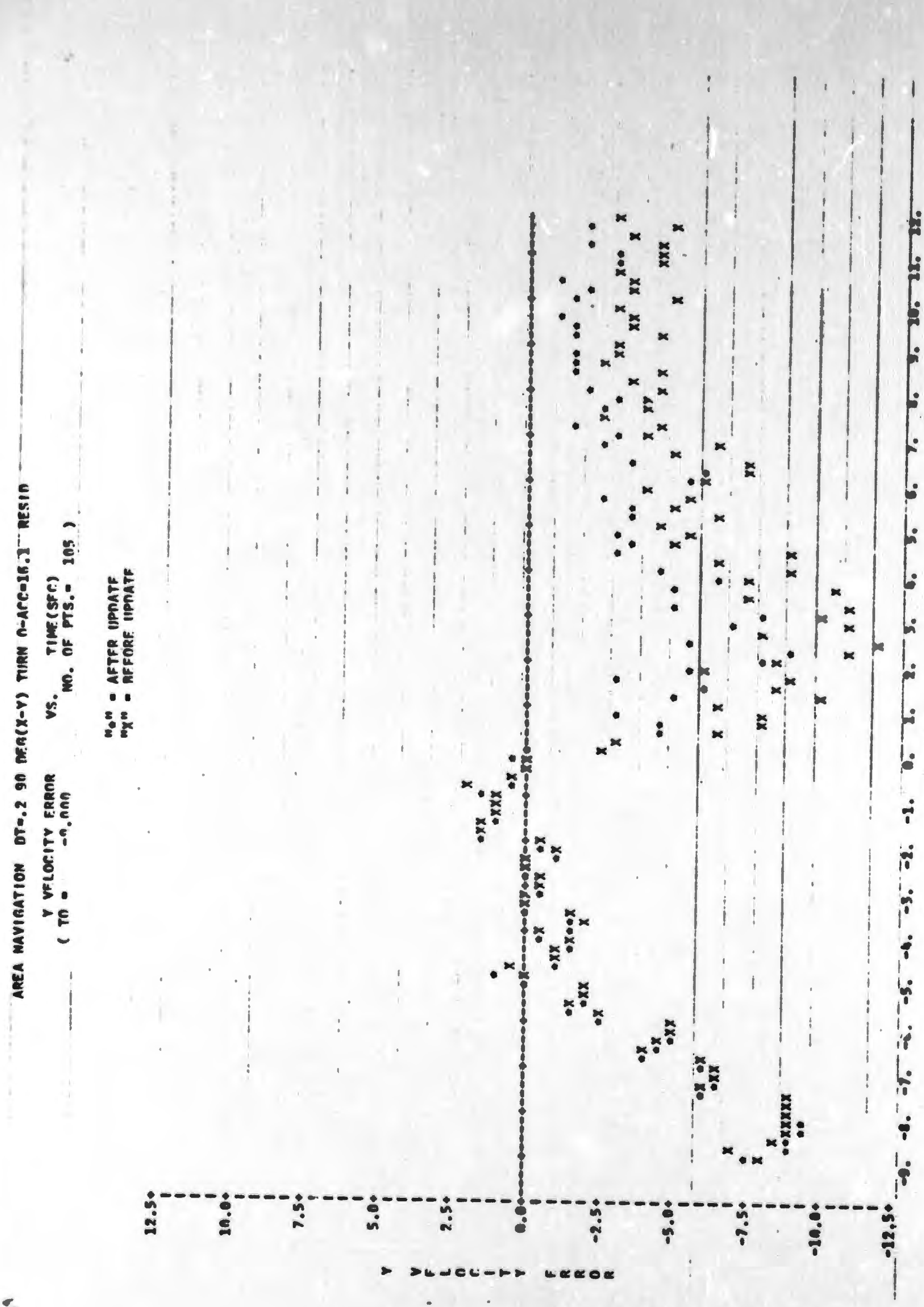


Figure 5-29 Area Navigation Velocity Residual

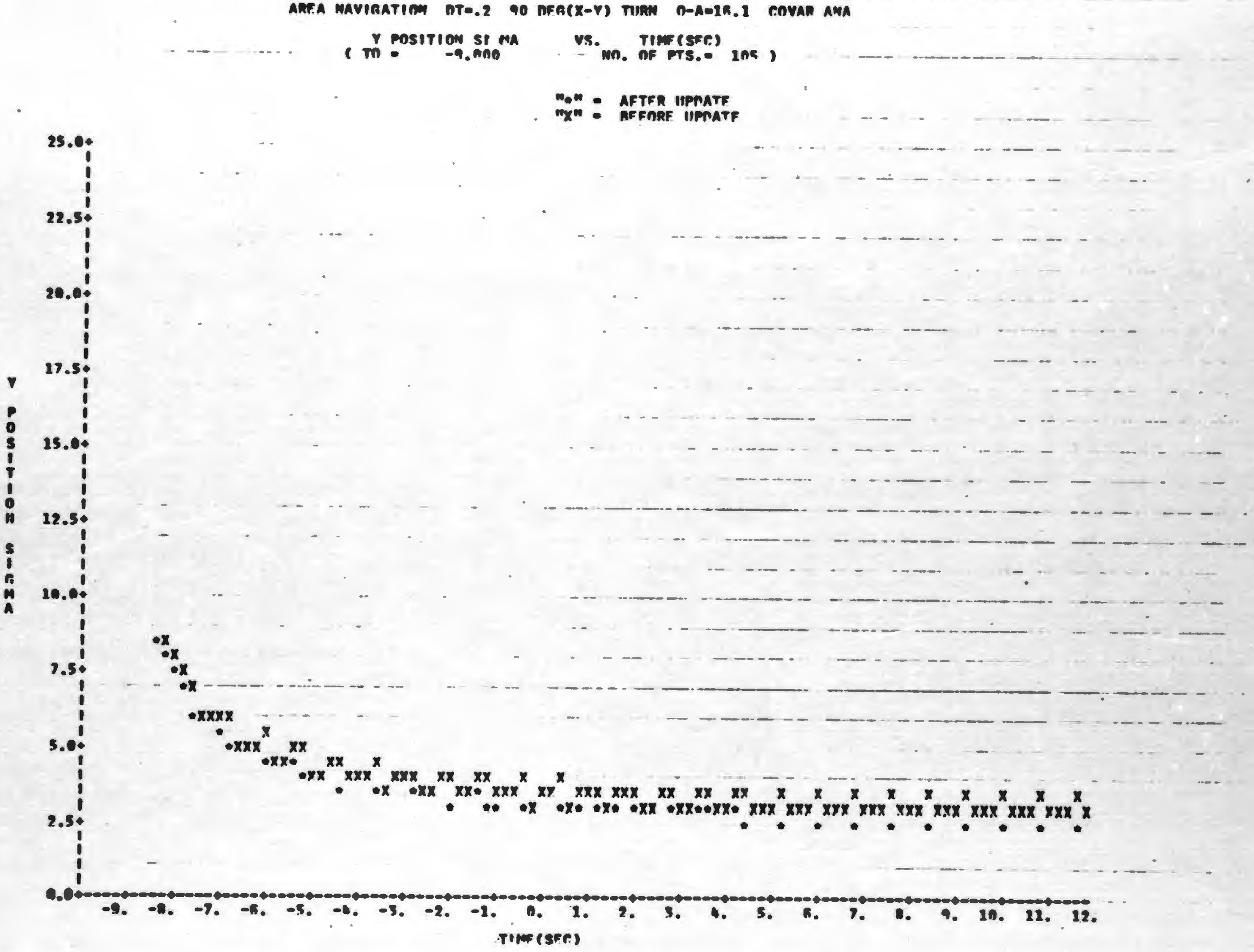


Figure 5-30 Area Navigation Position Error (1σ)

5.4 DATA PROCESSING

The data processing procedure for the single channel demonstration will utilize the system software developed for the four channel receiver tests. The details and the software are discussed in Reference 1. Only minor modifications will be necessary for the proposed application. The only significant change will be the employment of a navigation solution which processes the single-channel data sequentially. The single channel navigation algorithm was demonstrated (Figures 5-4 thru 5-17) However, further analysis is required to optimize the filter gains. This will be addressed during Phase II.

5.4.1 Navigation Algorithm

The navigation algorithm used in the preliminary analysis will now be described. No attempt has been made to optimize the computation with regard to either navigation accuracy or computational efficiency, but the algorithm does demonstrate the feasibility of both area navigation and ILS navigation.

5.4.2 Filter Description

At a given sample time, t_n, it is assumed that the navigation filter receives the following data:

$$(i,\ R_i,\ \dot{R}_i)$$

where

i designates the transmitter whose signal is being received (i = 1, 2, 3, or 4)

R_i is the pseudo range measurement

$\dot{R}_i$ is the pseudo doppler measurement

The measurements are incorporated into an 8-state Kalman Filter whose equations are summarized below:

$$\hat{S}_{m+1} = \phi_m \hat{S}_m + \hat{U}_m$$

$$\hat{Z}_m = \hat{f}_m(\hat{s}_m) + \hat{V}_m$$

$$H = \frac{\partial \bar{f}_m}{\partial \bar{s}_m}$$

$$Q_m = E\left[\bar{U}_m \bar{U}_m^T\right]$$

$$R_m = E\left[\bar{V}_m \bar{V}_m^T\right]$$

$$P_m = E\left[(\hat{\bar{S}}_m - \bar{S}_m)(\hat{\bar{S}}_m - \bar{S}_m)^T\right]$$

$$P_m^* = \phi_m P_m \phi_m^T + Q_m$$

$$P_m = P_m^* - K_m H_m P_m^*$$

$$K_m = P_m^* H_m^T (H_m P_m^* H_m^T + R_m)^{-1}$$

$$\bar{S}_m = \phi_m \hat{S}_{m-1} + K_m \left(\hat{\bar{Z}}_m - \bar{f}(\phi \hat{\bar{S}}_{m-1})\right)$$

The state S, is defined by

$$\bar{S} = \begin{bmatrix} y_1 \\ y_2 \\ Y_3 \\ B \\ V_1 \\ V_2 \\ V_3 \\ \varepsilon \end{bmatrix} \begin{matrix} \left.\begin{matrix} \\ \\ \\ \end{matrix}\right\} \text{Position} \\ \text{— Bias} \\ \left.\begin{matrix} \\ \\ \\ \end{matrix}\right\} \text{Velocity} \\ \text{— Bias Rate} \end{matrix}$$

The transition matrix is:

$$\phi = \left[\begin{array}{c|c} I_4 & I_4 \Delta T \\ \hline 0 & I_4 \end{array}\right]$$

$$\Delta T = t_m - t_{m-1}$$

The measurement matrix, which has dimensions 2 x 8 is:

$$H = \begin{bmatrix} \bar{\gamma}_i^T & 1 & 0 & 0 & 0 & 0 \\ \bar{F}_i^T & 0 & & \bar{\gamma}_i^T & 1 & \end{bmatrix}$$

where,

$$\bar{\gamma}_i = (\bar{Y} - x_i)/r_i \qquad r_i = \text{RANGE}$$

$$F_i = (\bar{V} - \dot{r}_i \bar{\gamma}_i)/r_i$$

The ø matrix was chosen ad-hoc. It is not necessarily the best choice of gains but has been demonstrated by simulation to provide reasonable results, both for straight line flight and for worst case helicopter maneuvers:

Using $a = 0.5g = 16 \text{ ft/sec}^2$

$Q_{ii} = (\frac{1}{2} a \, \Delta t^2)^2$ $i = 1, 2, 3$

$Q_{ii} = (a \, \Delta T)^2$ $i = 5, 6, 7$

$Q_{ii} + 4 = \frac{a^2 \Delta T^3}{2}$ $i = 1, 2, 3$

$Q_{ii} = \sigma_B^2$ $i = 4$

$Q_{ii} \quad \sigma_\varepsilon^2$ $i = 8$

All other Q terms are zero

5.4.3 Initialization of the Software

The navigation solution employed in the preliminary analysis used a static solution to initialize the filter. A complete discussion of the static navigation solution is found in Reference 1.

A static solution required four pseudo ranges and four pseudo range rates, processed simultaneously. For the single channel receiver, the static solution was performed at the fourth time sample using the following approximation:

$$R_1(t_4) = R_1(t_1) + \dot{R}_1(t_1)(t_4 - t_1)$$

$$\dot{R}_1(t_4) = \dot{R}_1(t_1)$$

5.5 ANALYSIS OF ROTOR MODULATION EFFECTS

The effect of propeller modulation on a normally incident plane wavefront has been estimated. The field behind the blade has been found to be a complex function of time which is both amplitude and phase modulated. Both the amplitude and phase modulation components has been expanded in a Fourier series which shows the presence of high harmonics of the blade frequency. The fundamental frequency of the Fourier series expansion is a function of the rotor speed, with a minimum value of 9.8 Hz and a maximum of 10.8 Hz. The amplitude variation over the period of blade rotation is small, and is not expected to cause significant amplitude modulation on the incoming signal. In addition it is expected that the frequency components will fall outside the tracking loop bandwidth.

The phase modulation component of the field, however, may be significant, and its effect on the performance of the tracking loops both during acquisition and tracking will be examined in detail during Phase II.

5.5.1 Analytical Derivation

The analysis is based upon the premise that the techniques of "Fourier optics" are applicable to the solution of the inhomogeneous wave equation with specified boundaries. That is to say, that the opaque blades can be thought of as an optical aperture and Babinet's principle may be applied for finding the field using the idea of complementary screen. The rotation of the blade (aperture) in the spatial domain is handled as a one-to-one rotation of coordinate axis in the transform domain. Having found the field behind the blade at a point in free space we can theoretically remove the blade and assume that the field existed there by some means. Since the receiving antenna pattern is known with respect to the ground plane (helicopter structure) the total field will be merely weighed by the antenna pattern. The weighting of the field by the antenna pattern and the associated polarization effects will be examined in detail during Phase II. The discussion at present will be limited to finding the incoming field behind the blades.

The geometry of the problem under consideration is given in Figure 3-3 showing the two candidate receiving antenna locations. The equivalent geometry used in the mathematical formulation is shown in Figure 5-31.

The assumptions upon which the analysis is based are listed below:

- The incident field is generated by a harmonic source
- The incoming field is a uniform plane wave normally* incident to the blades
- The Kirchoff's approximation is valid for the solution of the inhomogeneous wave equation. (The problem of finding the diffracted field becomes a solution of an integral rather than a hopelessly complicated boundary value problem)
- The physical dimensions of the blade, the wavelength of the source and the distance from the receiving antenna to the blade satisfy the criteria for Fresnel diffraction (near zone)
- The near zone diffracted field behind the opaque blade can be found from Babinet's principle

It is shown in Ref. 6 that the field behind an aperture in the Fresnel diffraction region for three-dimensional signals may be expressed as the two-dimensional Fourier transform of:

$$g(x,y) = f(x,y)\, e^{jk(x^2+y^2)/2z_0} \tag{1}$$

evaluated at $u = \frac{kx_0}{z_0}$, $V = \frac{ky_0}{z_0}$, where f(x,y) is the two dimensional aperture function, the exponential term is the "Fresnel kernel", u and v are the transform variables, k is the wavenumber,

---

* Note: The case of oblique incidence can be derived as an equivalent condition of normal incidence with the proper change of variables

x_0, y_0 and z_0 are the coordinates of a point in space where the field is to be evaluated.

The two-dimensional Fourier transform of the function g(x,y) is defined as (Ref. 6):

$$G(u,v) = \iint_{-\infty}^{\infty} g(x,y)\, e^{-j(ux+vy)}\, dx\, dy \tag{2}$$

In this case, since the aperture is opaque and occupies a finite region in space, the field cannot be found directly using the above formulation. But we know that if the opaque aperture was not present the total field would be equal to the incident field, g^{i}. Applying Babinet's principle (Ref. 7), the total field may be expressed as:

$$g = g^{i} - g_c \tag{3}$$

where g_c is the diffracted field obtained from Equation (2) by integrating over the bounded region of the aperture.

Therefore, in the above formulation, in reference to Figure 5-31, the field at a point $P(x_0, y_0, z_0)$ in free space behind the aperture may be expressed as:

$$g(x_0, y_0, z_0, t) = A e^{jkz_0} e^{-j\omega t} \left\{ 1 + \frac{j}{\lambda z_0} \int_{-a}^{a}\int_{-b}^{b} g(x,y)\, e^{-j(ux+vy)}\, dx\, dy \right\} \tag{4}$$

Where in the region of integration, f(x,y) = 1.

After some manipulations, the field can be expressed as:

$$g(x_0, y_0, z_0, t) = A e^{jkz_0 - j\omega t} \left\{ 1 + j\sqrt{\frac{\pi}{2}}\, \frac{e^{-j\left(\frac{u'^2+v'^2}{4\xi^2}\right)}}{\lambda z_0 \xi} \left[F\left(\xi a - \frac{u'}{2\xi}\right) F\left(\xi b - \frac{v'}{2\xi}\right) + F\left(\xi a + \frac{u'}{2\xi}\right) F\left(\xi b - \frac{v'}{2\xi}\right) + F\left(\xi a - \frac{u'}{2\xi}\right) F\left(\xi b + \frac{v'}{2\xi}\right) + F\left(\xi a + \frac{u'}{2\xi}\right) F\left(\xi b + \frac{v'}{2\xi}\right) \right] \right\} \tag{5}$$

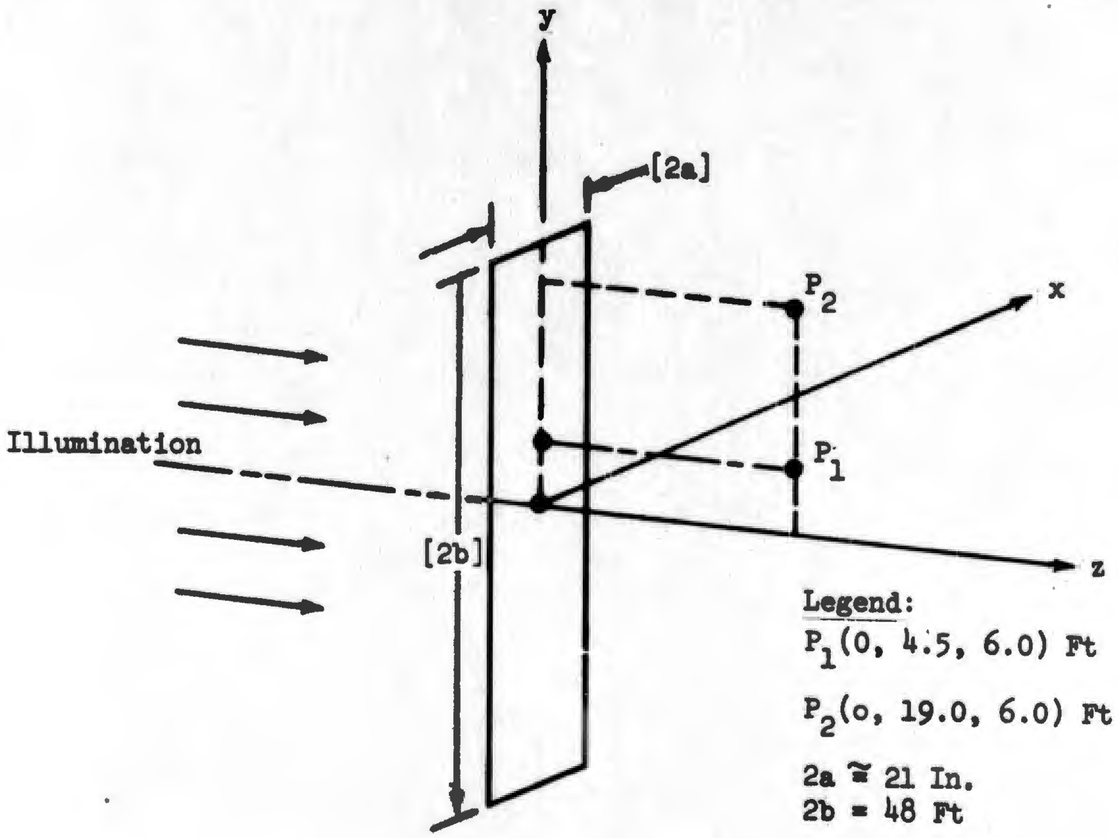


Figure 5-31 Rotor Modulation Geometric Representation

where $\xi = \sqrt{\frac{k}{2z_0}}$, $F(x)$ is the complex Fresnel integral function defined as

$$F(x) \doteq \sqrt{\frac{2}{\pi}} \int_0^x e^{jy^2} dy \tag{6}$$

The primed variables, u' and v' are referred to the rotated coordinate system, and are given by

$$\begin{aligned} u' &= u \sin\theta + v\cos\theta \\ v' &= u\cos\theta - v\sin\theta \end{aligned} \tag{7}$$

where $\theta = 2\,\omega_{ROTOR} t.$

Expanding F(x) into its real and imaginary parts, where

$$F(x) = C(x\sqrt{\frac{2}{\pi}} + jS(x\sqrt{\frac{2}{\pi}})$$

$$C(c) = \int_0^c \cos y^2 \frac{\pi}{2}\, dy \; ; \quad S(c) = \int_0^c \sin \frac{\pi}{2} y^2\, dy \tag{8}$$

and making suitable substitutions to accommodate the definition of Ref. 8 for Fresnel integral, Equation (5) may be expressed in a form suitable for computer computation, where in terms of the definition of the stored Fresnel integrals in Ref. 8 the expression for F(x) becomes:

$$F(x) = C\text{comp}(x^2) + S\text{comp}(x^2)$$

$$C\text{comp}(z) = \frac{1}{\sqrt{2\pi}} \int_0^z \frac{\cos t}{\sqrt{t}}\, dt, \quad S\text{comp}(z) = \frac{1}{\sqrt{2\pi}} \int_0^z \frac{\sin t}{\sqrt{t}}\, dt \tag{9}$$

Now making the necessary substitutions in Equation (5), the field is expressed as:

$$g(x_0, y_0, z_0, t) = A e^{jkz_0} e^{-j\omega t} \left\{ 1 + j\gamma e^{-jW} [\alpha + j\beta] \right\}$$

where $\gamma = \frac{1}{\sqrt{2\lambda z_0}}$, $\xi = \sqrt{\frac{\pi}{\lambda z_0}}$, $k = \frac{2\pi}{\lambda}$,

$$W = \frac{u^2 + v^2}{4\xi^2} \tag{10}$$

$$\alpha = [C_1 + C_3]C_2 - [S_1 + S_3]S_2 + [C_1 + C_3]C_4 - [S_1 + S_3]S_4$$

Now making the necessary substitutions in Equation (5), the field is expressed as:

$$\beta = [S_1 + S_3]C_2 + [C_1 + C_3]S_2 - [C_1 + C_3]S_4 + [S_1 + S_3]C_4$$

$$C_1 = C\left[\left(\xi a - \frac{u'}{2\xi}\right)^2\right] \qquad S_1 = S\left[\left(\xi a - \frac{u'}{2\xi}\right)^2\right]$$

$$C_2 = C\left[\left(\xi b - \frac{v'}{2\xi}\right)^2\right] \qquad S_2 = S\left[\left(\xi b - \frac{v'}{2\xi}\right)^2\right] \qquad (10)$$

and

$$C_3 = C\left[\left(\xi a + \frac{u'}{2\xi}\right)^2\right] \qquad S_3 = S\left[\left(\xi a + \frac{u'}{2\xi}\right)^2\right]$$

$$C_4 = C\left[\left(\xi b + \frac{v'}{2\xi}\right)^2\right] \qquad S_4 = S\left[\left(\xi b + \frac{v'}{2\xi}\right)^2\right]$$

The magnitude of $g(x_0, y_0, z_0, t)$ is obtained by multiplying Equation (10) by its complex conjugate and taking the square root of the resulting expression

$$|g| = A\sqrt{1 + \gamma^2(\alpha^2 + \beta^2) - 2\gamma\beta\cos W - 2\gamma\alpha\sin W} \qquad (11)$$

The phase of $g(x_0, y_0, z_0, t)$ is given by:

$$\phi(t) = \tan^{-1}\left[\frac{\sin(kz_0 - \omega t) + \gamma\alpha\cos(bz_0 - \omega t - W) - \gamma\beta\sin(kz_0 - \omega t - \omega}{\cos(kz_0 - \omega t) - \gamma\beta\cos(kz_0 - \omega T - \omega) - \gamma\alpha\sin(kz_0 - \omega t - \omega}\right]$$

(12)

which may be expressed in a slightly modified form as:

$$\phi(t) = \tan^{-1}\left[\frac{\cos\omega t\,[X\sin kz_0 + Y\cos kz_0] + \sin\omega t\,[Y\sin kz_0 - X\cos kz_0]}{\cos\omega t\,[X\cos kz_0 - Y\sin kz_0] + \sin\omega t\,[X\sin kz_0 + Y\cos kz_0]}\right]$$

(13)

where:
$$X = 1 + \gamma\alpha \sin W - \gamma\beta \cos W$$
$$y = \gamma\alpha \cos W + \gamma\beta \sin W$$

Having obtained the magnitude and phase of the resultant field, we may represent it as:

$$y(t)\Big|_{P(x_0, y_0, z_0)} = |g| \cos[\phi(t)] \qquad (14)$$

The above expression shall be used in later sections to model the effect of changing field on the receiver performance.

The magnitude of the field has been computed as a function of blade rotation utilizing the IBM 67 Time-Sharing computer for $\lambda = 0.6'$, A = 1, for the two antenna locations P_1 and P_2 in Figure 5-31. The result for P_1 is plotted in Figure 5-32.

The magnitude of the field is periodic in $(0, \pi)$ with even symmetry and a relatively small ripple (approximately 1.5 dB). The waveshape is very complex as seen from Figure 5-32 and expected to contain high harmonics of the blade frequency.

A Fourier analysis of both the magnitude and phase of the field on the IBM 67 Time Sharing computer, utilizing the FORIF Scientific Subroutine package indicates a high harmonic content with significant terms up to the 10th harmonic of blade frequency.

Both the magnitude and the phase of the field has been expanded in a Fourier series of the form:

$$f(t) = a_0 + \sum_{k=1}^{10} \left[a_k \cos k\omega_b t + b_k \sin k\omega_b t\right] \qquad (15)$$

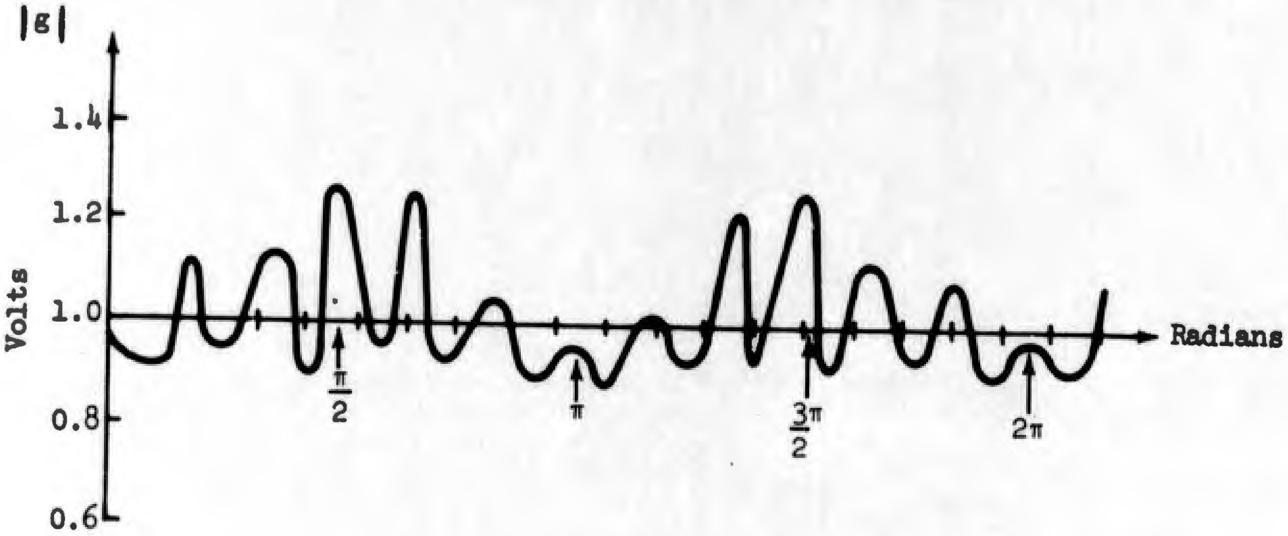


Figure 5-32 Magnitude of Field at P_1 = (0, 4.5, 6.0) Ft vs Blade Rotation Angle - an Approximate Sketch

where ω_b = blade frequency (radians/sec)

with $\omega_b = 2\,\omega_{ROTOR} = 2N\frac{\pi}{30}$, $N = 324$ rev/min, $x_0 = 0'$, $y_0 = 4.5'$

or $y_0 = 19.0'$ and $z_0 = 6.0'$

the amplitude of the resultant harmonics are computed in the order listed below and their magnitude is listed in Figure 5-33.

$$\begin{bmatrix} a_0 & a_1 \\ a_2 & a_3 \\ \vdots & \vdots \\ a_{10} & b_0 \\ b_1 & b_2 \\ \vdots & \vdots \\ b_9 & b_{10} \end{bmatrix}$$

While the harmonic content of the signal is high, the amplitude variations is small, therefore the effects on loop performance are not expected to be significant.

The phase modulation component, Equation (12) has also been evaluated on the IBM 67 Computer as a function of blade rotation. The phase variation has been found to be in the range from approximately 0.2 to 0.6 radians.

The fact that the relative harmonic content of the phase and amplitude are comparable indicate that the field is a "narrow band" FM like signal. The effects of this signal on the loops performance will be examined in detail during the course of the study. The fourier series expansion of ($\phi(t)$) in the interval $(0, \pi)$ has been examined and shows the same significant harmonics present as the amplitude modulation components with slightly different weights.

Fourier Components of Amplitude of Field
Antenna Location: P_1 = (0, 4.5, 6.0) Ft

0.1002E 01	0.6466E-02
0.3039E-02	0.242.E-02
0.2233E-02	0.1682E-02
-0.8962E-02	0.6193E-02
0.5691E-02	0.6427E-02
0.8486E-02	0.0
-0.4691E-03	-0.5293E-03
-0.7133E-03	-0.9027E-02
-0.8700E-03	0.4626E-02
-0.4840E-02	-0.4846E-02
-0.6243E-02	-0.9154E-02

Fourier Components of Phase of Field
Antenna Location:

P_1 = (0, 4.5, 6.0) Ft		P_2 = (0, 19.0, 6.0) Ft	
-0.4133E 00	-0.5938E-02	0.1108E-01	0.2789E-02
-0.3239E-02	-0.3489E-02	0.3099E-02	0.1475E-02
-0.3906E-02	-0.4975E-02	0.5716E-03	0.3417E-02
-0.1774E-01	-0.7365E-03	0.1889E-01	-0.9511E-02
-0.2862E-02	-0.4327E-02	-0.1522E-02	-0.1805E-02
-0.6529E-02	0.0	-0.2223E-02	0.0
-0.1033E-02	0.2236E-03	0.4569E-02	0.2794E-02
0.8454E-03	0.1464E-02	0.1697E-02	0.2719E-02
0.2335E-02	0.9837E-02	0.4413E-02	-0.1587E-01
0.2233E-02	0.3692E-02	0.9930E-04	0.3844E-03
0.5478E-02	0.8453E-02	0.2950E-03	0.1330E-02

Figure 5-33 Field Amplitude and Phase Harmonics

5.5.2 Comparison of Two Antenna Locations

The difference in the received field at the two antenna locations, P_1 (0, 4.5. 6.0); P_2 (0, 19, 6.0) are compared.

Both the amplitude and phase of the field of P_2 exhibit larger variations as a function of blade rotation than the field of P_1. This may be anticipated since P_2 is located near the upper edge (outer edge of rotor) of the aperture where the diffracted field should have larger variation as a function of aperture position.

The variation of the amplitude of the field at P_2 is 1.7 dB while at P_1 the variation is 1.5 dB.

The phase variation is also more pronounced at P_2 than at P_1. The quantitative effect of phase variation will be evaluated during Phase II.

5.5.3 Doppler Effects

The rotation of the helicopter rotor is going to introduce a doppler shift on the incoming signal.

The doppler shift is proportional to:

$$f_d = \frac{V}{c} f_{CARRIER}$$

where v is the relative velocity between a moving point and the reference point c is the speed of light, and $f_{carrier}$ is the carrier center frequency.

The maximum relative velocity v_{max} may be esimated as

$$V_{max} = r\,\omega_b$$

where r = radius of the blade (24').

For a maximum rotor speed of 324 rev/min,

$$V_{max} \approx 1630 \text{ FPS}$$

The maximum doppler shift at a carrier center frequency of 1.575 GHz is:

$$f_{d_{max}} \approx 2.5 \text{ KHz}$$

Note, however, that since the doppler is proportional to the relative velocity of the blade with respect to the antenna, the magnitude of the doppler will be a function of the antenna location and the angle of incidence. The magnitude of the doppler shift will vary linearly between 0 to 2.5 KHz, depending on the position of the antenna relative to the mast and end of the rotor. The effects will be investigated during Phase II.

5.6 MULTIPATH EFFECTS

The multipath errors engendered in range and range rate in the area navigation and ILS configurations have been modeled in earlier work for a coherent detector, Reference 1. The mathematical models developed in Reference 1 are directly applicable to all helicopter flight profiles and tie-down tests for a coherent receiver (Option I, see Section 8). An extension of the previous analysis that includes the averaging effect of the carrier tracking loop on the range rate error due to multipath is presented herein. Further refinements in modeling ground roughness and effective ground reflection coefficient shall be carried out during Phase II for both a coherent and a non-coherent (Option II) receiver.

5.6.1 Analytical Representation

An annotated summary of equations for the range and range rate errors as the result of specular multipath for the 621B receiver mechanization are presented below:

(1) The range error output of the early-late gate discriminator is expressed as:

$$\Delta R = \begin{cases} d\left(\frac{R_1}{1+R_1}\right), & d < 50(1+R_1) \\ (150-d)\frac{R_1}{2-R_1}, & 50(1+R_1) < d < 150 \\ 0, & d \geq 150 \end{cases} \qquad (1)$$

where

$$R_1 = R\cos\left(\frac{2\pi}{\lambda}d - c\right)$$

is the magnitude of the voltage reflection coefficient, λ is the wavelength (ft), d is the differential delay (ft) and c is the phase angle of the voltage reflection coefficient (rad).

Note that, the above equation does not include the effect of bandlimiting on the signal prior to the early-late gate discriminator. The effect of bandlimiting is to extend the range of differential delay over which the multipath range error takes on significant values. The effect of bandlimiting on the multipath range error will be analyzed during the study.

(2) Multipath Velocity Error

The rate of change of phase between the direct and interfering signals may be shown to be

$$\dot{\alpha} = \frac{\Delta\omega R\left(R+\cos(\Delta\omega t+c)\right)}{R^2+2R\cos(\Delta\omega t+c)+1} \tag{2}$$

where,

$$\Delta\omega = \frac{2\pi}{\lambda}\dot{\ell} = \frac{2\pi}{\lambda}(\dot{r}_M-\dot{r}_d)$$

is the differential doppler or fade frequency, r_M is the multipath signal path length and r_d is the direct signal path length. It may be shown [3] that Equation (2) can be expanded in a Fourier series of the form:

$$\dot{\alpha} = \Delta\omega\sum_{n=1}^{\infty}(-1)^{n+1}R^n\cos[n(\Delta\omega t+c)] \tag{3}$$

In terms of the carrier tracking loop parameters, the velocity error caused by $\dot{\alpha}$ may be written as:

$$\Delta\dot{R}_{gps} = \frac{\lambda}{2\pi}(\Delta\omega)\sum_{n=1}^{\infty}(-1)^{n+1}R^n P_{B_L}(\Delta\omega)\cos[n(\Delta\omega t+c)]$$

$$P_{B_L}(x) = \begin{cases}1 & |x|<B_L\\ 0 & |x|>B_L\end{cases}$$

where B_L is the one-sided loop noise bandwidth of the carrier tracking loop.

Note that the above expression shows the effects of bandlimiting on the velocity error, i.e., - if $n\Delta\omega > 2\pi B_L$ there is no error in velocity due to multipath.

5.6.2 Helicopter Self-Induced Multipath

There are two causes of self-induced multipath. One is from the basic structure and the other is from the rotor. The helicopter self-induced multipath will be a function of antenna locations. In order to assess the magnitude of the range error induced by the helicopter structure, scaled model or actual antenna pattern measurements are necessary to determine the voltage reflection coefficient. If we assume that the reflections from the helicopter structures are less than 50 ft, the maximum RMS range error for small R may be approximated as:

$$\Delta R \leq \frac{Rd}{\sqrt{2}} \text{ ft.} \quad , \quad 0 \leq d < 50$$

During low grazing angles (with respect to the ground transmitters), which occurr during the ILS, the rotor may reflect some of the incident energy back to the antenna located at the nose. This will create a periodic multipath-like signal that can cause both range and range-rate errors. The range rate error will be a function of the helicopter ground track velocity, the speed of the rotor and the grazing angle. Due to the geometrical relationship between the tip of the rotor and the relative position of the antenna, the grazing angle will exceed the Brewster angle creating a reversal of the polarization of the reflected wave. The antenna will therefore reject the reflected wave by more than 20 db, thereby significantly reducing the error from this source. The values shall be determined during Phase II.

5.6.3 Polarization Effects

A discussion of the polarization effects on the multipath errors engendered in the 621B system were given in Reference 1.

For the Area Navigation the helicopter 621B antenna is on the bottom centerline up forward (see Figure 3-3). In the ILS test, the helicopter 621B antenna is in the forward position (see Figure 3-3). From antenna pattern measurement (see Reference 1) the antennas will provide the following rejection during the test (for opposite polarization):

1) Area Nav - >30 dB (ground reflected signal, high grazing angle)

2) ILS - >20 dB (Balloon reflected signal, high grazing angle)
0 dB (Ground reflected signal, low grazing angle)

5.6.4 Tie Down Test and Monitor Link

The multipath errors engendered during the tie down test are comparable in magnitude to that of the monitor links (Reference 1).

The details shall be examined during Phase II.

Typical Results

Table 5-4 indicates the typical error values which can be expected. They are not expected to degrade performance.

Table 5-4 Typical Expected Multipath Errors

	$\lvert \Delta R \rvert$	$\lvert \Delta \dot{R} \rvert$ (3)	Diff. Delay	Grazing Angle	Type of Multipath
Area Nav (1)	< 0.5	< 0.05	12.8'	39.8°	Diffuse
ILS Ground (2)	> 1	< 0.05	0.5'	1.7°	Specular
Balloon (1)	> 1	< 0.05	83'	56°	Diffuse
Tie Down (2)	< 0.5	0	0.05'	0.2°	Specular
Self Induced	TBD	TBD	TBD	TBD	Diffuse & Specular

Note: (1) Includes antenna polarization rejection of LHCP wave

(2) No antenna polarization rejection

(3) Helicopter ground track velocity 100 fps

TBD To Be Determined

5.7 RECEIVED POWER COMPUTATIONS FOR TIE-DOWN TESTS

The 621B transmitter power output is specified in Reference 1 and summarized below for convenience:

	Long Code	Short Code
Primary Antenna, P_{dbm}	+ 20 to -35	+ 37 to + 27
Monitor Antenna, P_{dbm}	- 6 Minimum	+ 4 Minimum

The tie-down test geometry and relative distances between transmitters and helicopter are shown in Figure 3-1. The ground based transmitting antenna gains and antenna pattern are shown in Reference 1. A summary of the extremes of received power levels from the ground based transmitters without rotor modulation effects is given in Table 5-5. The transmission loss shown in the table includes the ground proximity effects as well as space loss.

The results indicate that with proper setting of the transmitter power levels, the received power is well within the range for good receiver performance, as well as falling within the assumed nominal range of operational performance of -123 dbm.

Table 5-5 Received Power Levels

	Max	Min
Transmitter Power:	+ 20 dbm	- 35 dbm
Cable Losses:	- 2 dbm	- 2 dbm
Polarization Loss:	- 3 dbm	- 3 dbm
Transmitting Ant. Gain	- 8 dbm	- 8 dbm
Transmission Loss*	-123 dbm	-123 dbm
Receiving Ant. Gain	- 15 dbm	- 15 dbm
Cable Loss	-2 dbm	-2 dbm
Received Power (Long Code)	-123 dbm	-178 dbm

Note: * Assumes longest link

5.8 HELICOPTER PERFORMANCE*

A major consideration in the design of the flight tests is the performance capabilities of the helicopter at the Northrup Strip at WSMR. Northrup strip ground level is 4000 ft above sea level. It is anticipated that the flights will take place during the summer, when the maximum temperature is 38°C at ground level. Flight duration of one and one-half hours are anticipated at a nominal altitude of 4000 ft AGL where the maximum temperature is approximately 24°C (Reference 10).

Figure 5-34 indicates a maximum continuous shaft horsepower of 840 available for the nominal test altitude of 8000 ft ASL at 22°C. From Figure 5-35, for a shaft horsepower of 840 at test altitude of 8000 ft ASL, the fuel consumption is 540 lb/hr. A fuel load of 1040 lb (160 gallons) has been selected for the test. Therefore, if the helicopter were being flown at maximum shaft horsepower (840), which will not be the case, then after 1.5 hours approximately 200 lb of fuel would remain, a more than adequate margin. Flights lasting 1.5 hours are anticipated.

5.8.1 Helicopter Weight and Balance

Helicopter flight performance is a direct function of the weight and CG location which results due to the loading of the helicopter. This section therefore addresses helicopter loading to insure adequate flight performance.

Basically, for option I or II, (see Section 8), the equipment loading of the helicopter will consist of three racks with equipment, cables, etc., and an inverter. See Section 9.4 for details. Table 5-6 indicates weights of added equipment. Table 5-7 is a helicopter loading analysis for the UH-1H helicopter, reflecting

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* Data and curves for this section taken from Refs. 3 and 4.

UH-1H T53-L-13
6600 Engine Output Shaft RPM

Note: Based on Model LTCIK-4 Specification No. 104.33 corrected for the Following Installation Conditions:

1. Compressor Inlet Temperature Rise = 1°C
2. Compressor Inlet Pressure Ratio = 0.987
3. Air Bleed = 1.15% of Total Air Flow
4. Horsepower Extracted = 0.4 Horsepower
5. Exhaust Losses = Zero
6. Bleed Air Heater Off
7. Anti-ice Off

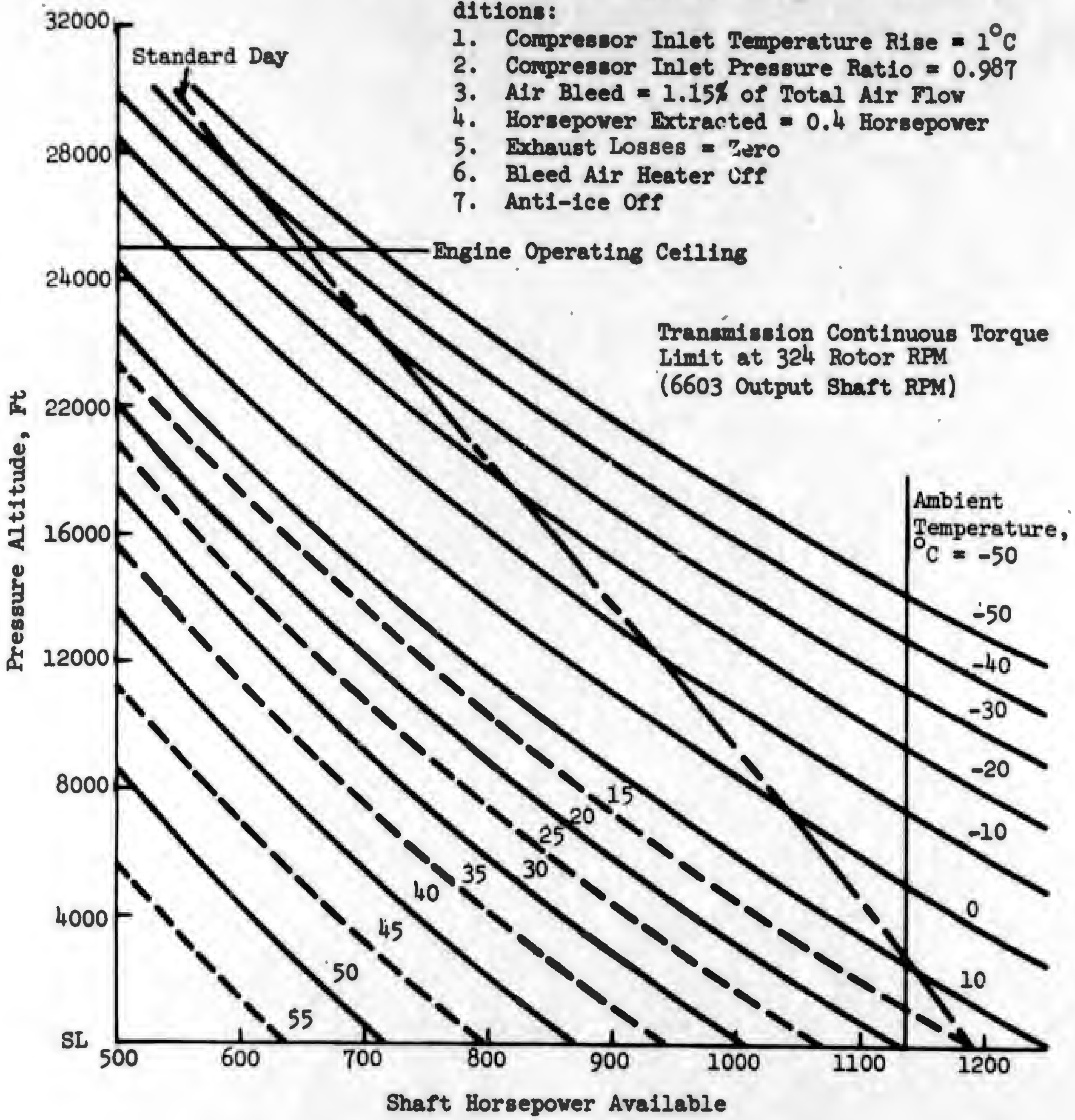


Figure 5-34 Maximum Continuous Shaft Horsepower Available

UH-1H T53-L-13
Standard Day 6600 Output Shaft RPM

Note: Based on Model LTCK-4 Specification No. 104.33
Corrected for the Following Installation Conditions:
1. Compressor Inlet Temperature Rise = 1°C
2. Compressor Inlet Pressure Ratio = 0.987
3. Air Bleed = 1.15% of Total Air Flow
4. Horsepower Extracted -0.4 Horsepower
5. Exhaust Looses = Zero
6. Bleed Air Heater Off
7. Anti-Ice Off

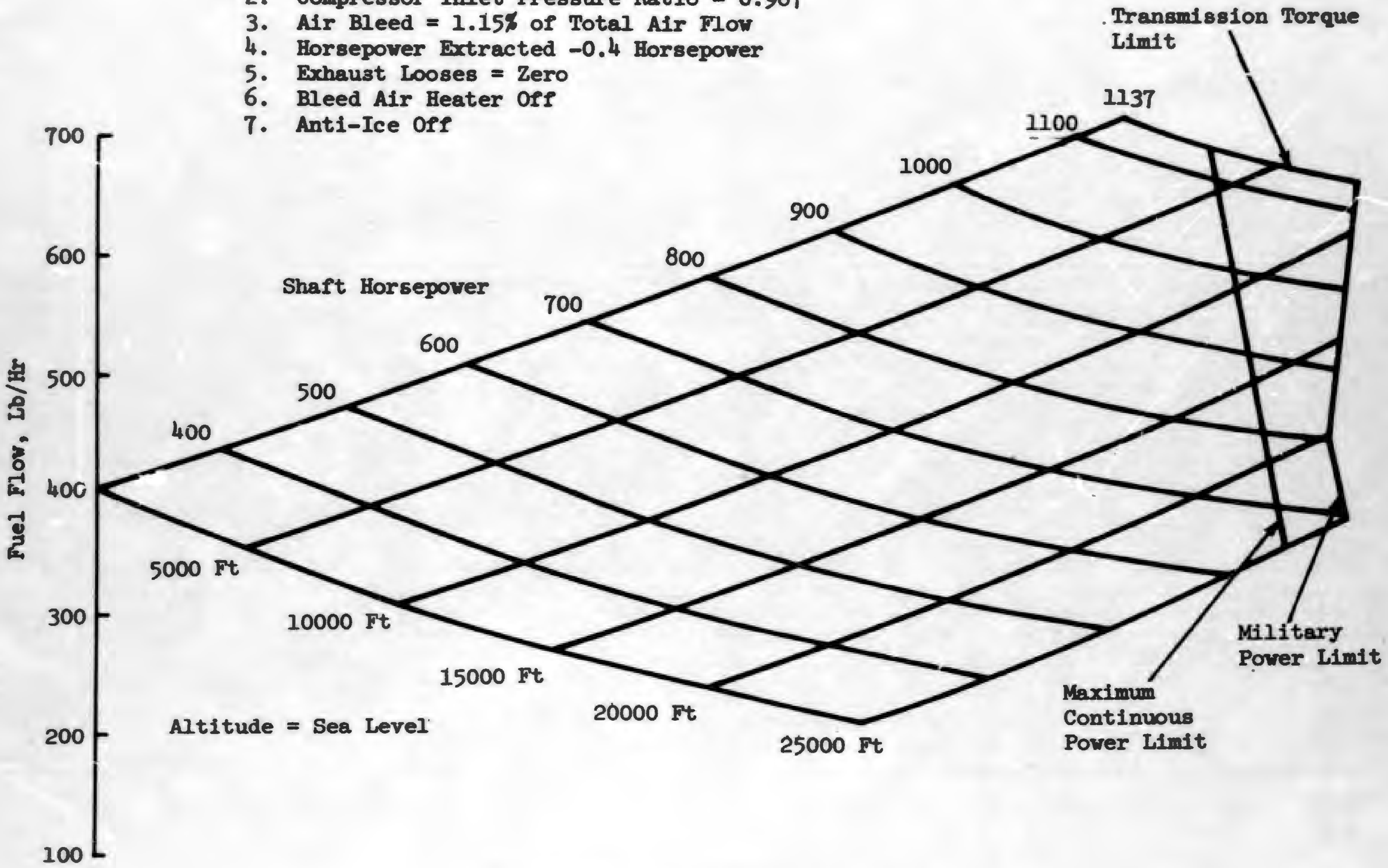


Figure 5-35 Specification Fuel Flow

Table 5-6 Added Weights

Cabinet I

621B Receiver	85 lbs
Power Supply	85
Multiplexer	40
Multiplexer Test Panel	5
Cabinet	75
Blower	3
Isolation Mounts	12
Stabilizer Bars	8
Cables	17
	330 lbs

Cabinet II

Analog Signal Conditioner	14 lbs
A/D Converter	17 lbs
Power Panel	8
IU Power Panel	30
Power Supply Assembly	60
Cabinet	75
Blower	3
Isolation Mounts	12
Stabilizer Bars	8
Cables (feeder from circuit cabin)	25
	252 lbs

Cabinet III

Time Code Readout	10 lbs
IU Panel (Recorder)	38
Tape Recorder	50
Memory	29
Cabinet	75
Blower	3
Isolation Mounts	12
Stabilizer Bars	8
Cables	5
	230 lbs

Inverter Assy

Inverter	65 lbs
Contacter	2.5
Controller	2.
Circuit Breaker Panel	4.
Chassis	8.
Associated Cables	7.
	88.5 lbs

Control Panel

Hazeltine Receiver Control Panel	5. lbs
Instrumentation Control Panel	5.
Antennas	4.
	14 lbs

Total Added Weight - 914.5 lbs

Table 5-7 Helicopter Loading (5)

Item	Weight (lb)	Arm (inches)	Moment/100
Basic Helicopter	5330	143.2	7630
Pilot	200	46.7	93
Oil-Engine	24	173.0	42
System 621B Equipment			
-Rack #1	330	113	373
-Rack #2	252	149	376
-Rack #3	230	149	343
-Wire	127	130	165
-Inverter (1)	30	200	60
Minimum Loading Gross Weight	6523	139.2	9082
Add: Fuel (160 gal) (2)	1040	145.1	1509
Passenger	200	46.7	93
Take Off Gross Weight (3)	7763	137.6	10684
Reduce: Fuel to 85 gals (4)	-1040	145.1	-1509
	553	127.1	703
Most forward-flight Condition	7276	135.8	9878
Reduce: Fuel to 30 gals	-553	127.1	-703
	195	144.0	281
Normal Landing Gross Weight	6918	136.7	9456

Notes:

1. 2500 VA inverter is to be installed in place of the HF set AN/ARC-102 which will not be utilized for these tests. The weight entered in the table is therefore the estimated weight difference between the inverter and HF set.
2. Weight density of a gallon of fuel = 6.5 lb/gal
3. Most aft condition
4. Most forward condition. See Figure 5-38 for fuel C.G. travel
5. Data and figures derived from reference 3 and 4.

equipment listed in Table 5-6. It can be seen that the CG location computed in Table 5-7 for all flight conditions falls well within the recommended limits given in Figure 5-36. Reference to Figure 5-36 indicates that for the worst case weight, computed in Table 5-7, the recommended maximum airspeed limit for the test nominal altitude (above sea level) of 8000 ft, is 110 kt, which is well beyond the nominal 80 kt projected for the area navigation test. Figure 5-37 indicates that, under all weight conditions, the nominal flight ceiling of 8000 ft ASL is well within the service limits.

The real-time computer additions, as proposed in Option III are estimated to weigh less than 25 lbs, and will therefore not significantly alter helicopter performance from the nominal computed previously.

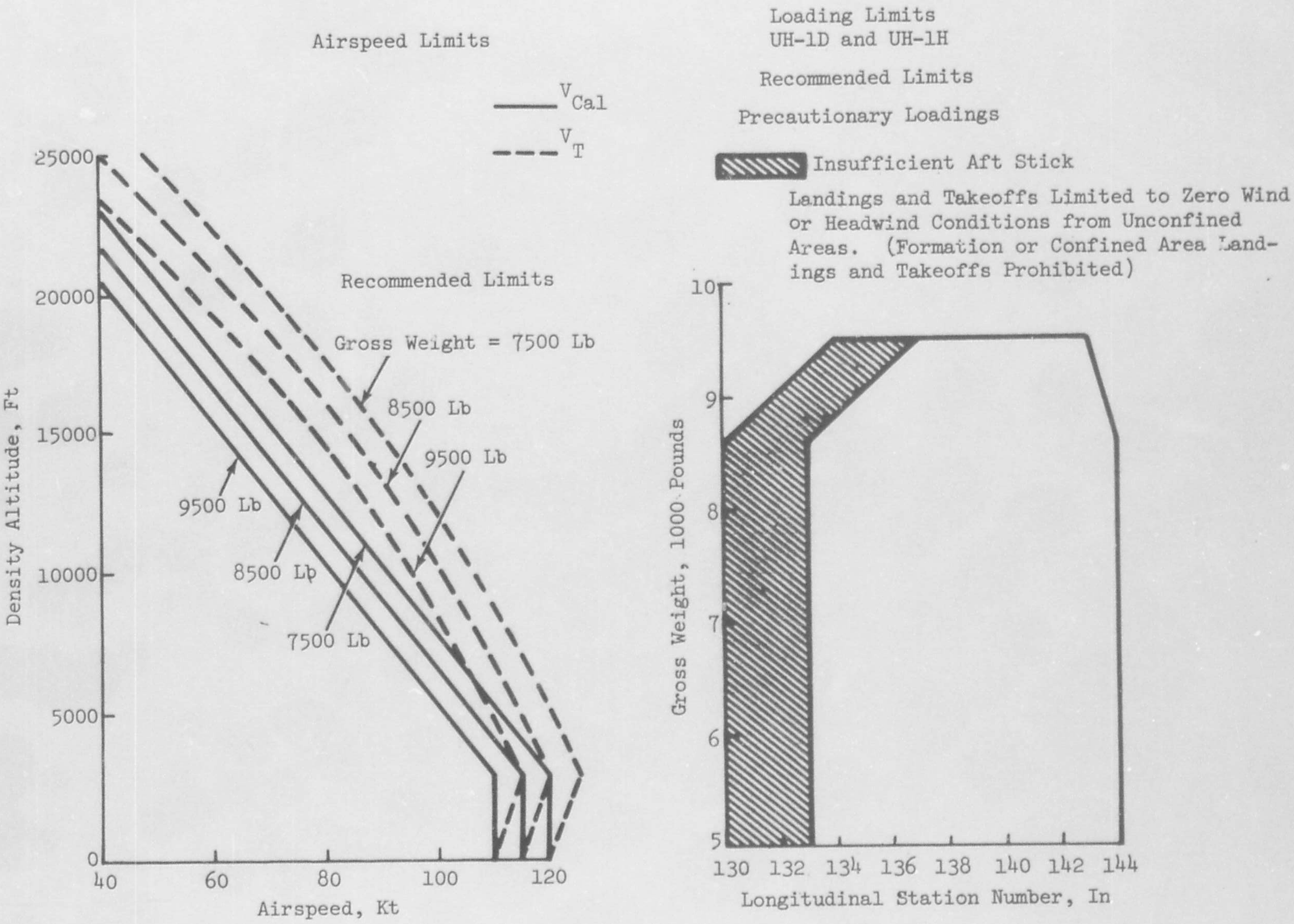


Figure 5-36 Airspeed and Loading Limits

UH-1H T53-L-13
Military Power 324 Rotor RPM

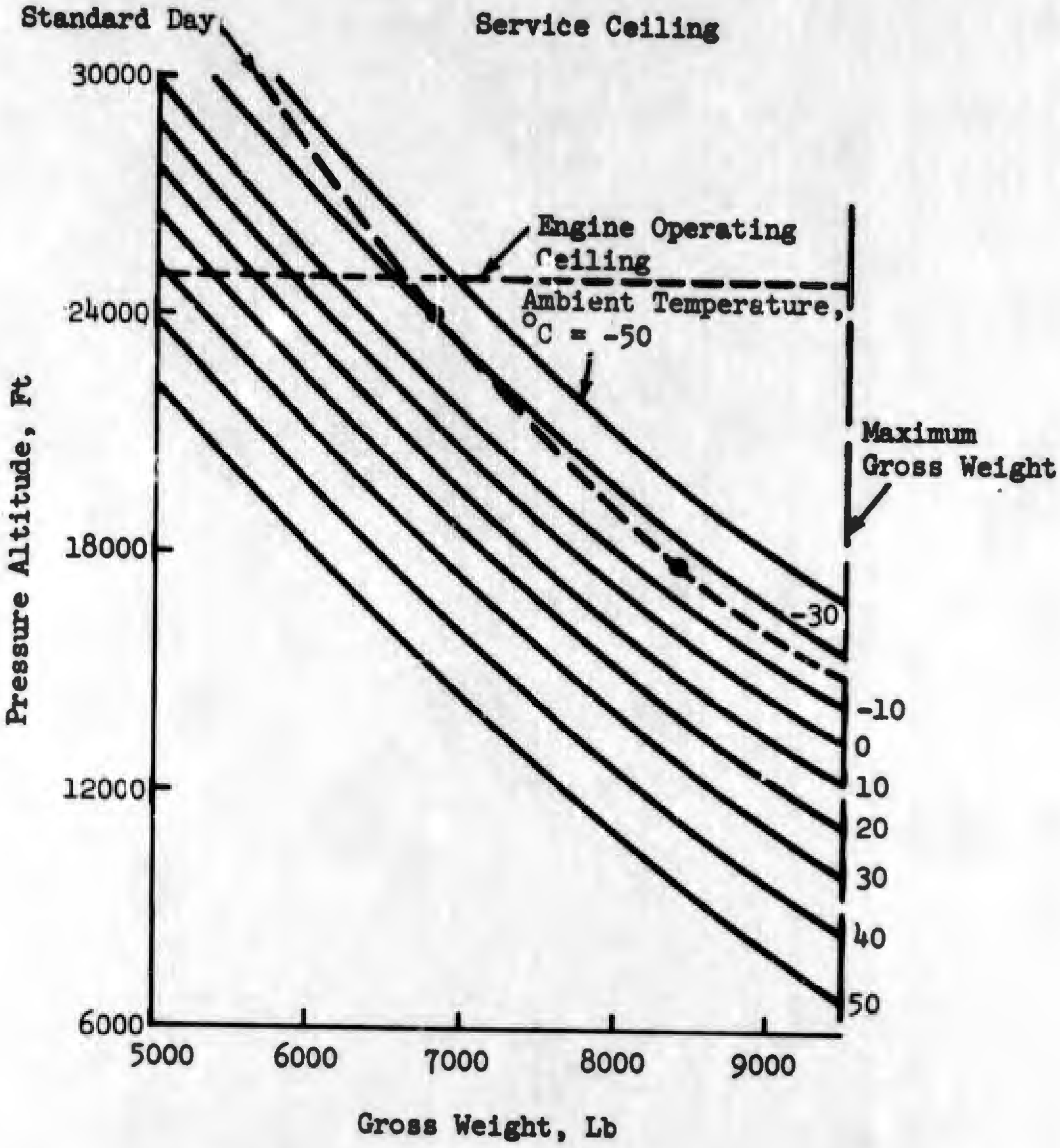


Figure 5-37 Maximum Service Ceiling

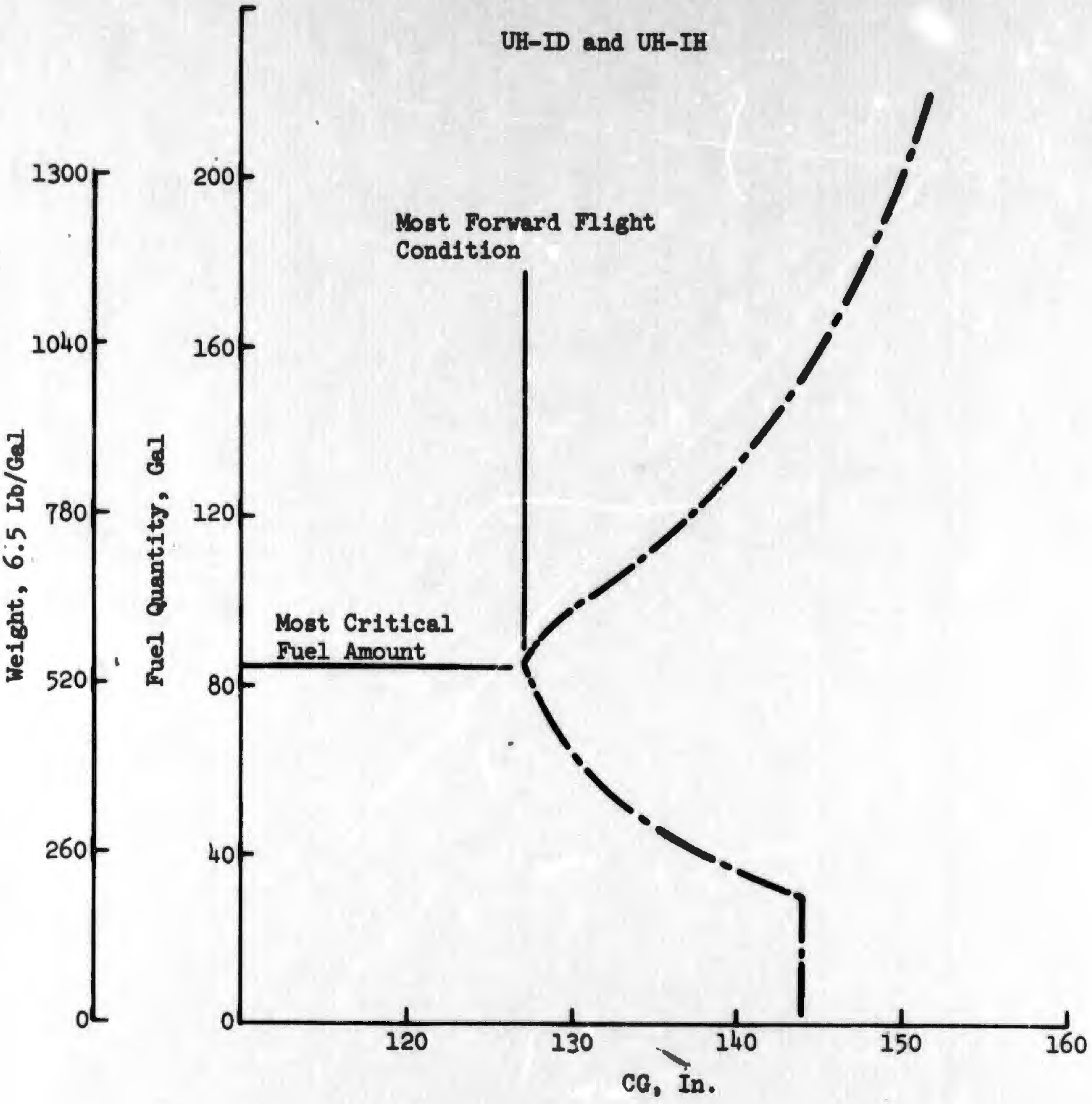


Figure 5-38 Fuel Loading - Regular (UH-ID and UH-IH)

6. TEST PLAN

Virtually all equipment to be used for this program will be physically located at WSMR at the completion of the NC-135 tests. It is therefore more cost effective to perform the equipment modification and testing in the field utilizing the actual transmitter configuration and test set-up which exists. Therefore, all integration tests will be performed in the field at the completion of modification of the equipment. The exception to this procedure is the receiver, which will undergo preliminary testing at Hazeltine, the nature of which will depend on which Option is selected (Section 8). These factory receiver tests are addressed in Section 9.1. This section addresses all the field tests.

6.1 ELECTROMAGNETIC COMPATIBILITY (EMC) PROGRAM

The EMC program for the helicopter consists of analysis and tests directed to take into account the unique aspects of the helicopter, and to validate that system electromagnetic compatibility has been achieved to the extent required for the evaluation tests.

The program can be divided into three main areas:

- An antenna system analysis
- An EMI survey of the helicopter at 1575 MHz
- System electromagnetic compatibility tests

The purpose of the antenna system analysis to determine the helicopter transmitter fundamental signal levels that will be present at the 621B receiver antenna input. These levels will be compared with the design requirements/test data for the four channel receiver designed for the SAMSO System 621B user equipment evaluation program. If it appears that the helicopter transmitter RF environment poses compatibility problems, the receiver will be tested and appropriate corrective action will be undertaken. Thus, this helicopter-unique aspect of EMC will be resolved.

The most significant remaining area is the RF environment of the helicopter at 1575 MHz. This environment is produced by helicopter electrical/electronic functions and RF transmitters. A survey will be performed by measuring the interference at 1575 MHz at each of the four locations for the System 621B antenna while exercising the helicopter in a manner representative of the evaluation program. The measured levels will be compared to the levels that will affect the evaluation program. Problem area will be resolved by appropriate corrective measures.

The remaining areas of EMC are covered by the basic equipment EMI design requirements, and, good installation practices with respect to cable routing and shielding.

System compatibility will be validated by a series of system tests in the helicopter. This series includes both ground and flight tests that are designed to be cost effective.

6.1.1 Ground Tests

The helicopter, with the 621B system installed, will be exercised in a manner representative of the evaluation program while monitoring critical points in the system for interactions. Initially the tests will be performed on ground power. The engine power tests will permit exercising of helicopter functions that could not be evaluated on ground power. The other selections will be tests that produced interaction on ground power, plus, arbitrarily selected tests to validate the ground power test results.

6.1.2 Flight Tests

The system will be exercised while monitoring critical points for interactions to evaluate functions that could not be exercised on the ground, and, to validate the ground test results. The ground test results are validated by checking for interactions observed on ground power, and, arbitrarily selecting functions that did not produce interactions on the ground. EMC problems will be identified by Grumman and solutions within Grumman control that are essential to the program objectives will be enacted.

6.2 INTEGRATION TESTS

A series of integration tests will be performed in the field. These tests are intended to certify the integrity and performance of the individual components and interface as well as insuring that the integrated system will perform as specified.

The following tests will be performed;

- Bench Test (individual units)
- Systems Integration Test
- Installation Acceptance Test
- Preflight Acceptance Test
- Preflight and Postflight Test

6.2.1 Bench Test

A bench test will be performed on each unit comprising the Grumman helicopter installation. In general, the bench test procedure will consist of:

- Inspection to determine if unit has been damaged due to handling and transportation.
- Electrical test to determine if the unit is operating properly.

This bench test will be performed on units prior to System Integration testing and should show that units meet all design goals.

6.2.2 Systems Integration Test

The Systems Integration Test (SIT) is intended to demonstrate the integrity of the entire 621B System, both ground and airborne units, prior to the actual installation in the helicopter. The test configuration is shown in Figure 6-1 and will be integrated in the MCS on site.

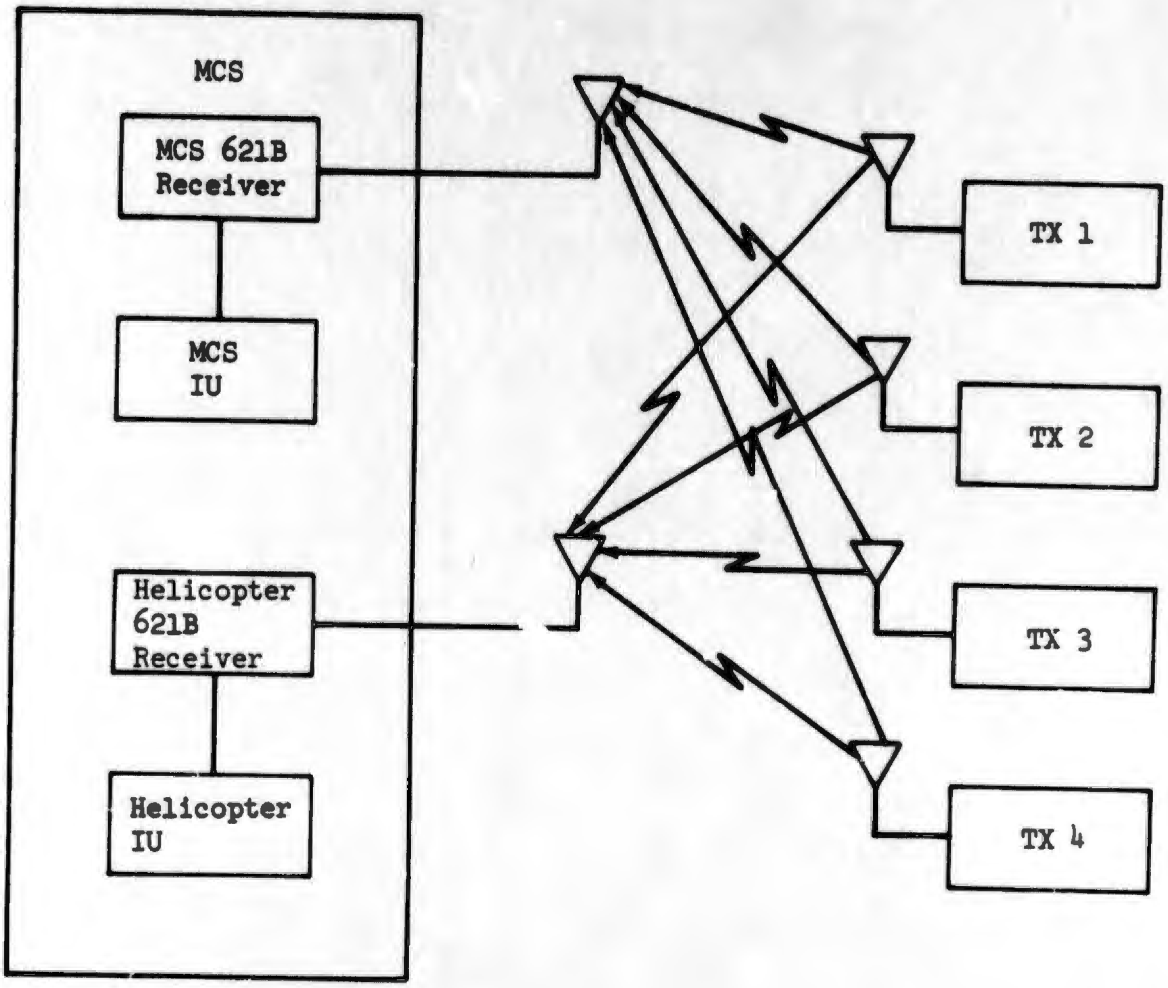


Figure 6-1 System Integration Test Configuration

Basically the test will consist of transmitting RF signals to both the Helicopter and the MCS receivers which in turn feed their respective recorders. The recorded information will then be decoded.

The tests will be performed at:

- Expected signal levels
- Minimum Acceptable signal levels
- Signal levels at expected signal levels reduced to below minimum acceptable signal levels and then quickly brought back to expected signal levels (testing reacquisition).

6.2.3 Installation Acceptance Test

The installation acceptance test (IAT) is a one-time test performed at the helicopter site by Grumman to demonstrate system integrity. The IAT will confirm the mechanical and electrical interface and will consist of the following: electrical wiring test for shorts, opens, and voltages, workmanship test, mechanical fit test, electrical connection test, and a 30-minute hot check using ground power and engine power. The United States Army and, if desired, the U.S. Air Force will designate and provide an inspector to witness the (IAT). Approval will be through the U.S. Air Force.

6.2.4 Preflight Acceptance Test

Preflight Acceptance Test (PAT) is a one-time test intended to demonstrate that the 621B installation in the helicopter is operational. PAT will be performed by Grumman. PAT may not be performed unless the IAT has been satisfactorily completed.

PAT will include an EMC system test to demonstrate that the 621B system will not be degraded by electromagnetic interactions when tested on the ground utilizing both ground and internal power.

The EMC system test will commence after it has been established that the 621B Helicopter system is functioning properly. The EMC system test will be performed in an appropriately "quiet" area. The 621B system will be exercised in a normal functional manner and the Helicopter systems operated in a manner representative of the 621B system tests. Normal outputs (and possibly some other critical points) will be monitored for degradation of performance. The functional exercising of the system (621B and helicopter) may require external transmitters, signal generators, and test sets. United States Army and, if desired, the U.S. Air Force will designate and provide an inspector to witness PAT. Approval will be made through the U.S. Air Force.

In general EMC problems identified by these tests will be evaluated in flight prior to instituting corrective action. This is the best procedure because interactions uncovered in ground testing may be due to the proximity of the earth.

6.2.5 Preflight and Postflight Tests

Detailed preflight and postflight test plans will be written during phase II.

A preflight test will be performed prior to each flight to ascertain the performance status of the system 621B receiver and test instrumentation. These tests will make maximum use of the self test capability of the receiver and test instrumentation (reference Section 9). The preflight test will be performed a sufficient time prior to each flight to permit corrective action for any minor discrepancies discovered. Discovery of discrepancies requiring mission abort should permit the timely change of the flight schedule resulting in minimum lost time and effort on the part of the support personnel and equipment.

A postflight test similar to the preflight test will be performed immediately upon completion of the test flight to obtain a confidence factor for data retrieval and subsequent scheduling of the next flight. This will also result in the timely detection of discrepancies, if any, providing for speedy corrective action to minimize flight schedule delays.

6.3 PROPOSED TEST PLAN

The total field systems demonstration test time will require seven weeks to accomplish. It is anticipated that these tests will take place during the summer of 1972.

An estimated two weeks will be required for the test site configuration tests and tie down tests and a four-week period encompassing 11 test flights of 1 1/2 hours each, will be required to fulfill the objectives of the systems demonstration tests. These tests are outlined in the test plan matrix shown in Table 6-1. The number of field tests were selected to meet army requirements consistent with program costs.

The number of flights required is directly related to the statistics associated with the sample. In particular, a sufficient sample must be drawn upon which statistical inferences can be drawn with some confidence.

Confidence level values vary according to the program objective being examined. For basic system accuracy tests a confidence level of 90% is established as a reasonable value. For less important objectives, e.g., general tracking capability during maneuvers, a smaller confidence level, perhaps 50% is reasonable.

The trade-off among test program cost, number of tests required to satisfy the objectives with reasonable confidence, and the test program reliability factors noted has resulted in the present test selection. This is by no means a final solution but is continuously re-evaluated, particularly during the flight program where insight into the actual system behavior will usually cause a restructuring of priorities.

Table 6-1 Test Plan Matrix

Tie-Down Ground Tests

Tests	Objectives	Test Method	Comments
1. Systems integration, Environmental Tests (EMI, Vib, Accoustics)	1a. Determine EMI effects	1a. The A/C Sys Equip will be cycled. EMI effects will be monitored and reported.	Initial sys checkouts are required to verify all equipments are functioning properly (User equip, site equip, data collection and data processing)
	1b. Determine vibration and accoustical noise effects on system	1a. & 1b. Evaluate systems effects with helo pwr and gnd pwr	
	1c. Determine system data acquisition and baseline accuracy	1c. 621B Sys data will be recorded and processed against survey helo location	
2. Rotor modulation and multipath	1. Determine rotor modulation and multipath effects on single chan receiver	1a. Test effects at min/max rotor speeds 294/324 RPM	Determination of rotor modulation and multipath effects on 621B system ability to acquire and obtain design accuracy in presence of rotor mod
		1b. Evaluate Rotor reflection angles at balloon xmtr altitudes of 5 K/1 K-ft	
		1c. Evaluate effects at near Pos Fwd Top Ant (4 ft from rotor hub) and rear top ant (19 ft from rotor hub)	
	2. Determine 621B stationary system accuracy in presence of rotor modulation	2a. 621B System data will be recorded, processed and analyzed to known survey helo. pad location	

Table 6-1 Test Plan Matrix (Continued)

Tie-Down Ground Tests

Tests	Objectives	Test Method	Comments
3. Survey testing Demonstration	Determine stationary long term position accuracy without rotor effects	Helicopter rotors stationary System recording data	Demonstrate attainable accuracies of vehicle man pack 621B utilization Comparison to four-channel rcvr data
4. Signal Power Level systems performance	To determine chan. sequencing and sys performance at the following power levels -125 dbM, -130 dbM, -135 dbM,	Vary transmitter power and measure field strength at the test pad Test with gnd power and helicopter power	Define systems operational threshold and accuracy
ILS Tests			
5. 1st flight basic air worthiness and flight environment systems	5a. Baseline systems performance in flight	Fly shallow normal and steep ILS profiles	Verify system WSMR tracking capability and ability to maintain ILS corridor
	5b. Determine ILS capability to touch down		
6. ILS Approaches (in presence of rotor modulation)	6a. Establish systems range and range rate accuracy	Balloon xmtr 5K-ft	Direct data comparison to NC 135
	6b. Landing performance data on a helicopter installation	Fly 2.5° glide slope to touch down	Normal helicopter ILS approach
		Fly 8° glide slope Fly 16° glide slope	Helo steep angle app/ more realistic relative nav solution problem
7. ILS Approaches (without effects of rotor modulation)	7a. Repeat test no. 6 above	Balloon xmtr at 1K-ft Repeat test no. 6 above	Direct data comparison of ILS performance with and without rotor

Table 6-1 Test Plan Matrix (Continued)

ILS Tests	Objectives	Test Method	Comments
8. ILS Ground Multipath Test (Test data from four-channel testing may negate this requirement)	8a. Determine extent test config. multipath degrades system accuracy	Theortically apply grnd multipath measurements during test 6 & 7 (from NC 135 program tests)	Demonstrate Sys sensitivity to multipath
Area Navigation Tests			
9. Systems Accuracy Demonstration	9a. Determine initial systems accuracy	Fly straight and level flights over demo corridor at 4K ft	Determination of single channel rcvr/sequencer accuracy vs. NC 135 four channel rcvr accuracy
	9b. Evaluate helo flt environment on systems accuracy	Fly moderate helo turns over demo configuration	
	9c. Evaluate effects of helo moderate maneuvers on sys accuracy		
10. Signal Power Level Systems Accuracy Demonstration	10a. Determine area navigation system performance at power levels of -125 dbM, -130 dbM, -135 dbM	Fly area navigation profile corridor Transmitted pwr output levels will be varied to predetermined levels	Define system thresholds and accuracy

6.3.1 Field Tests

The field test plan will be divided into three major parts:

- Helicopter tie-down tests
- ILS/Relative navigation tests
- Area navigation demonstration

All tests will be conducted at WSMR, Northrop Strip facility. Tests 1 thru 4 of the test plan matrix does not require WSMR trajectory data for the helicopter. Survey data and balloon position data is required however.

The tie-down tests uses the same transmitter configuration as in the NC-135 ILS tests. The helicopter will be tied down to the surveyed landing pad, and the following objectives will be accomplished:

- Environmental effects
- Rotor modulation/multipath
- Stationary baseline system accuracy with/without rotor modulation
- Systems sensitivity/sequencing time as related to field strength power

A very significant test will be the determination of rotor modulation and multipath effects of the helicopter main blade on receiver performance. This test is conducted with the helicopter in a tied down condition. The UH-1H is delevered with a tie-down eye installed on the main beam directly in line with the rotor mast. Preliminary investigations reveal that a single point tie-down can be accomplished with a reinforced concrete weight and turnbuckle arrangement. Helicopter torque effects are negated by rudder/tail rotor control as in flight. Details are included in the PI, Section 7.

A single antenna will be used at two locations during this test phase, approximately 4 feet from the mast and 19 feet from the mast respectively, thereby establishing systems performance at various rotor distance and blade speeds.

At both locations the balloon transmitter will be observed at three angles by raising and lowering the balloon from 1500 to 5000 feet. Also 2-3 helicopter rotor speeds will be evaluated for the rotor modulation effects on system performance.

Environmental tests (EMI, vibration, accoustics) will verify the equipment installation and provide qualitative data concerning the environment in which the equipment will function. These tests will be conducted with ground power and helicopter power. In addition, temperature sensors presently installed in the GFE 4 channel receiver will be retained.

The effects of other helicopter avionics on the System 621B equipment will also be evaluated for EMI compatibility.

The baseline system accuracy/survey demonstration will be conducted with the helicopter tied down at a known surveyed point (± 0.5 ft.). The results of this test will yield very accurate data concerning the static accuracy of System 621B. Further, comparison of this data with that of the MCS (at a known surveyed point with respect to the helicopter) will yield static accuracy comparison data between the one and four channel receiver (MCS receiver is four channel), and allow statistical inferences to be drawn concerning relative navigation. The MCS can be used as a user receiver, since in a relative navigation situation, the transmitter time biases will drop out of the equation.

System operational thresholds and accuracy will be evaluated by varying transmitter power and measuring field strength at the antenna.

The reduced data obtained from these tests will permit verification of the theory concerning the effect on accuracy of received power level and cycling time (dwell time at each code position). For the Option I receiver, the capability will be provided to reduce the code search range uncertainty during channel sequencing. This will provide data representative of the type of data obtained by ground based users. For the Option II receiver, due to the rapid cycling rate, the code search range uncertainty is always much less than 1 chip (100 ft).

6.3.2 ILS Test

The second major field test objective is to evaluate the potential of this system for landing guidance. The test configuration which has been selected (Figure 6-2) approximates one of the proposed operational system configurations. The objectives to be accomplished during this test are:

- Establish 621B systems accuracy with and without the presence of rotor modulation
- Establish the range and rate accuracy of the system during helicopter final landing approach
- Characterize the system performance at the instrument landing decision points for Categories I, II, and IIIA.
- Establish the system vertical velocity accuracy during landing
- Obtain landing guidance performance data on a "typical" helicopter installation using a "typical" operational system configuration.

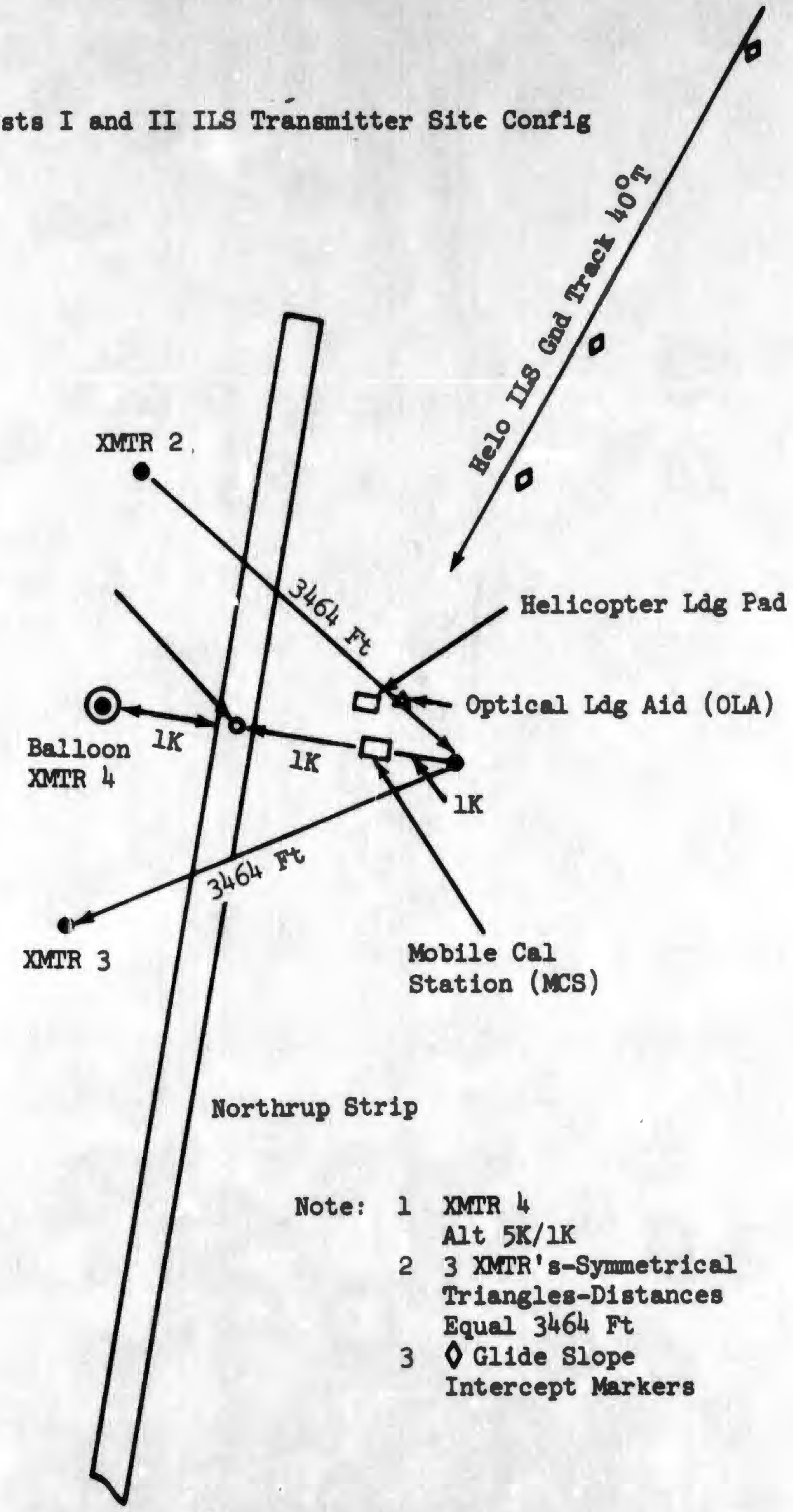
The ground transmitters will be located for this test in the same configuration as the tie-down tests. One transmitter will be mounted in a tethered balloon at approximately 5000 feet above the runway in order to simulate a satellite. This transmitter is located laterally at 1000 feet off the runway centerline.

In order to obtain data that does not contain rotor modulation effects, it will be necessary to lower the tethered balloon to 1000 feet altitude. This will enable the helicopter forward antenna installation to view the balloon transmitter signal at all ILS flight slope angles (2.5, 8, and 16 degrees) without rotor interference as shown in Figure 6-3. This provides the pilot with a pitch attitude safety margin of approximately 8° worst case.

The forward antenna installation and location of the landing pad provides azimuth look angles of 200° to all four transmitters as shown in Figure 3-1. All landing

Presently Planned NC-135 I.L.S XMTR Configuration

Tests I and II ILS Transmitter Site Config



Note: 1 XMTR 4
Alt 5K/1K
2 3 XMTR's-Symmetrical Triangles-Distances Equal 3464 Ft
3 ◊ Glide Slope Intercept Markers

Figure 6-2 Presently Planned NC-135 I.L.S. XMTR Configuration

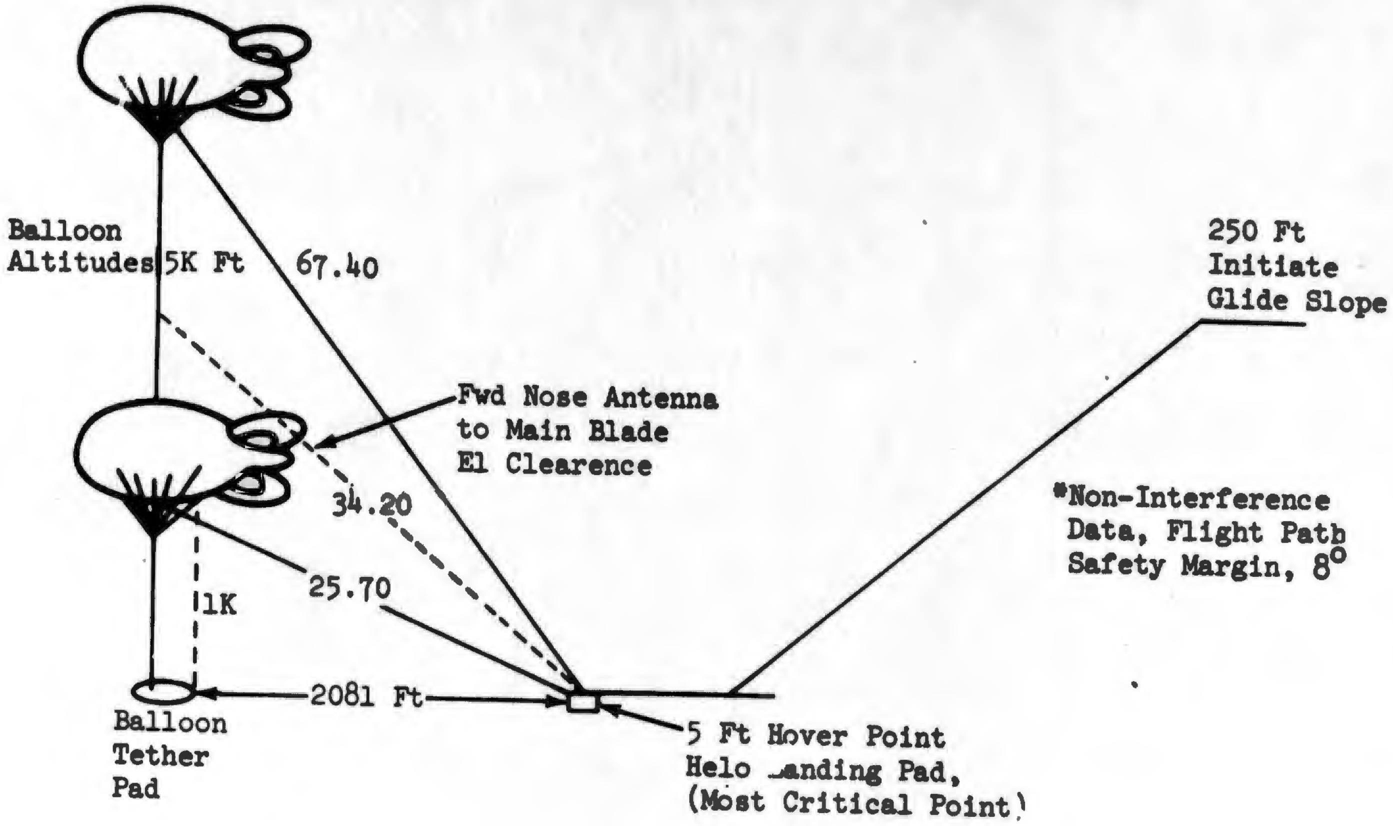


Figure 6-3 Balloon Altitude Relationship to Helicopter ILS Trajectory with and without Rotor Blade Interference

approaches will be terminated at the helicopter landing pad for end point data confirmation to a known point.

Table 6-2 defines flight path parameters associated with the simulated ILS demonstrations. Since, there are very few simulation constraints, the procedures are straight forward and will approximate a normal landing sequence. Balloon altitude above 5000 feet AGL will not be attempted, to minimize operational difficulties and to allow pay load weight to be reasonable. For one series of ILS tests the balloon will be lowered to 1000 feet.

In order to obtain consistent data, a landing aid is planned for the pilot to keep approach variations minimized. The optical landing aid mirror device or Fresnel array, retained from the NC 135 test program is interesting due to its simplicity and reliability (see Figures 6-4 and 6-5). This devices provides the pilot with elevation cues by projecting a light beam up the glide slope. The pilot sees a spot, called the meatball, in reference to a datum line created by a row of green lights. When the meatball is lined up vertically with the datum, the aircraft is on glide slope (see Figure 6-6). The glide slope angle can be adjusted from 2° to 7°. The meatball is visible in daylight about 1 n.mi. away. Pilot accuracy in maintaining glide slope with this device is about 0.25°.

In order to obtain greater adjustment of the OLA a tiltable platform/incline ramp will be constructed to achieve angles to 20°. This should provide a relatively cost conservative approach and still be sufficient to satisfy the ILS tests. It should be noted that this system will be used for the NC-135 tests and will therefore be readily available for the Army ILS tests.

Table 6-2 Test II - Simulated ILS Profiles (Northrop Strip Area)

X 2.5° Glide slope - Data comparison to NC 135 data

Characteristics	Unit	Acq.	Data/Start	Hover	Data End
Altitude	Feet-AGL	250	200	5	0
Velocity	Feet/sec.	87	87	48	0
Range *(Intercept pt.)	Feet	-7265	-5165	750	0
Rate of Descent	Feet/sec	4	4	0	0
Time from ACQ	Seconds	0	15	70	80
XX 8° Glide slope - Normal helicopter landing					
Altitude	Feet-AGL	250	200	5	0
Velocity	Feet/sec	83	83	43	0
Range *(Intercept pt)	Feet	-2400	-2000	-700	0
Rate of Descent	Feet/sec	10	10	0	0
Time from ACQ	Seconds	0	4	23	32
XXX 16° Glide slope - Steep helicopter/relative navigation simulation					
Altitude	Feet-AGL	250	250	5	0
Velocity	Feet/sec	92	82	39	0
Range *(Intercept pt)	Feet	-1575	-1378	-675	0
Rate of Descent	Feet/sec	26	23 - 12	0	0
Time from ACQ	Seconds	0	2	13	22

* All ranges to helo landing pad

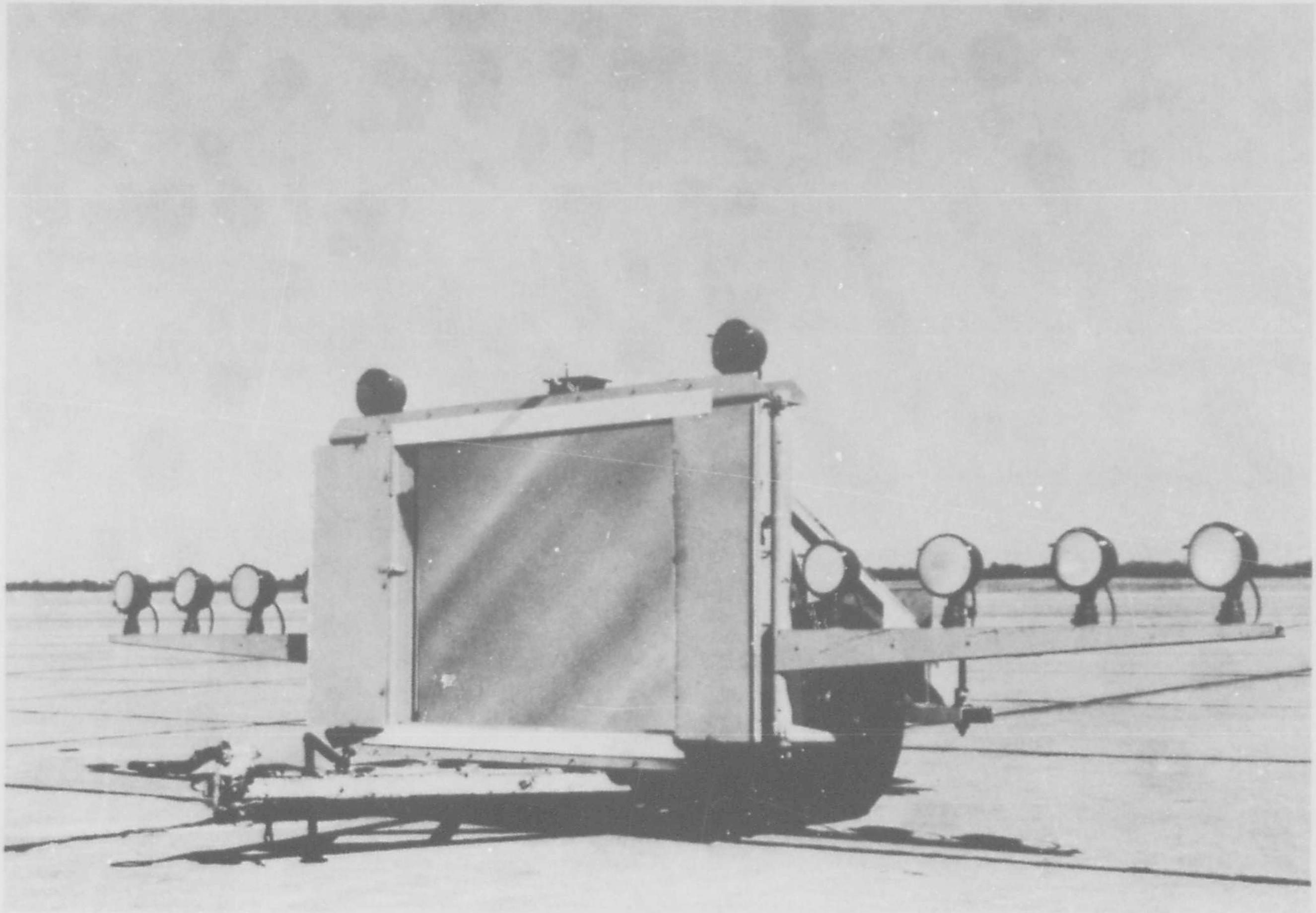


Figure 6-4 Optical Landing Mirror

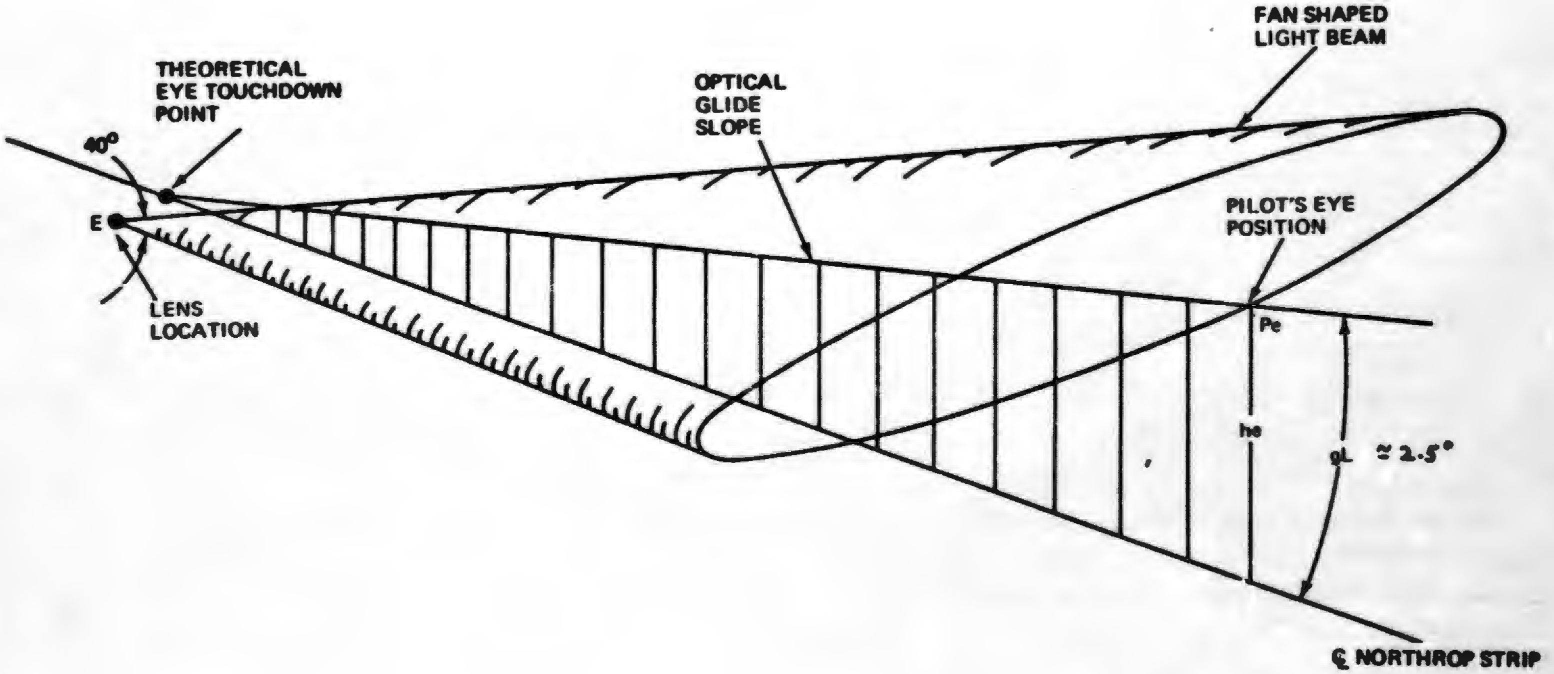


Figure 6-5. [illegible] View of Light Beam

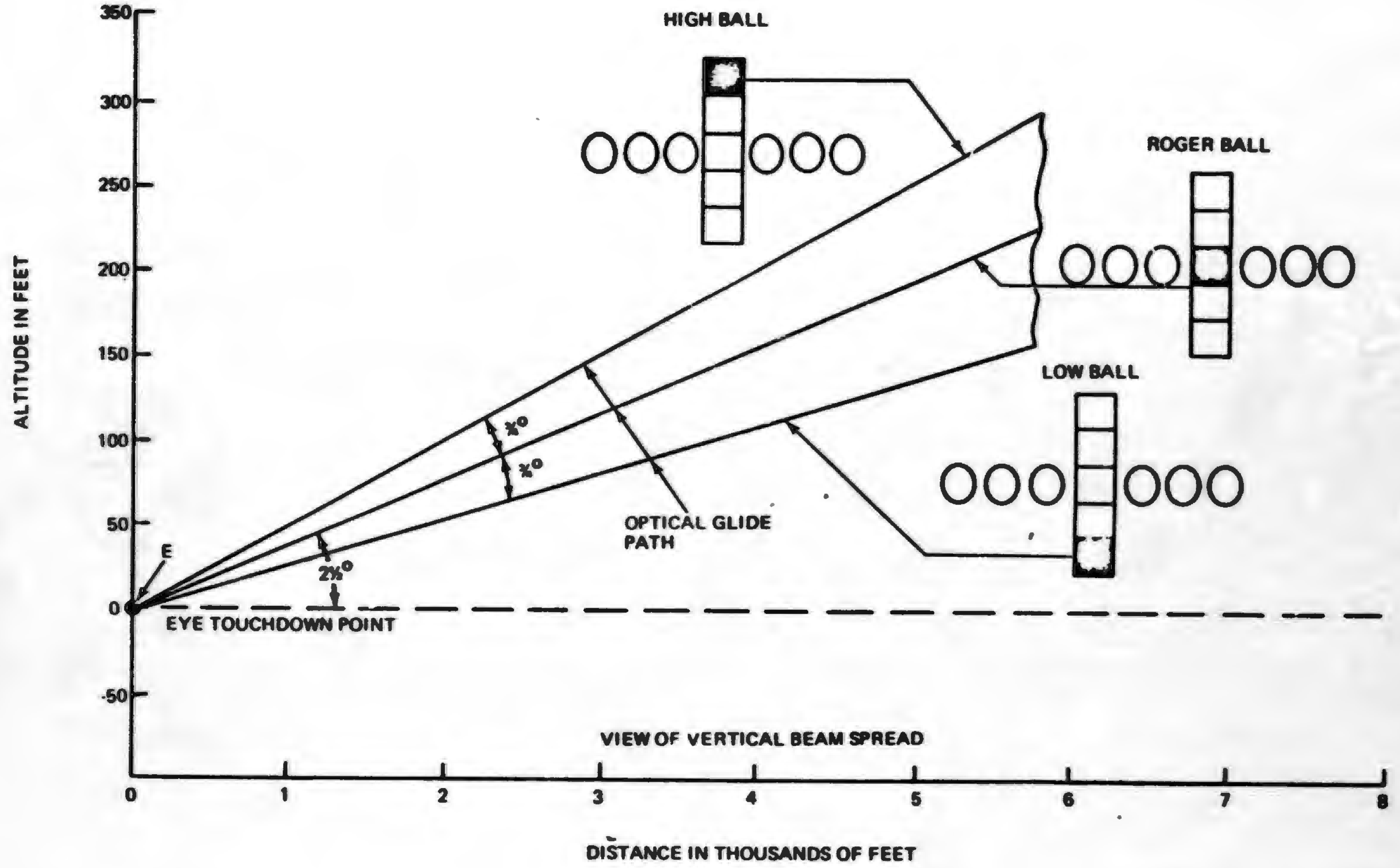


Figure 6-6 Pilot's Glide Slope Display

6.3.3 Area Navigation Tests

The third or final field test objective is to establish system navigation performance. The objectives to be accomplished during this phase are:

- Determine the 621B single channel navigation system performance in a simulated satellite environment.
- Determine the effects of normal helicopter maneuvers on navigation system performance.
- Demonstrate receiver thresholds and sequencing time effects on system performance at lower transmitted signal strengths.

The recommended transmitter configuration for the area navigation test is depicted in Figure 6-7.

The rationale for the selection of this configuration is detailed in Section 5.3.

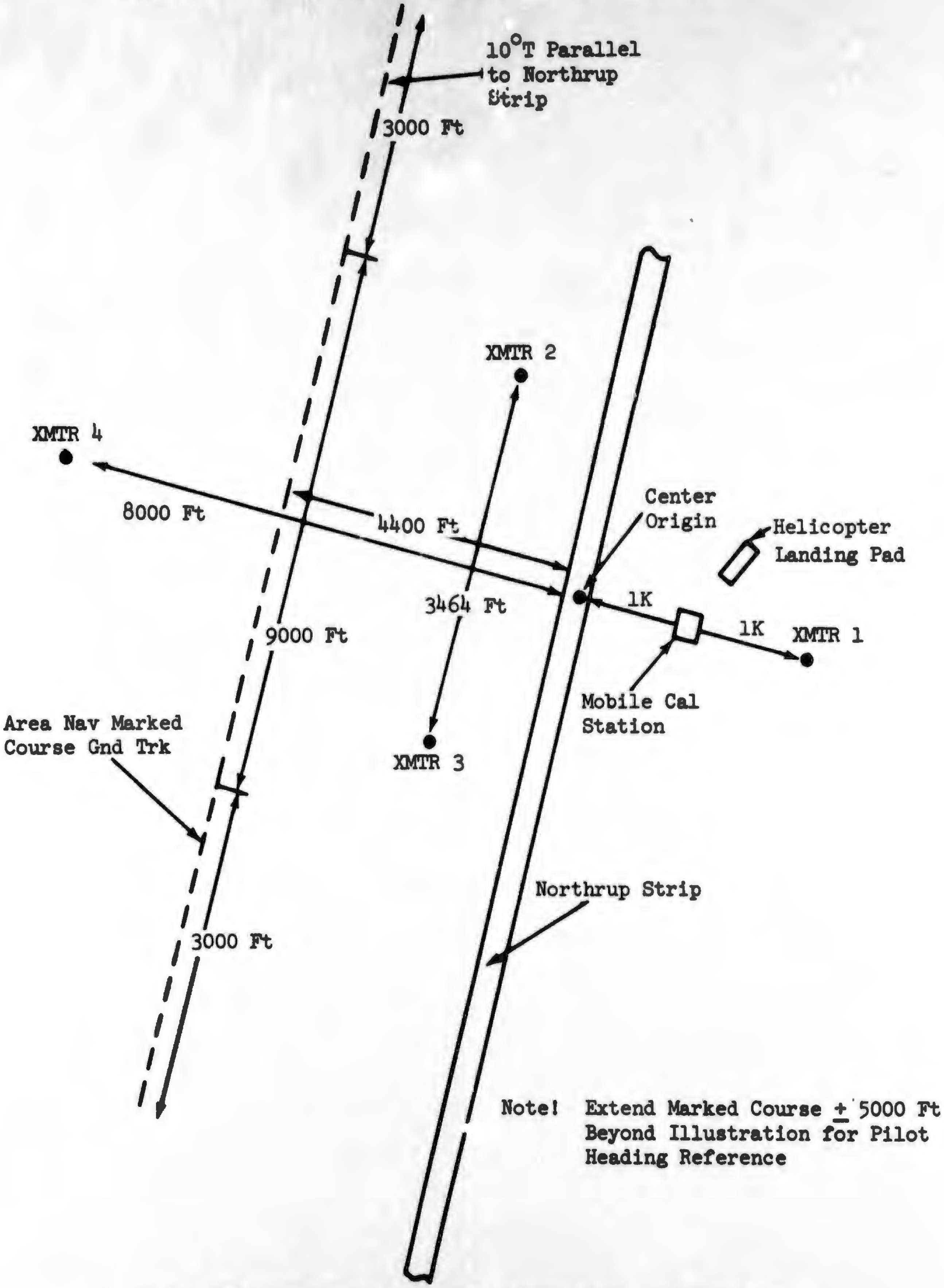
The helicopter flight profile of area navigation tests based on simulated operational constraints and vehicle performance dictates 4,000 feet as the best selection of altitude, thereby providing ranges of approximately 9,000 feet of (sufficient GDOP) ground track for data analysis (Figure 6-8). Due to the low level flight, radar vectoring may not be feasible to maintain the data flight corridor. A very simple alternate method of a marked ground track course is contemplated which will enable the helicopter pilot to maintain a flight corridor of ± 200 feet. The range tracking and data coverage support at WSMR to conduct ILS and area navigation test flights will require the use of multiple cinetheodolities and fixed cameras.

6.3.4 Flight Test Operations

Flight test operations center around flight planning, preflight and postflight equipment checkouts, crew briefing test range coordination, and actual flights. See Figure 6-9.

Elongated Diamond Transmitter Configuration

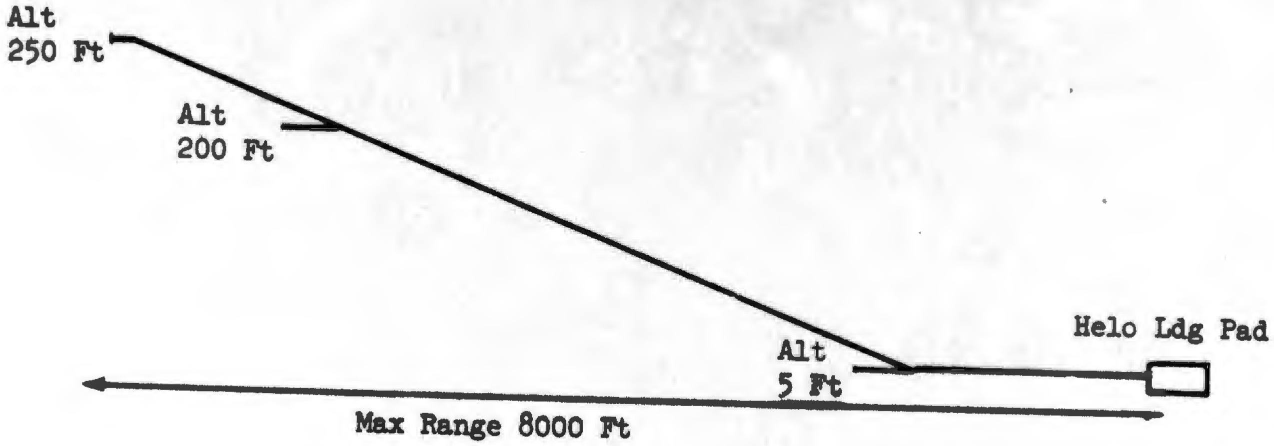
Test III Area Nav Demo Transmitter Site Configuration



Note! Extend Marked Course ± 5000 Ft Beyond Illustration for Pilot Heading Reference

Figure 6-7 Elongated Diamond Transmitter Configuration

1. ILS



2. Area Navigation

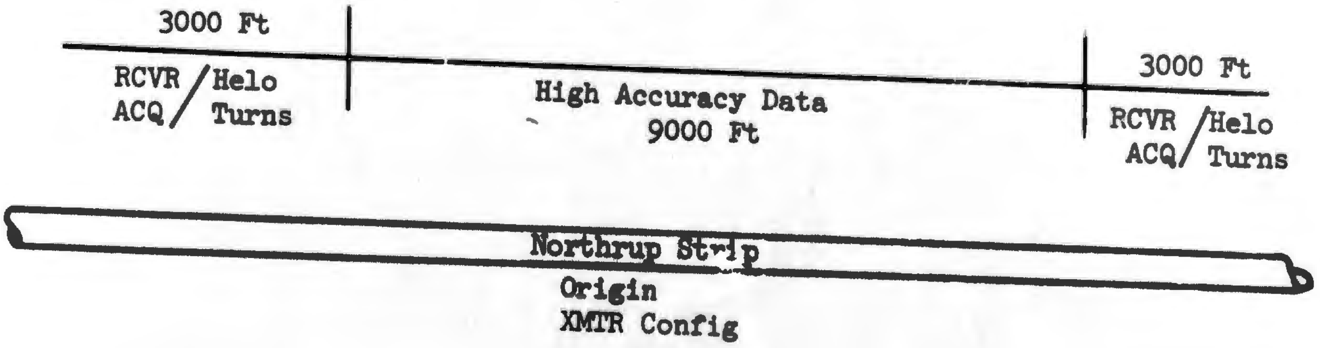


Figure 6-8 Typical Data Coverage

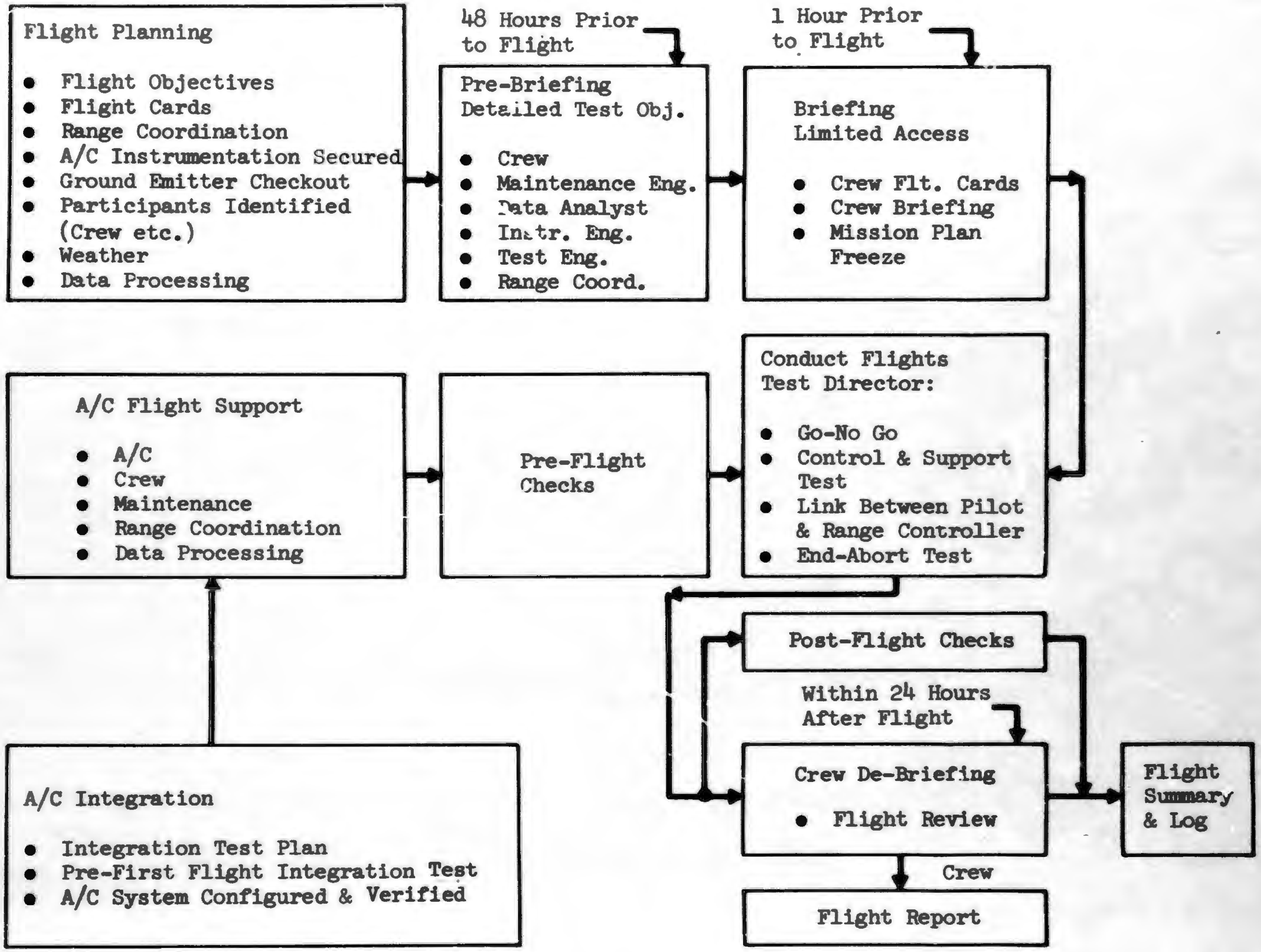


Figure 6-9 Flight Test Operations

Flight planning is conducted on a level sufficient to establish test configuration control that will satisfy the established flight objectives while considering helicopter performance characteristics, data recording system constraints, weather constraints, avionic equipment characteristics and performance limits, optimum sequence of tests which act as constraints on other tests, achievable test program progress indicators, and supporting requirements.

Preflight and postflight checkouts insure the integrity of, the vehicle, equipment to be tested, and instrumentation systems, before flight and the status of these equipments after flight. Grumman will insure the integrity of all Contractor furnished equipment by conducting the above preflight and postflight checkouts. During helicopter integrity tests, Grumman will interface with the United States Army test team to maintain complete integration of all CFE and GFE.

Crew-briefing is usually done in two phases:

(1) A "pre-briefing" is conducted after the objectives from the master flight test schedule for the coming flight have been modified as a result of previous flight results accomplishment, changes in instrumentation or equipment configuration, but not later than approximately 6 hours before scheduled take-off time. All test team personnel are involved: A/C maintenance, analysts, flight crew, instrumentation personnel, equipment engineers, and range coordinators. The test objectives and technical considerations are discussed in detail, compatibility with existing status in everyone's area of responsibility is determined, and objectives or test procedures are modified as required.

(2) A flight "briefing" is begun one hour before scheduled flight crew aircraft walk around inspection. The briefing which presents the flight plan on crew flight cards, is conducted formally describing objectives, run content, special test considerations, aircraft configuration, helicopter weight and balance data, weather and wind aloft, mission abort criteria, flight safety considerations, communications frequencies and identifications. Attendance is limited on a need-to-know basis and changes in the mission plan are generally not allowed.

7. PROGRAM INTRODUCTION

This section contains the planning Program Introduction (PI) based on the field test designed in the previous section. It has been written to stand alone and can be submitted to relevant agencies as a separate and complete document.

REVISION NO ______________

REVISION DATE ______________

CLASSIFICATION

UNCLASSIFIED

PROGRAM INTRODUCTION	1. PI DATE	2. PI NO.

CATEGORY 1 (1000-1999) PROGRAM INFORMATION, ADMINISTRATIVE & TECHNICAL

3. PROGRAM TITLE 621B Single Chan. User Equip. Test & Demo	4. SHORT TITLE 621B Single Chan. Field Tests

RESPONSIBLE AGENCIES & KEY PERSONNEL LAUNCH VEHICLE UH-1H PAYLOAD User Rcvr.

DEVELOPMENT AGENCY Samso, Los Angeles, Calif. *

USER PROJECT OFFICER Major F. Carnes, 6585th Test Group, H.A.F.B., N. M.

CONTRACTOR Grumman Aerospace Corp/Hazeltine Corp.

CONTRACTOR REP R. Laho, Grumman Aerospace Corp.

LEAD SUPPORT AGENCY W.S.M.R., N. Mexico

SUPPORT AGENCY REP S. V. Jennings, 678-1864/3303

SUPPORT RANGE(S) W.S.M.R., N. M.

IDENTIFICATION INFORMATION

BEGINNING DATE	1 April 1972	DOD ELEMENT NO.	
FIRST TEST DATE	15 May 1972	MUL PRECEDENCE	
COMPLETION DATE	15 July 1972	PRIORITY NO.	
PGM/PROJ NO.	System 621B	PROGRAM STATUS	
CONTRACT NO.	F04201-71-C-0176		

THE SERVICES REQUESTED HEREIN ARE REQUIRED FOR CONDUCT OF THE TEST PROGRAM AND ARE NOT WITHIN ANY CURRENTLY APPROVED CONTRACTUAL SCOPE OF WORK EXCEPT AS FOLLOWS:

* Sponsored by U.S. Army SATCOM, Ft. Mommouth, New Jersey

SIGNATURE ______________	SIGNATURE ______________
NAME AND TITLE	NAME AND TITLE
AGENCY	AGENCY

SUPPORT AGENCY RECEIPT

SIGNATURE ______________	SIGNATURE ______________
NAME AND TITLE	NAME AND TITLE
AGENCY	AGENCY
DATE ______________	DATE ______________

UDS FORM 1
JULY 70

CLASSIFICATION

UNCLASSIFIED

PI PAGE 1

REVISION NO ______

REVISION DATE ______

CLASSIFICATION
UNCLASSIFIED

PI NO ______

PI DATE ______

1000-1099

SYSTEM BACKGROUND INFORMATION

System 621B is a Satellite Navigation System using continuously transmitting Earth Synchronous Satellites,permitting passive non-radiating users to calculate 3 axis coordinate position and velocity information. Initial deployment will be a constellation of 4 or 5 satellites in the Western Hemisphere. Three constellations will provide near worldwide coverage. Further information is containedin the following documents: (1)Development Plan,System 621B,Defense Navigation Satellite system, 1 Aug.1970,A.F. Space and Missile Systems Organization, Los Angeles, California,(SECRET)

(2)Concept Formulation Package/Technical Development Plan (CFP/TDP) for System 621B,Satellite System for Precise Navigation,SMA00-69-200-2, A.F.Space & Missile Syst.Organization,Los Angeles,Calif. Nov.1969(SECRET)(cont'd.on pg. 2.1)

SYSTEM DEVELOPMENT MILESTONES

DEVELOPMENT PHASE	FY 71		FY 72		FY		FY		FY		FY	
	1	2	1	2	1	2	1	2	1	2	1	2
Award Contracts			X									
Field Tests				X								

1100-1200

PROGRAM & MISSION INFORMATION

This test program will consist of experiments and demonstrations to determine the accuracy of the System 621B single channel User Equipment. The flight program, to be conducted at HAFB/WSMR, will be divided into three phases,(TestI)Gnd. Tiedown Tests(Test II) simulated ILS final approaches at Northrop Strip Area. (Test III) area navigation system demonstration. The receiver output will be recorded on board the aircraft and the derived position and velocity vectors will be determined post flight by the contractor. These data will be referenced to time-correlated aircraft trajectory/Geodetic Survey data provided by the WSMR computation center. The test envelope and data requirements for Test I,Test II and Test III will be discussed on Page 4,para.1700 & 2100. The transmitter site requirements

(cont'd. on page 2.1)

ACTIVITY PLAN	FY 71				FY 72				FY 73			
	1	2	3	4	1	2	3	4	1	2	3	4
Install Equip.HAFB/WSMR							↔					
Conduct Test								←	→			
VEHICLE LAUNCHES												
OTHER TESTS												
RECOVERY OPERATIONS												

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SYSTEM BACKGROUND INFORMATION (cont'd.from pg.2 - para. 1000 - 1099)

(3) DNSS Applications to Army Position Fixing Navigation & Survey Requirements. Report No.UF-2986-B-1 Cornell Aeronautical Laboratory, Buffalo, New York - February 1971 (SECRET)

PROGRAM & MISSION INFORMATION (cont'd. from pg.2 - para. 1100 - 1200)

are discussed and sketches are provided in para.5600, pgs. 8.3, 8.5 and 8.6

Test I -- Will be conducted with 621B single channel receiver and airborne recording equipment installed in a UH-1H helicopter. Helicopter will be located at a first order ground survey point in a tied down configuration. System will be evaluated for rotor modulation/multipath,EMI & vibration effects. Concurrently,baseline system accuracy data will be obtained during the above tests. Definition of receiver sensitivity & sequencing time as a function of signal power level will also be tested.

Ground site configuration will consist of three ground transmitters, the fourth carried by the tethered balloon and a mobile calibration station.(Ground configuration the same as NC135 I.L.S.Test).

The 621B recorded output data will be referenced to WSMR first order Geodetic Survey data and balloon position tracking data. Additional support requirements will be detailed on Page 8.1 & 8.2. Approximately 10 working days are planned for test completion.

Test II -- I.L.S./Relative Navigation

Test II -- will employ 621B equipment in a Terminal Area - Simulated ILS Navigation Test. Three ground transmitters and a mobile calibration station will be located near the center of Northrop Strip,and a fourth transmitter will be carried by a tethered balloon. Dynamic characteristics of the balloon will require that an accurate time history reference of the balloon's position be provided by the WSMR computation center for each simulated ILS approach. The receiver output recorded onboard the helicopter will be referenced to WSMR trajectory data. The Helicopter landing pad configured (see pg.8.5)for Test I will be the I.L.S.Termination Point.

I.L.S. landings will be conducted without and in the presence of rotor modulation. Effects on systems accuracy will be demonstrated by comparison. Recording of data at the M.C.S. Ground based 621B receiver(at a known location with respect to the helicopter landing pad) will indicate very accurately the relative navigation capabilities of System 621B. Concurrent with above tests multipath evaluations will be conducted. Two balloon altitudes approx. 1K and 5K will be required for the above tests.

Test III -- Area Navigation

Test III-- will employ four ground transmitters positioned in an elongated diamond configuration as shown in page 8.6 and a mobile calibration station (MCS)

(cont'd. on pg. 2.2)

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Test III (cont'd. from Page 2 - Paragraph 1100 - 1200)

located at High Accuracy survey points and a 621B test receiver installed in a UH-1H helicopter to determine area navigation accuracy. For this test the balloon transmitter and antenna will be removed from the balloon and located at the -8000ft. ground location. Systems accuracy as a function of signal power level will be evaluated for comparison to NC135 data.

GROUND TRANSMITTER CHECKOUT

Checkout of the ground based transmitters will be required, prior to each scheduled flight (approximately two hours prior to range time)and transmitter checkout not directly related to schedule will be required approximately once for each two scheduled flights. Frequency clearance will be required for these tests (see section 1400 - 1500 for frequency of transmitters) but no frequency protection will be required.

RANGE COMMANDERS

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1300

VEHICLE AND PAYLOAD INFORMATION

LENGTH	42 ft.(Rotor turning) 57 ft.	MAX ACCEL	.5G (steady state)
DIAMETER	(swept circle) Rotor 48' 3"	CPE	
WIDTH	9 ft.	SPIN RATE	
PROPUL SYS	T53-L-13	WT DRY	6500 lbs.
GUID SYS	Pilot	WT LAUNCH	T/O G.W. 7800 lbs.
LAUNCHER TYPE	UH-1H Helicopter	BO TIME	

OTHER TEST OBJECT CHARACTERISTICS

Test III Area Nav. Systems Accuracy Demo. (Typical flt. profiles)

CHARACTERISTIC	UNIT	(L) ACQ.	DATA	REF.	TIME CORRELATED PERFORMANCE DATA					End	(1)
ALTITUDE	ft/AGL	4K	4K	4K						4K	
VELOCITY	ft/sec	100-170	100-170	100-170						100-170	
RANGE	Naut.Mi.	-2	-1	0						+1	
ACCELERATION	Steady St										
TIME FROM LAUNCH	Seconds	0	35-60	70-120						105-180	

PAYLOAD DESCRIPTION

*ACQUISITION -- Indicates test receiver signal lock on, no trajectory data required at this point.

*DATA -- Indicates start of WSMR trajectory data.

*REFERENCE-- Point of Maximum interest. (Ref. PI page 8.4)

*END -- Indicates end of WSMR trajectory data for this run. Typically, 10 runs/flight.

TEST II ILS (cont'd. on pg. 3.1)

1400 1500

VEHICLE INSTRUMENTATION/GROUND SUPPORT INSTRUMENTATION/EQUIPMENT

A. GROUND SUPPORT EQUIPMENT

1. Test I. (Stationary tie-down tests) Three ground 621B transmitters & one tentatively located as shown on pg.8.5, balloon borne transmitter at 5000', will be operated approximately 2 hrs. before & during scheduled tests & at other times for checkout. They will have the following characteristics:

   Carrier Frequency - 1575 MHz
   Bandwidth - 20 MHz
   Power - 3 Watts

   A Mobile Calibration Station (MCS), located 1000' from transmitter center at Northrop Strip will be operated & manned before & during flight tests & for checkout.

(cont'd. on pg. 3.1)

1300 - Vehicle and Payload Information (cont'd. from pg. 3)

Test II - Simulated I.L.S. Profiles (Northrup Strip Area)

X 2.5° Glide slope - Data comparison to NC 135 data.

CHARACTERISTICS	UNIT	ACQ.	DATA/START	HOVER	DATA END
Altitide	Feet-AGL	250	200	5	0
Velocity	Feet/Sec	87	87	48	0
Range *(Intercept pt.)	Feet	-7265	-5165	750	0
Rate of Descent	Feet/Sec	4	4	0	0
Time from ACQ.	Seconds	0	15	70	80

XX 8° Glide slope - Normal helicopter landing

Altitude	Feet-AGL	250	200	5	0
Velocity	Feet/sec	83	83	43	0
Range*(Intercept pt)	Feet	[illegible]	[illegible]	-700	0
Rate of Descent	Feet/Sec	10	10	0	0
Time from ACQ.	Seconds	0	4	23	32

XXX 16° Glide slope - Steep helicopter/relative Nav. simulation

Altitude	Feet/AGL	250	200	5	0
Velocity	Feet/Sec	92	82	39	0
Range*(Intercept pt)	Feet	[illegible]	[illegible]	-675	0
Rate of Descent	Feet/Sec	26	-12	0	0
Time from ACQ.	Seconds	0	2	13	22

* ALL RANGES TO HELO. LANDING PAD

1400-1500 GROUND SUPPORT EQUIPMENT (cont'd. from pg. 3)

2. Test II - Three ground 621B transmitters and one balloon borne 621B transmitter, tentative locations as shown on page 8.5 will be operated in the same manner and with the same characteristics stated in paragraph 1. The MCS will also be operated for Test II. One tethered balloon at approximately 5,000/1,000 ft.AGL, 1,000 ft. off Northrup Strip Centerline will be used for Test II. A standard Cambridge Research Laboratories radio control unit will be employed. Test-bed helicopter flights are required during Test II. A mobile radio control vehicle (UHF ground to air) will be employed during Test II.

(Test III next page).

1400-1500 GROUND SUPPORT EQUIPMENT (cont'd. from pg.3.1)

3. Test III - The configuration is the same as Test I and II except one 621B transmitter will be relocated at -8K' from origin (center Northrop Strip) in an elongated diamond configuration. The MCS will be required. Approximately 3 to 4 area navigation flights are anticipated. Transmitters and high gain antenna's will be mounted on trailers moved from the NC-135 Salt Site Configuration by the contractor.

B. WSMR EQUIPMENT

A mobile radio control vehicle is required at Northrop Strip in addition to site instrumentation for helicopter trajectory.

C. BALLOON EQUIPMENT

The balloon command/destruct transmitter furnished by AFCRL will be used in conjunction with the balloon. This transmitter is designated Aerocom Model 1046 and operates between 2 and 20 MHz. The balloon is required for test I and II, it is not required for test III.

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1600

SYSTEM READINESS PROCEDURES/TESTS

A. Prior to commencement of field test milestones, the following site readiness activities are planned:

1. Site Survey
2. Helicopter Ground Track, Marked Course
3. Helicopter Landing Pad.

B. Prior to each flight normal preflight tests will verify equipment operation in the following test areas:

(cont'd. on pg. 4.1)

1700

TEST ENVELOPE INFORMATION

Ft AGL

TRAJECT	RANGE	ALT	QE	AZIMUTH	MAX PERF	TEST DIST	REMARKS
MAX	± 3NM	5K			100 KTS		Area Nav. Test envelope
TYPICAL	± 2NM	4K			60-80KTS		for cine.data cov.see pg.8.4
MIN	± 2NM	500-0			60 KTS	(Entry Speed)	Typical I.L.S.envelope

1800

TEST PROGRAM OPERATIONAL HAZARDS

Test

a. Eng. Test Personnel conducting test with the helicopter running in the tie-down configuration. Safeguard against operational hazards such as electrical hot airframe, acoustical noise, sand blasting, etc.

b. Helicopter I.L.S. and landing flight profiles should be inbound at 220° T to eliminate overflight of test site configuration, and maintain 621B forward antenna coverage of site configuration.

c. Helicopter rotor wind effects on O.L.A.(optical landing aid) and M.C.S.(Mobile Calibration Station) which are approx. 500' from the helicopter landing pad.

CATEGORY 2 & 3 (2000-3999) TEST/MISSION OPERATIONAL REQUIREMENTS

2100

METRIC MEASUREMENT AND DATA REQUIREMENTS

TRAJECTORY SEGMENT/TEST PHASE	POS	VEL	ACCEL	PITCH	YAW	ROLL		
UNIT	FT	FPS					FT	FPS
TEST II I.L.S./CROSS TRK	4-6	1.0					50	50
ALONG TRK	4-6	1.0					50	50
VERTICAL	4-6	1.0					50	50
TEST III AREA NAVIGATION								
HORIZONTAL	4-6	1.0					50	50
VERTICAL	4-6	1.0					50	50
BALLOON TRANSMITTER TRK								
HORIZONTAL	1-2	1.0					50	50
VERTICAL	1-2	1.0					50	50

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1600 SYSTEM READINESS PROCEDURES/TEST (cont'd. from pg.4)

1. Test Bed Avionics
2. MCS Van
3. GND Transmitters
4. WSMR Instrumentation

C. EQUIPMENT INSTALLATION AND INTEGRATION PLANS

1. Receiver modifications will be accomplished at the contractors facility.
2. Helicopter modifications and installation to be accomplished at Holloman A.F.B.
3. Electronic integration test to be conducted at Holloman A.F.B/W.S.M.R. Northrop Strip, M.C.S. (Mobile Calibration Station)
4. Office and Lab. space presently available (at Holloman A.F.B.) for NC-135 tests to be retained for the duration of the Army schedule presented below.

ARMY PROGRAM PLAN AND SCHEDULE
MONTHS AFTER AUTHORITY TO PROCEED

	M5	A6	M7	J8	J9	A10	S11
1. Receiver Modifications	▲ START MODS						
2. Field Installations		▲ START HELO. INSTALLATIONS					
3. Field Integration Tests			▲ ALL EQUIP.AVAILABLE AT HOLLOMAN GENERATE DATA PROCESSING TEST TAPE				
4. Field Demo Tests				▲ START FIELD TESTS			
5. Data Analysis				▲ START DATA ANALYSIS			
6. Site Dismanteling					▲ START TEARDOWN		
7. Reports - Field Report						▲ REPORT COMP.	
8. GAC Final Report							▲ REPORT COMP.

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REQUIREMENT	X	REMARKS	NOTE
2100 (CONT) TIME CORRELATED PHOTOGRAPHY			
2200 TELEMETRY			
2300 COMMAND/CONTROL DESTRUCT			
2400 AIR-GROUND COMMUNICATIONS	X	One UHF ground to air frequency is required for helicopter to ground test personnel. Back-up U.H.F. channel desired.	
2500-2600 COMPOSITE & OTHER SYSTEMS			
2700 GROUND COMMUNICATIONS	X	Test intercommunications among project rep, Mobile Calibration Station and - see pg. 5.1.	
2800 OTHER COMMUNICATIONS TIMING	X	WSMR supplied IRIG B time will be available at the MCS sites. WSMR will supply timing to trajectory tracking devices. See pg. 5.1	
TELEVISION			
3000 REAL TIME DISPLAY & CONTROL	X	Plotting board records are required for test III. For radar quick look trajectory.	
3100 DOCUMENTARY PHOTOGRAPHY	X	Color still photos and collor 16 mm movies of installed program equipment will be requested. Photos of ground & balloon borne-see pg. 5.1.	
3200 METEOROLOGICAL	X	Support required for tethered balloon operation during Tests I & II. Rawinsonde data at 100ft.intervals(Pressure,Temperature & Humidity) see pg. 5.1	
3300 RECOVERY			
3400 OTHER TECHNICAL SUPPORT FREQUENCY CONTROL	X	Reference para. 1400-1500 pg. 3 of PI for frequencies planned to be utilized in test. Frequency protection in band occupied-see pg. 5.1.	
RANGE SHIPS & AIRCRAFT			
TARGETS			
MISCELLANEOUS	X	Transmitters, Helicopter Landing pad, & MSC sites will be surveyed with such accuracy that positioned uncertainty of the sites with respect to each other and high-see pg. 5.1.	

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2700 (CONT)	ground transmitter sites is requested. A range telephone at the mobile calibration station (MCS), is required. Project intercom will be adequate for MCS and transmitter sites.
2800 (CONT)	WSMR will provide mobile IRIG timing sync to the testbed aircraft at Bldg 868, Holloman AFB, before and after each flight. Timing tolerance (± 1 Millisecond). IRIG B time from on board generator will be recorded on magnetic tape.
3100 (CONT)	transmitters will be required along with samples of film data from cinetheodolite cameras and other instrumentation cameras.
3200 (CONT)	up to 5 K ft. AGL is required in the transmitter test area within one hour of the midpoint of the flight.
3400 (CONT)	by 621B transmitters is required during tests.
MISCELLANEOUS (CONT)	Accuracy tracking devices used for A/C trajectory determination should be less than one-half foot. A frequency standard (Rubidium or Cesium) will be needed full time for the duration of the testing to calibrate the fundamental oscillator at each transmitter site.

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CATEGORY 4 (4000-4999) POST FLIGHT DATA PROCESSING & DISPOSITION

4000-4100 COORDINATE SYSTEMS DESCRIPTION/DATA PROCESSING FLIGHT EVALUATION

Test I Requirements

Data Category:

1. Provide quick look balloon borne transmitter position data in the White Sands Cartesian Co-ordinate System.
2. Provide BET balloon trajectory (position and velocity) in the White Sands Cartesian Co-ordinate System.
3. All data other than tabular listings will be in digital form on mag tape and will be delivered to Lt. James Bybee 6585th Test Group
Holloman AFB, New Mexico 88330

NOTE: Data categories below refer to the paragraph above. For example, the quick look trajectory data requested in Paragraph 1 is required in 2 working days.

UNIVERSAL DOCUMENTATION SYSTEM

4200 DATA DELIVERY AND DISPOSITION REQUIREMENTS

DATA CATEGORY	1	2	3			
QUICK LOOK	2 wd	5 wd	8 wd			
PRELIMINARY						
FINAL						

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CATEGORY 4 (4000-4999) POST FLIGHT DATA PROCESSING & DISPOSITION

4000-4100 COORDINATE SYSTEMS DESCRIPTION/DATA PROCESSING FLIGHT EVALUATION

Test II Requirements

1. Provide quick look balloon borne transmitter position data in the White Sands Cartesian Coordinate System.
2. Provide calibrated aircraft ground tracking sensor data.
3. Provide BET balloon trajectory (Position and Velocity) in the White Sands Cartesian System (WSCS).
4. Provide N station optically derived aircraft trajectory in the WSCS.
5. Provide accurate aircraft reference trajectories in the WSCS. These trajectories shall be referenced to the nose 621B helicopter antenna. The metric measurement requirements indicated in block 2100 refer to the quality of the smoothed Best Estimate Trajectory (BET).
6. All data other than the tabular listings are to be in digital form on magnetic tape and will be delivered to Lt. James E. Bybee, 6585th Test Group (GDAF), Holloman AFB, New Mexico 88330.

NOTE: Data categories below refer to the paragraph numbers above. For example, the quick look trajectory data requested in Paragraph 1 is required in 2 working days.

4200 DATA DELIVERY AND DISPOSITION REQUIREMENTS

DATA CATEGORY	1	2	3	4	5	6
QUICK LOOK	2 wd	5 wd	10 wd	15 wd	20 wd	23 wd
PRELIMINARY						
FINAL						

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CATEGORY 4 (4000-4999) POST FLIGHT DATA PROCESSING & DISPOSITION

4000-4100 COORDINATE SYSTEMS DESCRIPTION/DATA PROCESSING FLIGHT EVALUATION

Test III Requirements

Data Category:

1. Quick look trajectory data is required for Test III system demonstration. Digital tape accompanied by a tabulated listing, containing unsmoothed radar A/C latitude, longitude and altitude as a function of time within 18 hours after the flight is acceptable. Assume cinetheodolite tracking is utilized, a digital tape, accompanied by a tabulated listing, containing A/C latitude, longitude and altitude as a function of time from frames of data at 10 second intervals on data runs specified by the user is acceptable.

2. Provide calibrated ground tracking sensor data and the individual calibration values used for each sensor employed.

3. Provide an N station optically derived aircraft trajectory in the WSCS.

4. Provide accurate aircraft reference trajectories in the WSCS. These trajectories shall be referenced to the lower 621B helicopter antenna. The metric measurement requirements indicated in block 2100 refer to the quality of the smoothed Best Estimate Trajectory (BET).

5. All data other than the tabular listings are to be in digital form on magnetic tape and will be delivered to Lt. James E. Bybee, 6585th Test Group (GDAF), Holloman AFB, NM 88330.

Note: Data categories below refer to the paragraph numbers above. For example, the quick look trajectory data requested in Paragraph 1 is required in two working days.

4200

DATA DELIVERY AND DISPOSITION REQUIREMENTS

DATA CATEGORY	1	2	3	4	5	
QUICK LOOK	2 wd	5 wd	15 wd	20 wd	23 wd	
PRELIMINARY						
FINAL						

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CATEGORY 5 (5000-5999) BASE FACILITIES/LOGISTIC REQUIREMENTS

5100 PERSONNEL ASSIGNMENT SCHEDULES	FY 71				FY 72				FY			
	1	2	3	4	1	2	3	4	1	2	3	4
Contractor												
At Holloman A.F.B.												
Temporary on site							5					
Permanent on site							7	7				
At WSMR												
Temp							1	1				

REQUIREMENT	X	REMARKS	NOTE
5200 TRANSPORTATION	x	Provide transportation for transmitter antennas from NC-135 salt site location to Northrop Strip where they will be installed by the contractor prior to area navigation tests.	
5300 SERVICES SECURITY	x	Clearance and entry to Holloman, Kirtland A.F.B. and Northrop Strip area for approximately 20 personnel for duration of project.	
FIRE PROTECTION		If required by Army Operations for helicopter run-ups at Northrop Strip.	
UTILITIES			
WAREHOUSING & STORAGE			
PROPELLANTS			
FUELS & LUBRICANTS		Fuel for WSMR furnished motor generator sets.	
OTHER		One IRIG "B" Reader capable of converting the modulated 1KHZ signal to parallel BCD will be required for the M.C.S.	
5400 LABORATORY			

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5500 **MAINTENANCE SUPPORT**

5600 **FACILITIES GENERAL**	FY 71		FY 72		FY		FY	
	1	2	1	2	1	2	1	2
Provide helicopter landing pad			↔					

FACILITIES, LAUNCH

1. WSMR will estimate FY 72 funds required for reimbursable facility items.

CATEGORY 6 (6000-6999) OTHER SUPPORT REQUIREMENTS

6000 OTHER SUPPORT REQUIREMENTS

WSMR will identify estimated FY 72 funds required for all range derived support requirements.

1. Request the range provide a suitable Helicopter Landing Pad approximately 500' at 30° azimuth from the Mobile Calibration Station (MCS). This area should employ oil/chemical dust treatment for the landing area to eliminate excessive dust and sand blasting during tie down and ILS landing tests.

2. Suitable pad area markings and pilot references are required to conduct ILS landings Test II. In addition to an optical landing aid, glideslope intercept markers are required for a pilot aid to initiate glideslope trajectories of 2.5° - 8° - 16° to selected landing pad. The glideslope intercept points are deinfed on Page 3.1 as - ranges to helicopter landing pad.

(Continued on Page 8.1)

OTHER SUPPORT REQUIREMENTS - (Continued from Page 8 - Paragraph 6000)

3. Anticipation of FPS 16 clutter return problems in radar vectoring the Helicopter for the area navigation profiles at Northrop Strip requires an alternate method of holding cross track pilot error to ±100 ft. of planned ground track. This can be achieved by ground course heading markers , Locates approximately 2000 ft apart over a 4 mile course centered at transmitter origin shown on page 8.6.

4. Provide transportation of NC-135 Salt Site, transmitter antennas to the HA-7 site location at Northrop Strip where they will be installed by the contractor.

All tests will be conducted at Northrop Strip (Site HA-7). All facilities constructed for the NC-135 test program shall be retained by the range user. The following list of requirements are anticipated:

1. The transmitters should be located in close proximity to site HA-7 at Northrop Strip as shown on Page 8.5. Antenna and transmitter support stands for Test III will beCFE except that two telephone poles that were installed by the range at the MCS site shall be retained.

2. Each transmitter must have unobstructed hemispherical coverage overhead.

3. Communications, and electrical power (1.5 kilowatts, 60 Hz) must be present at transmitter sites to operate contractor furnished equipment at each site.

4. As indicated previously the Mobile Calibration Station (MCS) should be within the Line of Sight of the transmitters. Communications, timing, and electrical power must be available. (1.5 Kilowatts, 400 Hz and 5 Kilowatts, 60 Hz) should be provided to operate contractor furnished equipment. An outside telephone line, Sanitary facilities, Water, and IRIG "B" timing are required at MCS site.

5. Electrical power can be delivered to the ground transmitters by existing land lines or by motor generators operated by WSMR, rechageable batteries (CFE) will power the balloon borne transmitter. External power for the ground transmitters will be required beginning approximately 2 hours prior to test runs. Power must also be available to recharge balloon borne batteries.

6. A balloon will be used to carry one of the 621B transmitters during the ILS tests. A balloon launching pad (see Page 8.7) is required for ground handling during inflation, deflation, and for tethering the balloon during non-test periods. Dueing the ILS tests, the balloon will be tethered at an altitude of approximately 1000 and 5000 ft AGL from a mobile winch. The balloon launch pad should be constructed at the location shown for transmitter four on Page 8.5. Balloon support will be provided by Detachment 1, Air Force Cambridge Research Laboratory, Holloman Air Force Base, New Mexico.

OTHER SUPPORT REQUIREMENTS - (Continued from Page 8.1 - Paragraph 6000)

7. A user furnished optical landing aid (OLS) will be installed near the reference point shown on Page 8.5. Power will be required at this site (20KW, 115v, 60 Hz). Communication is not required.

8. Transmitter, OLA, Balloon, MCS and helicopter landing sites will be checked against above criteria by the Range, and approved by the user. The balloon Pad and helcopter landing pad should be constructed, and all sites except the balloon and OLS surveyed to the accuracy stated in 3400 (misc) by the Range prior to 1 Sept. 71. Balloon and OLS sites will be located within ± 20 feet.

9. A Ground Cooling cart will be required at Northrop Strip for helicopter equipment cooling during electronic preflight and test 1 (Gnd Tie Down Tests)

10. Ground power is required at Northrop Strip for electronic integration, pre-flight and ground tie down tests.

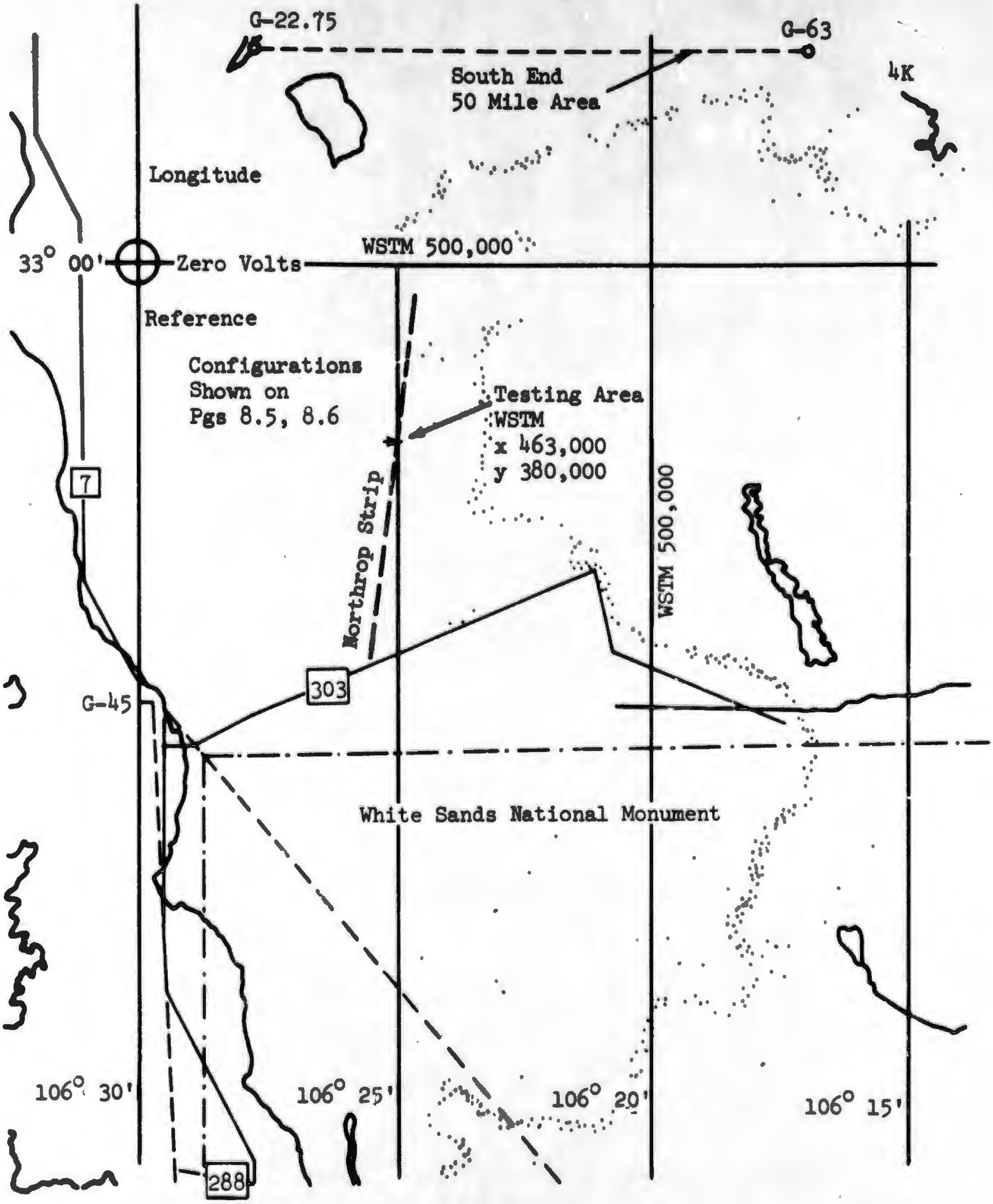
11. Provide accurate transmitter location at -6000 ft from center origin (surveyed to ±.5 ft)

12. a) Provide accurate helicopter pad position data (surveyed to ±.5 ft)

b) Provide 12 compass rose heading position markers at pad spaced at 30° increments, true heading.
(Item 12 will be primarily used in test I and for pre-flight checks of user receiver baseline position accuracy)

13. Provide a single point helicopter tie down pad. Three 25,000 lbs tie down methods are illustrated on page 8.7 and 8.8. Selection of a particular method from the proposed methods can be made by WSMR facilities personnel.

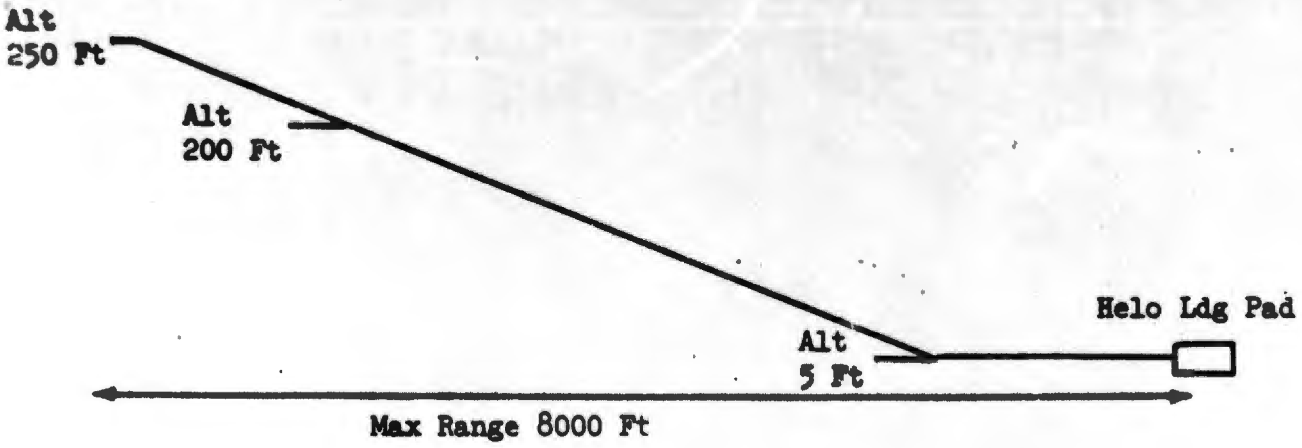
It is necessary that a rated helicopter pilot, man the helicopter during tie down operations to satisfactorily balance rotor torque effects.



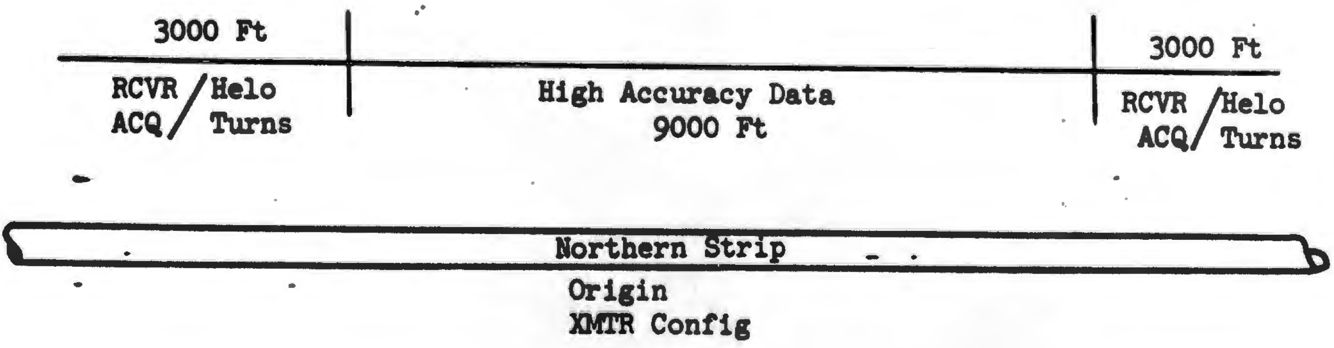
Helicopter Field Testing Area

PI PAGE 8.3

1. ILS

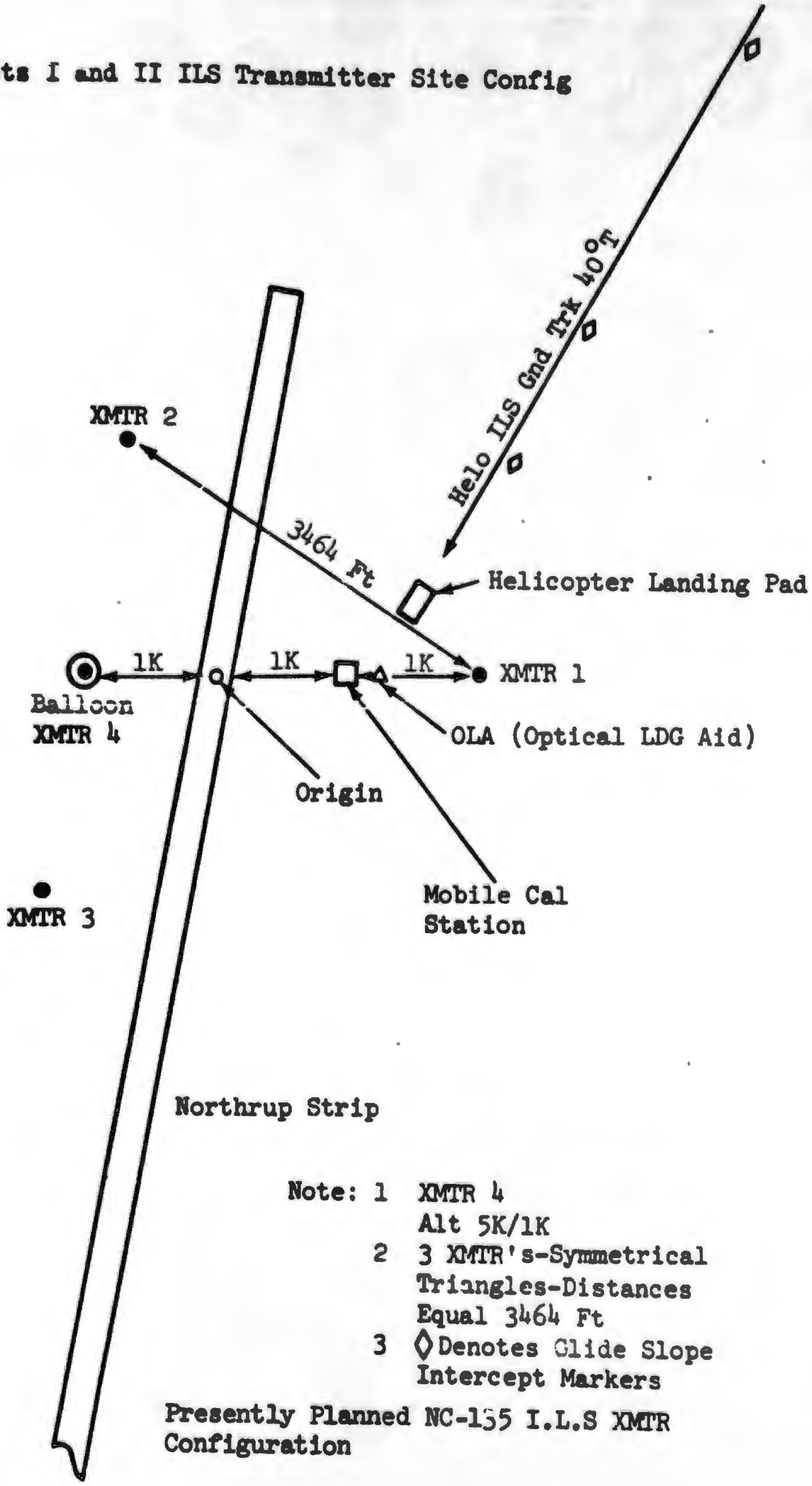


2. Area Navigation



Typical Data Coverage

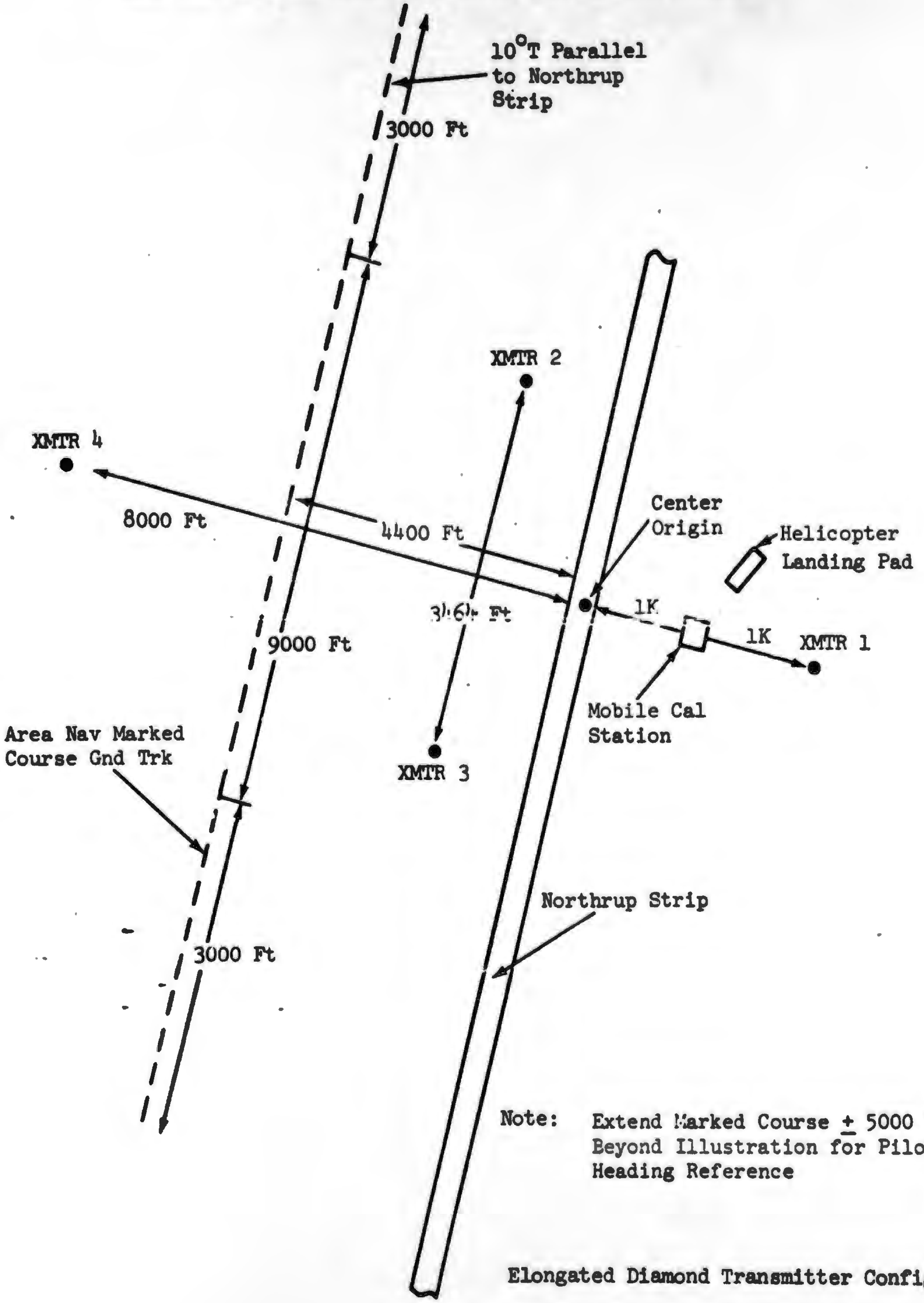
Tests I and II ILS Transmitter Site Config



Note: 1 XMTR 4
Alt 5K/1K
2 3 XMTR's-Symmetrical Triangles-Distances Equal 3464 Ft
3 ◊ Denotes Glide Slope Intercept Markers

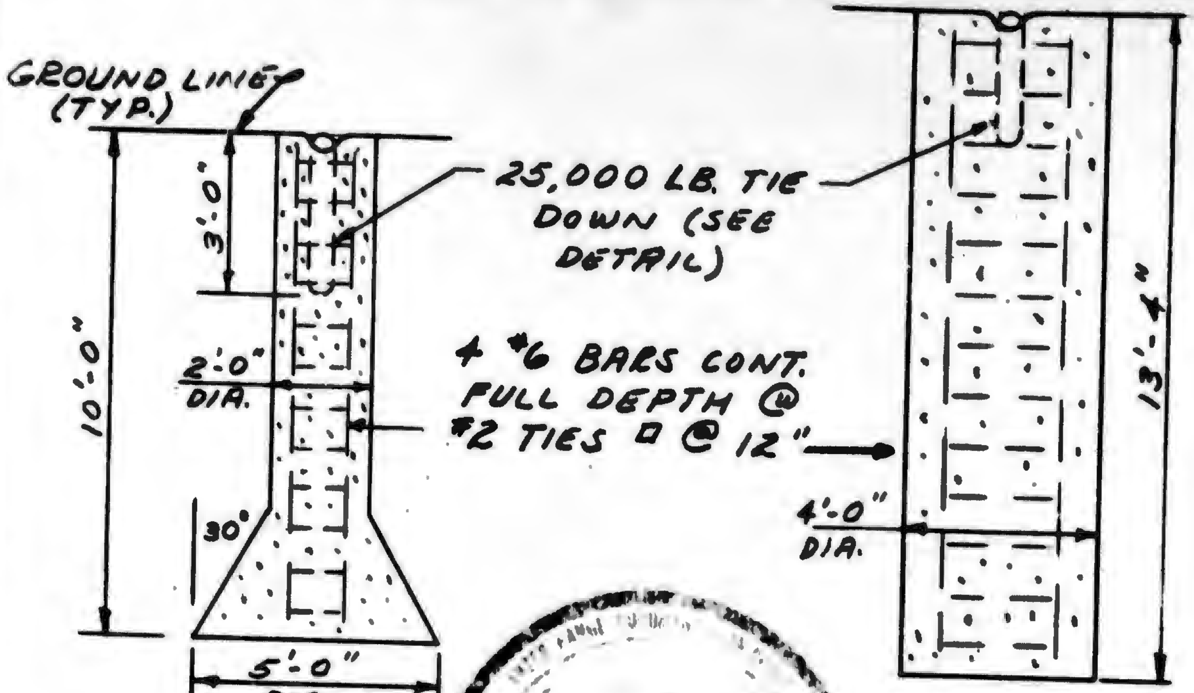
Presently Planned NC-135 I.L.S XMTR Configuration

Test III Area Nav Demo Transmitter Site Configuration



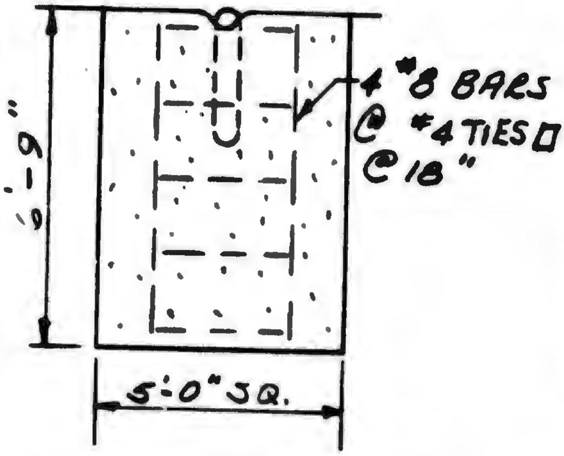
Note: Extend Marked Course ± 5000 Ft Beyond Illustration for Pilot Heading Reference

Elongated Diamond Transmitter Configuration



BELL DRILLED PIER METHOD

4'-0" DIA. STRAIGHT PIER METHOD



BAR DESIGNATION	UNIT WEIGHT PER FOOT	NOMINAL DIMENSIONS ROUND SECTIONS		
		DIA.	X SECT. AREA	PERIMETER
2	0.167 #	0.250 in.	0.05 in.^{2}	0.786 in.
4	0.668 #	0.500 in.	0.20 in.^{2}	1.571 in.
6	1.502 #	0.750 in.	0.44 in.^{2}	2.356 in.
8	2.670 #	1.000 in.	0.79 in.^{2}	3.142 in.

SQUARE BLOCK METHOD

APP. SCALE 1/4" = 1'

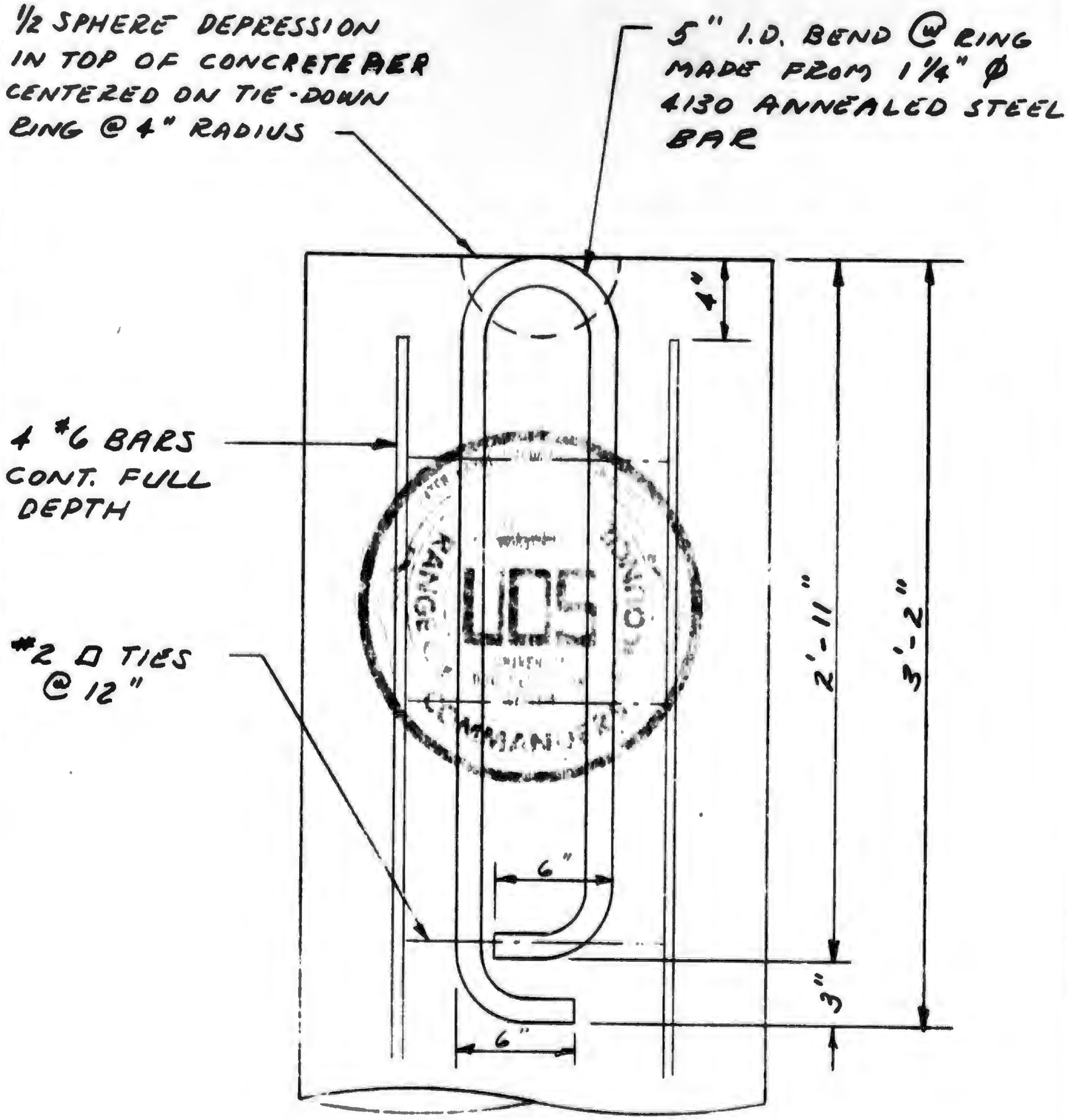
REVISION NO __________

REVISION DATE __________

CLASSIFICATION

PI NO __________

PI DATE __________



DETAIL OF 25,000 LB. TIE-DOWN HOOK

APP SCALE 1½" = 1'

UDS FORM 9
JULY 70

CLASSIFICATION

PI PAGE 8.8

8. OPTIONS

The basic objective of this program is to demonstrate that System 621B concept, with a single channel receiver, can meet Army position and accuracy requirements. There are several airborne hardware configuration options to demonstrate user operational aspects of System 621B. This section addresses these options in concept terms. Section 9 addresses the design and installation aspects.

The first two options concern the type of single channel-receiver which can be used. The third option considers the use of an airborne computer in a real-time navigation configuration.

8.1 OPTION I - MODIFIED GFE RECEIVER

The minimum cost approach is to modify the four-channel receiver that SAMSO will use for the NC-135 tests. After completion of the Army tests, if required, the receiver would be remodified to its original form and returned to SAMSO.

The modifications consist of using different processor code and carrier loop bandwidths and different acquisition parameters. The values of these parameters and the cnannel cycle time are the subject of the tradeoff analysis in Section 9.1. In the single channel mode, the input signal to three of the receiver processor channels is disabled while the fourth tracks. There are four code generators, each driven at a nominal 10 Mhz, except for the channel being tracked, which is run at the required rate to properly track the signal. Clearly, in an operational receiver there would only be a signal channel. The four-channel approach is proposed due to the constraint of using the GFE four-channel receiver. It should also be clear that the selection of the aforementioned parameters are also subject to the constraints of this existing receiver. While generally representative of the operational system, the values should not be considered typical.

With this GFE receiver approach, the Army will not have a receiver with which to conduct future additional testing. In order for the Army to acquire a receiver, one would have to be assembled. This leads to Option II. However, rather than assembling a reproduction of the SAMSO four-channel receiver, it is more desireable to produce a state-of-the-art single-channel receiver which would be representative of a realistic single-channel receiver with greatly improved performance.

8.2 OPTION II - SINGLE-CHANNEL RECEIVER

In this approach a new advanced state-of-the-art single-channel receiver design is proposed. The receiver utilizes digital processing that is time-shared and cycled between all four channels rapidly enough for the pseudo-range and range-rate data to appear virtually continuously. This cycle time, four milliseconds to cycle through four channels, is to be compared with the one-second cycle time in the Option I approach. The measurement rate approaches that of the four-channel receiver. In this approach four code generators are provided, the three quiescent channels being driven by the standard 10 Mhz clock. The tracked channel is driven by a phase shifted replica of the standard clock.

This receiver design is a representative prototype of an operational one-channel receiver, and as such could provide very relevant operational data. It is therefore recommended.

8.3 OPTION III - REAL TIME COMPUTER

A significant "next-step" in providing data for the operational system is to provide for real time navigation computation and display in the helicopter. Since the transmitters are running asynchronously, a real time transmitter time bias computation will be required in the MCS as well. The values would then be voice uplinked to the helicopter where they can be keyed into the computer. This procedure should suffice since the oscillators are very stable and updates should be required no more than once each run.

8.3.1 Approach

The real time navigation solution will be accomplished as follows. The oscillator time bias associated with each of the four transmitters will be computed by the MSC computer from the measurements taken with the Calibration Receiver. The time bias data will be voice uplinked to the System 621B operator in the helicopter and entered into the airborne computer via the control/display unit. This update is required once every several minutes.

The airborne computer will receive both the uplinked data and the raw navigational data (pseudo-ranges, pseudo-dopplers) from the airborne receiver via the computer interface unit. Every 250 msec the airborne computer will compute the receiver oscillator bias and bias rate and the helicopter position and velocity in the appropriate coordinate systems. This data will be recorded for comparison with the post flight reduced data. The post flight reduced data is derived from the recorded measurement data and is the basic data reduction procedure used for the NC-135 tests and the procedure planned for Options I and II. The real time position and velocity data will also be displayed in the helicopter for Operator and VIP observation.

8.3.2 Real Time Option Requirement

The real time option will require additional equipment installed in the helicopter and in the mobile calibration station along with interface changes. The helicopter will require the installation of an airborne computer, control/display unit and an interface unit to provide the computer/receiver interface, the computer/control/display interface and the computer/recorder system interface. This will necessitate increased installation and check-out requirements. The MCS will require the addition of a computer, control/display unit, an interface unit, and provision for voice uplink tc the helicopter.

The airborne computer and control/display unit will be consigned to the program by either Kearfott (SKC 2000) at nominal or no cost. The interface will be designed and fabricated by Grumman. The MSC computer and control/display will be consigned to the program by Grumman's Advanced Development Program Office (CDC-5360) or the Air Force (CIGTF, Holloman-HP 2114B) at no cost to the program. The interface requirements will be designed and fabricated by Grumman.

Modification to the recording system interface unit will be accomplished by Grumman. This is addressed in Section 9.2.

Development, check-out and implementation of the software program will be required for the real time programming of the airborne computer and the MCS computer. This effort will be accomplished by Grumman with assistance from the computer manufacturers.

Data processing of the data is addressed in Section 10.

9. EQUIPMENT DESIGN AND INSTALLATION

This section addresses the equipment design and installation proposed for the field tests for all options. It will be noted that where possible, equipment from the NC-135 tests are being used as is or modified. New designs have been resorted to only after a clear indication that the equipment which exists could not be used or that a new design is more effective.

9.1 RECEIVER CONFIGURATION SELECTION

9.1.1 Tradeoff Analysis

Methodology. The tradeoff analysis performed during the study program considered receiver configuration and design options. Their advantages and disadvantages were evaluated as they relate to the demonstration objectives. Based on the Army operational requirements, two approaches were selected and further evaluated. The resulting detailed designs were estimated as to their relative cost for the flight test demonstration phase. These approaches are presented as our recommendations for the Phase II test program.

Discussion. The first step in the tradeoff analysis was to identify reasonable combinations of receiver configuration options. The possibilities considered were:

- Use the four-channel receiver directly from the NC-135 test program as GFE
- Modify the GFE receiver using the four existing processors to act as a time-shared single-channel receiver
- Modify the GFE receiver with a new single-channel processor with four code generators
- Fabricate a new four- or one-channel receiver as above
- Fabricate a new one-channel receiver

These options and their advantages and disadvantages are listed in Table 9-1. A list of the demonstration objectives is presented in Table 9-2. It appears that the least expensive approach is to use the unmodified GFE (1a of Table 9-1), but this would not provide adequate data on a representative signal channel receiver design or channel sequencing techniques. The only new and useable data which could be obtained are: the receiver performance in the helicopter vibration and acoustic environment; the effect of rotor modulation; the effect of rotor multipath; and acceptable antenna locations. The most expensive approach is the development of a new single-channel receiver optimized for the helicopter application. This would provide the most meaningful data on one or more prototype processor designs.

The candidate approaches which were further analyzed were:

- Modify four-channel GFE to act as single sequenced channel using existing processor concept. An alternate to this approach is to fabricate another four-channel receiver and modify it in the same manner
- Fabricate a new single-channel receiver with various processor designs and retaining the existing RF/IF and frequency source designs

The first approach is the least expensive; its alternate provides an additional four-channel receiver with the ability to operate as a one-channel receiver for future tests and experimentation. The second approach provides a single-channel receiver with the following advantages:

- Closely representative of future operational receivers
- Flight tested in an operational environment
- Cycle time of about 1 millisecond per channel thereby making range and doppler available nearly continuously
- At the rapid sequence rate, it can easily be expanded to an 11 channel receiver

The use of an on-board real time digital computer during the flight tests is more for data reduction and real time display rather than for aiding the receiver. The

Table 9-1 Receiver Configurations

Source of Receiver	Number of Processors	Theory of Operation	Advantages	Disadvantages	Demonstration Objectives Satisfied		
					Primary	Secondary	Tertiary
1. GFE from SAMSO: a) Unmodified	4	All channels locked and data reduction software to simulate single channel	1. Inexpensive 2. Available (no development) 3. Maximum engineering information on sequencing data rate 4. Direct comparison with 4 channel (NC-135) performance	1. Single channel sequencing techniques not evaluated 2. Modification required to suit helicopter	#4 #5	#1 #3	#1 #2
b) Modified	4	Sequence at 1 second Disconnect quiescent channels Disable reacquisition circuits Quiescent channels coast at selected rates	1. Inexpensive 2. Minor Development 3. Minor modifications 4. Can simulate code & carrier rate aiding 5. One (1) single channel technique evaluated 6. Can be combined with 1 channel option below	1. Probably require GFE at HC for modification 2. May require mechanical modifications to add extra circuitry 3. Modification required to suit helicopter		All	
	1	Sequence at 1 sec. New processor uses 4 code generators Quiescent code generators coast at selected rates	1. One (1) single channel technique evaluated 2. Can simulate code & carrier rate aiding 3. Can implement various types of processors	1. Requires new processor design and/or circuit layout 2. Requires GFE at HC for modification		All	
2. Fabricate New Receiver	4 or 1	Carbon copy of 1a above	1. Army will obtain RCVR for future experiments			All	
		Carbon copy of 1b above	1. Army will obtain RCVR for future experiments			All	
	1	Sequence rate of 1 millisec per channel New receiver design	1. Can evaluate several processor concepts 2. Receiver can be small and cheaper in production 3. Most closely resembles future operational receivers	1. Requires new designs		All	

Table 9-2 Demonstration Objectives

PRIMARY OBJECTIVES

1. Determine accuracy of a single channel receiver in area navigation
2. Determine accuracy of single channel receiver in ILS
3. Determine accuracy of a single channel receiver and cycle rate at low signal levels for ground based users
4. Determine rotor modulation effects
5. Determine ground multipath effects

SECONDARY OBJECTIVES

1. Determine code and carrier rate aiding requirements
2. Determine accuracy of a single channel receiver with and without doppler information
3. Determine acceptable antenna locations
4. Determine reacquisition and channel sequencing capability

TERTIARY OBJECTIVES

1. Provide data to compare single channel performance versus NC-135A tests with 4 channel receiver
2. Determine vibration and acoustic effect on accuracy and sequencing
3. Evaluate real time computer workload for code and carrier aiding (Option III)
4. Determine data sample rate requirement for receipt of satellite ephemerides modulation

existing processor design does not require the computer. However, in the case of a new processor design, it may be necessary to provide some sort of code or carrier aiding, but only as a cost-effective tradeoff of hardware, software, computation speed, storage required, etc. These tradeoffs are described in Section 9.1.3.

Recommendations. There are two promising candidate approaches to a single-channel receiver configuration suitable for the Army helicopter demonstration. One approach, considered because it promises a modest amount of meaningful test data at minimal cost, consists of a GFE four-channel receiver modified to accommodate the physical environment and the dynamic characteristics of a helicopter. The modifications consist of using different processor code and carrier loop bandwidths and different reacquisition parameters. Its operation is such that the input signal to three of the processor channels are disabled, while the fourth is being tracked. The code generators of the three quiescent channels are clocked at a nominal 10 Mhz. The cycle time would be set to one second per cycle.

The second approach is to provide a new single-channel receiver with digital processing in the code and carrier loops, time-shared and cycled among all four channels and four code generators, driven by a common 10 MHz clock. The cycling is rapid enough (one millisecond per channel) for the output range and doppler data to appear "continuously" at a rate of five sets of data every second. This approach has been selected and is recommended because it provides a significant advance in tracking loop technology and a representative prototype for an operational receiver. Additional advantages are that it would be smaller and cheaper than the four-channel system while providing comparable accuracy in a helicopter or ground-based user environment.

The theory of operation of the two recommended approaches are given in Section 9.1.2. The design details are presented in Section 9.1.4. The specifications for the two approaches are presented (along with specifications for the 4 channel receiver) in Table 9-3.

The major design difference between the basic 4 channel receiver (utilized in the NC-135 Phase II tests) and both of the recommended receiver options proposed for the helicopter demonstration is that the reacquisition circuitry is modified to account for signal dropouts only of the order of 1 to 2 seconds. The nature of the initial receiver design is to provide reacquisition capability for a signal loss of about 5 seconds at an aircraft speed of up to M2.5. The resulting range uncertainty is then of the order of 12,000 feet (120 chips). The reacquisition circuitry was therefore designed to step ahead by about 140 chips and the code searched at 2 millisecond intervals to a point 140 chips back in increments of ½ chip for a total of approximately 1.2 seconds. This provided an improvement of better than 2:1 over the acquisition time of the short code whose repetition period is 3.3 seconds.

The analogous behavior of the proposed system 621B helicopter demonstration is that the position uncertainty due to helicopter velocity (200 fps) is 1000 feet after 5 seconds of a particular transmitter signal dropout. For the option I receiver, this would result in failure to attain lock-up on that transmitter signal for 5 successive search cycles. In order to search the 10 chip positions using the bandwidths and signal levels in the helicopter configuration there would have required a much longer time interval than the 3.3 second short code period. In that time. the helicopter would have covered a considerable portion of the flight probile so that the flight would neet to be repeated. The proposed system,

Table 9-3 Receiver Specification

	4-Channel Receiver Spec. Reqmt.	4-Channel Receiver Performance		Modified 4-Channel Receiver Performance		Digital Single Channel Performance	
Signal Sensitivity:							
For Tracking Threshold	-143 dbm	-143 dbm		-138 dbm		-143 dbm	
For Measurement Accuracy	-140 dbm	-140 dbm		-135 dbm		-140 dbm	
Dynamic Range	60 db	60 db		60 db		60 db	
Anti-jam for Input signal at -130 dbm	45 db	45 db		45 db		45 db (High level cw- Code 2 not included)	
Data Sampling Rate	5 sets/chan/sec	5 sets/chan/sec		1 set/chan/sec		5 sets/chan/sec	
Measurement Accuracy		-140 dbm	-123 dbm	-135 dbm	-123 dbm	-140 dbm	-123 dbm
Standard Deviation, 1σ:							
Pseudo-Range (Ea. Chanl)	1σ = 5 ft.	4.48	0.83	7.0	2.0	5.0	1.0
Pseudo-Doppler (Ea. Chanl) Ft/Sec	1 = 0.5 fps	0.356	0.281	0.35	0.28	0.36	0.28
RCVD Signal Level (-140 to -120), DB	NS	±1.5	±1.0	±1.5	±1.0	±1.5	±1.0
Measurement Resolution:							
Pseudo Range, Ft	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Pseudo Doppler, Ft/Sec	0.05	0.05	0.05	0.05	0.05	0.05	0.05
RCVD Signal Level, DB	NS	±1.0	±1.0	±1.0	±1.0	±1.0	±1.0
Max Dynamics for Measurement Accuracies							
$\dot{R}$, Ft/Sec	7000	7000		200		4300	
$\ddot{R}$, Ft/Sec^2	175 (Fighter)	175		16 (Helicopter)		16 (Helicopter)	
$\dddot{R}$, Ft/Sec^3	0	0		0		0	
RCVR Tracking, $\dddot{R}$, Ft/Sec^3	≈ 320 for 0.1 sec	320 for 0.1 sec		≈ 320 for 0.1 sec		≈ 320	
RF-IF Characteristics							
Center Frequency, MHz	1575	1575		1575		1575	
Noise, Figure, DB	NS	5.5		5.5		5.5	
3 DB Bandwidth, MHz	NS	22		22		22	
IAGC Action Time, sec	NS	10		10		10	
Intermediate Frequency MHz	NS	75		75		75	
Local Oscillator, MHz	NS	1500		1500		1500	
Matched Filer Characteristics (-100 dbm Initial ACQ signal) Number of Bits	NS	225		225		225	
Processing Gain (Realized), DB	NS	21.5		21.5		21.5	
Time Accuracy, NS	NS	12.5		12.5		12.5	
Signal to Thermal and Correlation Noise, DB	NS	15.5		15.5		15.5	
Probability of Detection	NS	0.99		0.99		0.99	

Notes:
NA = Not Applicable
NS = Not Specified
TBD = To Be Determined During Flight Tests

* This range bias error is for unprocessed system 621B data, it can be made nominally zero.

Table 9-3 Receiver Specification (Continued)

	4-Channel Receiver Spec. Reqmt.	4-Channel Receiver Performance		Modified 4-Channel Receiver Performance	Digital Single Channel Performance
Carrier Tracking Loop Characteristics		ACQ	Tracking		Frequency Estimator
Order of Response	NS	2ND	2ND 3RD	2ND	2ND
Bandwidth (Single-Sided)	NS	2.2 KHz	48 Hz 11 Hz	≈ 22	≈ 56
Code Tracking Loop Characteristics					
Order of Response	NS	2ND	3RD	2ND	2ND
Bandwidth (Single-Sided), Hz	NS	250	1.4	≈ 11	≈ 1
Reacquisition Characteristics					
Signal Level, DBM (min)	Precision Channel Capability; Reacquire Tracking Lock Without Initial Acquisition Aid	-123		(Not included due to short duration flight time. Data obtained during flight tests will provide information on duration of signal dropouts.)	Same as modified 4 channel receiver.
Maximum Time to Reacquire Lock When Signal is Present, Sec		2.7 sec			
Number of Bits Searched		±140			
Incremental Bit Search		1/2			
Dwell at Each Bit for Carrier Tracking Loop to Actuire Lock, MSEC		5.0			
Total Search Time (Adjustable, Sec		7-70			
Multipath Effects	NS	TBD		TBD	TBD
Rotor Modulation	NS	NA		TBD	TBD
Digitizer Characteristics					
Pseudo Range, Bits	NS	Coarse Fine 26 8		Coarse Fine 26 8	Coarse Fine 26 8
Pseudo Doppler Bits	NS	20 15		20 15	20 15
Standard Clock, Bits	NS	25		25	25
Output Data Rate KHz	NS	200 KHz		200 KHz	200 KHz
Receiver Size, inches	NS	10 x 14 1/2 x 20 3/8		10 x 14 1/2 x 20 3/8	10 x 14 x 16 1/4
Power Supply, inches	NS	9 x 14 x 13 5/8		9 x 14 x 13 5/8	9 x 14 x 13 5/8
Receiver Weight, Lb.	NS	82		82	TBD
Power Supply Weight, Lb	NS	64		64	64
Power Dissipation, Watts (Less Power Supply)	NS	400W		400W	TBD

therefore employs the initial acquisition mode, on the short code in order to minimize the necessity of repeated flights. It should be pointed out that in an operational situation, code and carrier aiding, on the order of that which could be provided by an air data system, could be used to reduce reacquisition time using reacquisition circuitry. However, as will be pointed out later, the modifications to the receiver to provide this rate aiding were not considered as cost-effective at this time and therefore ruled out for this program.

For the option II receiver, the reacquisition capability is not included, at this time, for the same reason as mentioned above. In order to implement the rate aiding, advantage of an external computer would be required. Although a good portion of the capability for such aiding is inherent in the digital nature of this single channel receiver, no circuitry is provided to accept code and carrier aiding commands.

9.1.2 Theory of Operation

Single Channel Receiver. The advantage of fabricating a new receiver, including a new processor, is to provide a smaller receiver package to perform only those functions required for the helicopter demonstration. This would be a prototype model for an operational receiver.

For this receiver only one RF/IF function and only one matched filter is required. Since only one processor is required, the distribution unit is not necessary. Four code generators will be provided, all driven by a common clock. The self test module will be redesigned to include tests of the time-sharing, cycling and sequencing circuits.

The output interface circuitry could have only one data line to sequentially transmit the coarse and fine pseudo-range and pseudo doppler and the standard clock. The data acquisition subsystem presently accepts data on separate lines for coarse range, fine range, coarse doppler and fine doppler for each channel plus another line for the standard clock. To keep overall program costs down, the single-channel receiver will provide data on seventeen lines rather than one line to prevent modifications to the data acquisition instrumentation.

The single-channel receiver consists of a newly designed chassis, processor and self-test circuits. The modules such as RF/IF, frequency source and frequency synthesizer are similar or identical to those provided for the four-channel receiver. The major design differences in any new circuits are that they are designed to meet the accuracy over the temperature range of 0°C to +55°C. The unit will be designed to operate at an ambient of up to +71°C without damage.

An overall block diagram of the receiver is shown in Figure 9-1. It consists of the following modules:

- RF/IF
- Matched filter and driver
- Frequency source and synthesizer
- Processor and channel sequencing
- Code generator (two modules)

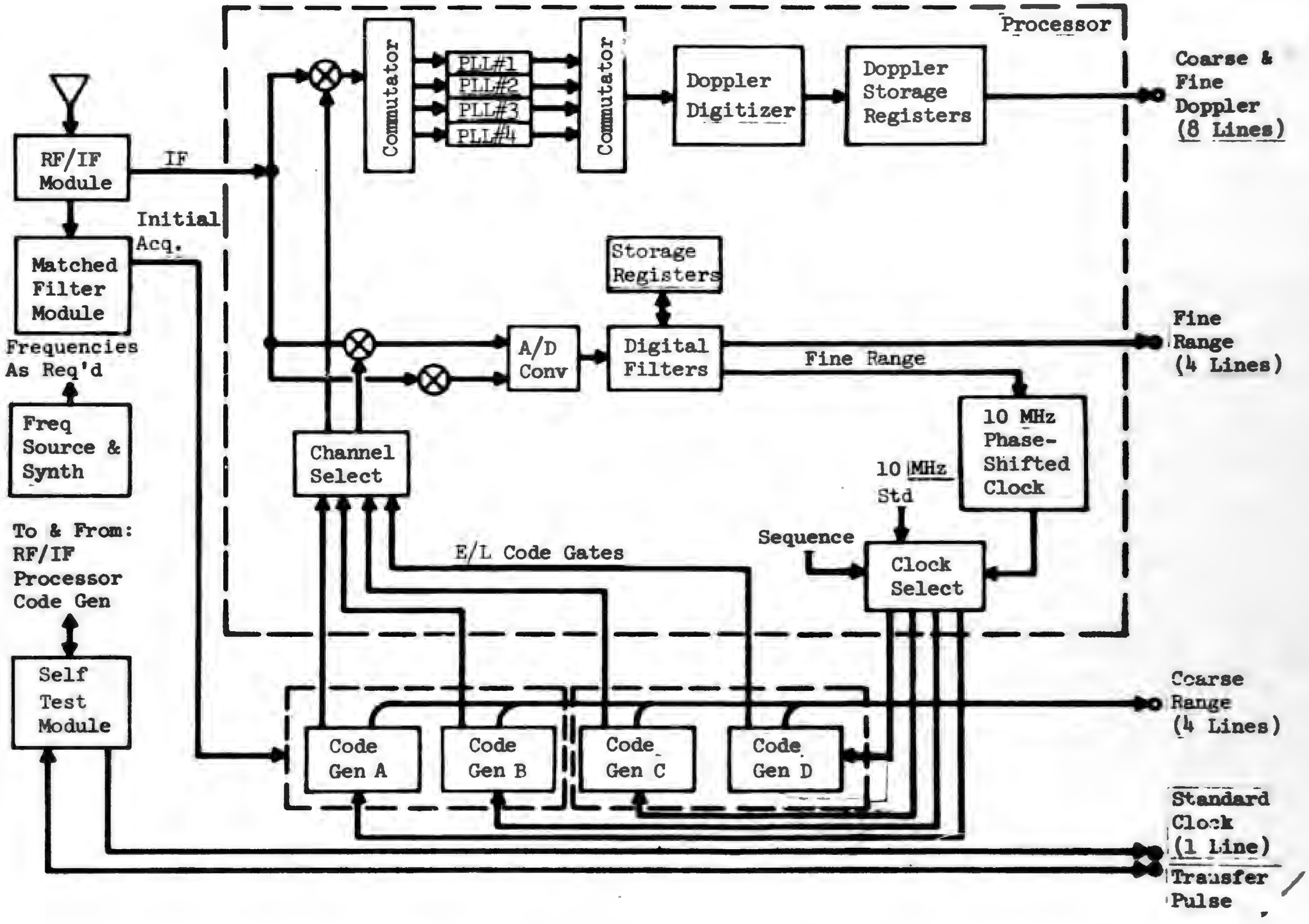


Figure 9-1 Single Channel Receiver

The processor uses a code tracking loop and a doppler estimator (rather than a carrier tracking loop). The code tracking loop is a non-coherent (envelope detection) correlator which has the advantage of faster reacquisition and independent of a carrier phase. The processor is a hybrid analog-digital device time-shared among the four channels at a sampling interval of about one millisecond per channel. When the loop is tracking, it operates as a sampled data servo system where an error signal is developed by the correlation of the input signal with a replica of the input signal contained in the early and late gates of the code generator and correction signals applied digitally and discretely to the phase of the code generator clock at the beginning of each sample period. The phase correction is determined by digital logic representing the mathematical calculations of digital equivalents to bandpass and low pass filters. Although there is only one set of arithmetic registers to perform the digital processing, there are four storage registers for the filter integrators, one for each of the four channels, which are retrieved and updated at each sample time for each channel.

The 10 MHz clock which feeds all channels has time-shared phase control circuitry which is switched to each channel in sequence. The phase selection is digitally controlled by the counting of the number of cycles of the 10 MHz and the 10.05 MHz clocks where the difference in time is in 0.5 nanosecond increments. The count of the number of cycles of the 10 MHz clock gives a selectable phase displacement of 0.5 nanoseconds up to a maximum of 100 nanoseconds. The signal which is thus obtained occurs at the difference frequency of 50 KHz, corresponding to a 20-μs period. This signal is used to synchronize an LC oscillator which provides the phase-displaced 10 MHz clock to drive the code generator.

During the channel off-time (3 of 4 milliseconds), the standard clock is used to increment the code generators.

The "carrier loop" for the helicopter application is reduced to circuitry for the estimation of the carrier doppler frequency. This is possible because the non-coherent nature of the code loop eliminates the code loop dependence on carrier phase. Therefore, as long as the frequency uncertainty in the received code signal is within the capability of the code loop design, there is no need to utilize a closed carrier loop.

The principle of operation is as follows. Assuming a condition of code tracking, the function of the doppler circuits is to estimate the doppler to about 0.3 Hz (0.2 fps) for each of the four channels. To do this, narrow-band, integrated circuit, phase-locked loops (PLL) are provided to develop noise-free replicas of the received carrier. The input signal to each loop consists of the received signal modulated (correlated) by the standard clock of 15 MHz (obtained from the frequency synthesizer) which is modulated by the selected code. The code is selected from one of the four generators at the channel sequencing interval of four milliseconds. During the one millisecond dwell time on each channel, the selected PLL is updated by the incoming signal. The output of the PLL is then a noise-free replica of the incoming signal that is continuously available.

The next step is to determine the frequency of each carrier to provide the data from which doppler will be obtained. There are several means of implementing the frequency counters in order to obtain a measure of the doppler. The technique selected is that employed in the basic 621B four-channel receiver. It consists of doppler counting circuits which count the number of cycles of a signal of approximately 125 KHz occurring in a specified interval of about 50 milliseconds or 100 milliseconds. This gives a number which is defined as the "coarse doppler." The "fine doppler" is determined by a count of the 10 MHz clock pulses proportional to the fractional portion of a cycle of the 125 KHz signal required to complete the 50 or 100 millisecond doppler interval.

The doppler data is obtained on all four channels, sequentially, thereby requiring 0.2 seconds (4 x 50 msec) or 0.4 seconds (4 x 100 msec) of real time. The doppler sample for any specific channel will be the average value for the 50 or 100 millisecond time period immediately preceding the readout transfer signal.

The code generator modules are two identical modules, each of which contain two identical 25-stage code generators similar to those contained in the four-channel receivers.

Modified GFE Receiver. If the existing processors are used, the input signals can be switched in and out based on the channel sequencing rate. At any one time, one channel will be enabled and tracking while the other three will be disabled and free-running. Preliminary studies have indicated that a channel sequencing rate of 1 second for a complete cycle is a reasonable figure to achieve at signal levels down to -135 dBm. The functioning of the system is such that all channels would be initially synchronized by the power boost/matched filter technique as used in the basic Phase II tests. The initial synchronization portion will take a maximum of 3 seconds for the first channel and 3 more seconds for the remaining channels. The only operational restriction during this period is straight and level flight.

After the interval of initial synchronization, the receiver is automatically switched to the normal channel sequencing program. The sequencing is such that each channel is switched into the input line for a dwell interval of 0.25 seconds. This permits a doppler counting interval of at least 0.05 seconds, giving about 0.20 seconds for the loop to recover from phase and frequency transients in both the code and carrier loops. The analysis of the performance of the loops due to noise and acceleration is treated in the section on dynamic loop performance.

At the end of the 0.25-second sampling interval, the pseudo-range, pseudo-doppler and standard clock readings are sampled and provided for output to the instrumentation system. The next channel in sequence is then selected and the stabilization process repeated.

When signal is lost due to antenna shadowing, the processor channel may not be sufficiently stabilized to indicate loop lock. The output information is then in error and a bit indicating out-of-lock is recorded in the instrumentation system. If this situation continues for several seconds, an initial acquisition mode is activated for the out-of-lock processor. The indication of repeated out-of-lock occurrences will be automatically obtained for each channel.

Since the initial acquisition mode can be activated at any time during the flight profile, it is necessary that the three remaining channels continue to be sequenced at about the 1 second interval while the fourth is awaiting the power boosted short code signal. This can be accomplished by transmitter timing adjustment on a daily basis so that the short codes from each are spaced approximately 0.8 seconds. The initial acquisition program of the receiver is so arranged that the 0.8 second interval is divided into three 0.25 second sub-intervals which are used for channel sequencing of three channels. This provides adequate time for maintaining track on the three channels plus a safety factor of 50 milliseconds (at a clock stability of 1 part in 10^8, the daily drift is only 1 millisecond). At the time of receipt of the last sync pulse, the channel sequencing program reverts to the normal sequencing of 4 channels every second. There are no flight constraints required for this initial acquisition mode.

9.1.3 System Analysis

Operational Signal Power Level. To design an operational processor, the received power level must be used to determine the processor parameters. There are two, different, major considerations for the helicopter demonstration program depending on the receiver Options I and II defined in Section 8. The consideration for Option I is to perform only those modifications which are cost-effective in terms of obtaining meaningful data on a single channel receiver. Using the specifications for the 4-channel receiver (defined in reference 1) as a baseline it is our design objective to meet the ranging accuracy of $\sigma r = 5$ feet at a signal level of -140 dbm and to maintain lock at a signal level of -143 dbm. It is shown later in this section that by performing relatively minor modifications to the 4-channel receiver processors a performance accuracy of $\sigma r = 7$ feet can be obtained at a signal level of -135 dbm. While not rigorously analyzed, it is expected that tracking will be lost at a signal level of approximately -138 dbm. Despite the fact that this performance is somewhat short of the 4-channel receiver requirements, the test and demonstration program will provide meaningful data on the sequencing performance in a helicopter environment. To improve the performance to the point of the 4-channel requirements would require major changes in both the receiver and related flight equipment. Foremost among the changes would be the need for code and carrier loop aiding - either internal to the receiver or external by means of a computer. As it is recognized that the largest contributor to the accuracy and cycle time performance is the doppler uncertainty and the number of code positions to be searched the 4-channel performance could be achieved by requiring only code searching at 3 places (± 50 feet and 0) for 50 millisec at each position and the doppler uncertainty reduced to about 40 fps. While this modification is not proposed, it is still possible to perform the modification at some future time.

The next consideration is that of the Option II receiver. It is shown later in this section that an accuracy of $\sigma r = 5$ ft can be obtained at a signal level of -140 dbm, which matches the requirements of the four-channel receiver - but only for accelerations of the order of 1 g (compared to 6 g) and for velocities of the order of 4000 fps (rather than 7000 fps).

The relationship of received signal level difference of from -143 dbm to -123 dbm (for the specification requirement of the 4-channel receiver) to the effect of a jungle canopy (foliage penetration) has been given in the classified reference [2]. The relationship is given in terms of elevation angle of the satellite and the distance the RF energy must penetrate.

The Army is interested in airborne (light aircraft or helicopter), vehicular-mounted (truck, tank or jeep), seaborne (patrol boats or air cushion), and manpack users. Operations may be in and around jungle canopies, so that the received signals may be attenuated to some degree. Most operators in that environment will be for the case when user motion is small, if not stationary. It is reasonable, therefore, to expect that a tradeoff can be made of cycle time versus signal level for the single-channel receiver. When user motion is slight, there is no need for rapid update cycles. This provides two benefits: The range uncertainty is reduced, thus reducing the number of code positions to be searched; The loop bandwidths can be narrowed to increase the signal to noise improvement ratio (processing gain).

These considerations, when related to the two selected receiver approaches, result in two different technical solutions. In the case of the new single-channel receiver containing a time-shared digital processor, the sampling rate is rapid enough (four milliseconds) that the code and frequency uncertainty is so small that no special search techniques are necessary. The processor acts as a sampled data system to provide range outputs at up to five samples per second and doppler outputs of two samples per second. The loop bandwidths are designed to provide the tracking accuracy of σ_r = 5 ft at -140 dbm.

On the other hand, in order to use a time-shared analog processor similar to that provided in the four-channel receiver, variable bandwidths and dwell times based on signal level are needed. While it is not proposed to incorporate such intelligence into the modification of the GFE receiver, it poses no serious problems to implement in an operational receiver. The proposed option (the modified four-channel receiver) will have the capability of a one-second sample interval at a signal level of -135 dbm. This gives a range accuracy of 7 feet (one sigma). In order to provide the processor with the capability of operation at -140 dbm, the loop bandwidths must be narrowed by about a factor of 10 to improve the signal to noise ratio. This has the effect of increasing the decision time, but if the number of code search positions is reduced as a result of low user motion, the cycle time could only increase to say 5 seconds (rather than 10 seconds).

If the doppler were known to 0.5 fps, then the position information obtained by dead reckoning to advance the three range and range rate measurements for up to 5 seconds introduces a resulting position error of 0.5 fps x 5 sec = 2.5 ft. This is quite reasonable for the helicopter application. Therefore, the modified receiver which could be provided as one option will have the capability of a fixed cycle time of 1 second determined by a signal level of -135 dbm. (The unit could be further modified at a later time to have an adaptable bandwidth based on signal level with an adaptable sample rate). The digital single channel receiver with a 4 ms sample rate will have the capability of maintaining lock at -140 dbm.

Doppler and Phase Prediction Requirements. These paragraphs present the results of a study to determine the requirements for prediction of the doppler (frequency) and phase of both the carrier and code correlators. This study was performed to establish an optimum relationship between sample interval, vehicle motion (acceleration and velocity), accuracy, and jitter errors. The study was performed for the two basic loops, the carrier loop and the code loop.

Carrier Loop Frequency and Phase Prediction. In order to maintain accurate carrier loop tracking, it is necessary to extrapolate carrier frequency and phase over the time interval that the other channels are being tracked. The prediction of carrier phase will minimize the phase noise injected into a coherent code loop and will assure rapid carrier loop stabilization and settling. An analysis was performed to determine the accuracy with which both the phase and frequency can be predicted based on the system accuracies, sampling interval, vehicle motion and satellite motion. The results of the analysis are presented here for the case of helicopter motion. The performance of an operational system has been qualitatively extrapolated from these results.

For the demonstration program, the helicopter will have a maximum speed of 120 kt (200 fps) and it is assumed that the maximum acceleration will be 0.5g. The demonstration set-up will use transmitters whose oscillators are periodically adjusted to maintain about one part in 10^8 or about 16 Hz for a carrier frequency of 1.6 GHz. The doppler frequency corresponding to 200 fps is 300 Hz at the carrier of 1.6 GHz.

For any navigation system where accelerations are not instrumented, such as in a helicopter, light aircraft, ground vehicle or manpack, the best estimate of future velocity is merely the value of velocity at the prior sample interval. Therefore, for this analysis, it is assumed that the velocity will persist for the duration between samples. It will be shown later that in some cases the position and velocity errors due to accelerations are quite small.

To determine the phase uncertainty in the carrier at the beginning of a sample interval, assume that the velocity information is known precisely at the conclusion of the prior sample interval. If the sequencing interval is 1 second, then each channel is apportioned 0.25 secs giving a total off-time for the channel being considered of 0.75 seconds. At the maximum acceleration of 0.5g the helicopter could deviate by $1/2 \times 16 \times (0.75)^2 = 4.5$ ft during the off time. At a carrier wavelength of 0.67 ft (1.6 GHz), this corresponds to almost 7 RF cycles. Obviously it is to no avail to attempt to predict the carrier phase.

On the other hand, if the cycle time were of the order of 30 milliseconds rather than 1 second, then the position deviation due to acceleration becomes $1/2 \times 16 \times (22.5 \text{ millisec})^2 = 2^\circ$ of phase change of the carrier. In this case, it appears feasible to predict the carrier phase.

When no accelerations are experienced, then the error in measured doppler becomes dominant. If the sample interval is 1 second and the doppler error is about 0.5 HZ, then the phase difference is 0.375 cycles or 135°. At a sample interval of 30 milliseconds, the phase difference is 0.01125 cycles or about 4°. This is still a reasonable value to accept for prediction at the high sample rate of 33 samples per second.

The above discussion considered a system wherein the doppler data from each channel was measured, stored, and used to predict the phase difference at succeeding sample times in order to minimize the phase transient. It was shown that such a technique is fruitful only at a high sample rate. If this technique is employed, it will provide the required capability of measuring, storing, and using the large velocities of the order of ±4000 fps to be encountered in an operational environment with actual satellites.

In the proposed approach to a single-channel receiver it is proposed that the code loop be implemented by an envelope correlator. This approach eliminates the dependence of the code loop on carrier phase, thereby eliminating the need for an accurate carrier phase lock loop. Since carrier doppler information is required, a simple way to implement the doppler estimator is employed which uses a time-shared doppler digitizer similar to the one provided in the processors of the 4 channel receiver. The technique is discussed in Section 9.1.4.

Code Loop Frequency and Phase Prediction. The sampling technique considered for the code tracking loop is to sequence through each of the four channels and measure the phase error during the dwell period on each channel. The measure is applied to time-shared filters in such a way as to reduce the error on successive sample intervals. There are two ramifications of such a technique, depending on the sampling rate (high or low) and the means of developing the control signal to drive the error to zero. In the case of the conventional analog loops and a cycle time of the order of one second, the control filter has sufficient time (0.25 seconds) to drive the error to near zero during the dwell time. Depending on the initial (transient) phase error, the transient response could be made to give an accurate estimate of the code phase at the end of the sampling interval.

For a high sample rate (4 millisecond) digital tracking loop, the phase transients from sample to sample will be very small. Thus, the phase corrections to the controlled oscillator can be made one sample period later, provided loop stability is maintained and the dwell time is long enough to average the effect of input noise.

Low Sample Rate Systems. Assume for the present discussion that the cycle interval is 1 second giving 0.25 seconds dwell time for each channel and an off time of 0.75 seconds for each channel. There are four possible processing concepts which can be considered for this application with respect to initial conditions at the time of switching.

Alternative A uses four code generators, each driven at the nominal rate of 10 MHz. The phase of the code generator at the time of switching is uncontrolled so that the loop must recover from a maximum phase transient within the 0.25 second dwell interval, including any code searching due to the effects of vehicle and satellite motion. For the case of the helicopter demonstration, the maximum velocity to be encountered is 200 fps. Assuming perfect tracking at the end of the prior sample interval, the maximum range uncertainty after 0.75 seconds is (0.75 x 200) = 150 feet. Since chip length is 100 ft, there could result an uncertainty of ± $1\frac{1}{2}$ code positions. Therefore, the processor must automatically initiate a search to explore the code cross correlation at 7 one-half bit positions (±150, ±100, ±50, 0). It will be shown that this can be accomplished at received signal levels of about -135 dbm.

The effect of code doppler will now be investigated. The ratio of carrier frequency (1.6 Ghz) to code frequency (10 MHz) is 160 so that the doppler of 300 Hz at 1.6 GHz corresponds to 1.9 Hz at the code rate. This represents a frequency difference of one part in five (5) million. Assuming the sample interval is divided into 7 intervals of 20 milliseconds each and one doppler and tracking interval of 110 milliseconds, the number of code bits which are clocked at 10 MHz are 20,000 per code search position. For a constant frequency difference between the local clock and the transmitted clock of one part in 5 million, the code error at the end of the sample interval is $20{,}000/(5 \times 10^6) = 0.004$ cycles of the code or 0.4 ft of range error. This will be interpreted by the processor as a range error of 0.2 ft, which is clearly insignificant.

In this approach the velocity term in the loop integrators is left to assume the correct value without any prior information due to the fact that a number of code positions must be searched. In the next approach, the code phase is advanced or retarded at the beginning of the sample interval to account for the position error due to motion, but the carrier loop integrator is reset to zero. (In alternate C, the performance can be improved by retaining velocity information of the carrier loop to initially set the integrator initial condition to the last known value. In alternative D, the bandwidth of the loops are switched to reduce the required search time and still retain acceptable accuracy.)

In alternative B, use is made of the last known doppler in order to eliminate the requirement for code position searches. There are two ways in which this can be done: The code generator can be run at the nominal 10 MHz rate plus the last known doppler; the code generator can be advanced or retarded discretely at the beginning of the next sample interval.

If doppler is known to say 0.5 Hz, then the residual error is 0.375 ft at the beginning of the sample interval. This is clearly insignificant. However, the major error comes from the position deviation due to vehicle acceleration. For the case of the helicopter maximum acceleration of 0.5 g, the position error comes to

$(1/2 \times 16 \text{ fps}^2 \times 0.75^2) = 4.5$ ft. This error falls within the operating range of the loop and is adequately handled. Since code searching is not required, the entire 0.25 seconds of dwell is available for loop settling, tracking, and doppler counting. The effect of code doppler is automatically taken into account due to the long dwell time, thus giving adequate time for the velocity integrator to assume the correct value. The major disadvantage with this approach is that it requires an oscillator (with memory) for each code generator, thus making this single channel receiver more like a four-channel receiver.

If the measurement of vehicle motion is used to advance or retard the phase of the code generator while using a common oscillator, only one oscillator is required for all code generators. This can be accomplished by using multi-state phase selection logic which selects the phase of a counted down clock in accordance with a stored value of last measured velocity. For example, an oscillator at 40 MHz could have 8 selectable phases when counted down to 10 MHz.

This approach works only when the total range uncertainty is less than 1 chip. If the uncertainty is greater than 1 chip, then the clock must be speeded up or slowed down until the code is in the correct position. This can be readily accomplished by running the code generator at 13-1/3 MHz or 5 MHz for several clock periods depending on the last measured velocity. This operation will reduce the uncertainty to about ± 50 ft, and the multi-phase clock could further reduce it to about ± 6 ft. For this case velocity need not be known too accurately (only 6 fps out of 200 fps or approximately 5 bits of digital data). Therefore, 5 bits of storage for each channel, plus gating for the fast or slow clock and the selection of one of 8 phases would be required.

In each of the above two cases, the code loop integrator is initially set to zero.

For these cases, the range accuracy is a function of the actual code doppler and the difference between the local oscillator and the transmitter oscillator. The performance can be improved by storing the velocity value for each channel and resetting the carrier loop integrator to that value.

In alternative C, the loop integrator is reset to the condition it had at the end of the previous sample interval. This has the effect of reducing the initial transient thereby allowing the loop to stabilize much more quickly. The only disadvantage to this approach is that the analog circuits require setting and resetting to specific values. This induces severe switching requirements because of the relatively large values of capacitance. Furthermore, if the signals are stored as digital values, then A/D and D/A converters are required. Although the performance is better than the former approach, the circuit complexity may be such as to discourage implementation.

In alternative D, the bandwidths of both the code and carrier loops are increased during the search period and are decreased to a narrow bandwidth for improved accuracy during tracking. The compromise to system performance for this approach is an occasional false lock indication due to noise present in the wide search bandwidth. It is expected that this will occur only of the order of 1 per cent and the only detrimental effect is to waste an occasional 20 millisecond dwell interval while still being able to detect lock during the remainder of the apportioned sample interval. Alternative D is proposed as Option I (Section 8).

High Sample Rate Systems. The main advantage to a high sample rate system, of the order of 1 to 50 millisecond intervals, is that the range and doppler data output appears to be continuous thereby permitting position fixes to be made at the high rate. This has the secondary effect of providing a sufficiently high data rate to be used to sense vehicle accelerations.

Assuming a sample interval of 30 milliseconds, the total off time is 22.5 milliseconds. The position deviation due to acceleration is only $(1/2 \times 16 \times (22.5 \times 10^{-3})^2 = 0.004$ ft, and the position uncertainty due to vehicle motion is 200 fps x 22.5 millisec) = 4.5 ft. This amount of uncertainty does not impose any sort of code generator clock speedup or slow down because the next sample time always occurs within one chip. However, for actual satellite doppler of ±4000 fps, the uncertainty will come to (4000 x 22.5 ms) = 90 ft. Because this is a slowly varying value, it could be stored as a digital value after initial acquisition is achieved. It would be subsequently updated by the effect of the digital filtering and always maintain the correct value.

Channel Sequencing Analysis (Analog Processor). One of the proposed approaches to the helicopter demonstration receiver is to modify an existing four-channel receiver to act as a single-channel receiver by disabling three processors in sequence at the desired sample rate. For optimal performance the processor bandwidths and reacquisition circuits must be changed. This section presents an analysis of the required bandwidths and the receiver performance to be expected in the helicopter tests. The mode of operation is that each channel is selected for tracking at an interval of one second. This provides 250 milliseconds during which the processor will search, acquire, settle and determine doppler. The time allotted for doppler counting is 100 milliseconds (as with the four-channel receiver) leaving 150 milliseconds for search and acquire. The code position uncertainty which determines search time will be computed.

The helicopter to be used in the demonstration has a maximum speed of 120 kt (200 ft per second). During the channel off-time of 750 milliseconds, the range error introduced is 150 ft. Assuming (for this GFE receiver) that no code loop velocity aiding is available, then the processor must search a range uncertainty of ±150 ft. This will be done in 50-ft increments (1/2 bit length) so that a search at 7 code positions will assure a high probability of code acquisition. Since the allowable time is 150 milliseconds, the search at each position can take no longer than 150/7 = 21.4 milliseconds. (In an operational system, the satellite motion of about ± 4000 ft per second will be measured and the velocity used to advance or retard the code generator.) This function will be accomplished discretely by storing a digital value of the doppler signal of about 7 bits (LSB = 32 fps) per channel and using the count to gate a clock into the code generator for the prescribed time or slipping back in time for the prescribed time. For example, assume a doppler measure of +3200 ft per second. This would be stored as the binary equivalent of 100. If the fast clock is at 13.3 MHz, the difference code rate is 3.3 MHz. In 3/4 second, the range will have changed by 3/4 x 3200 = 2400 ft, so that the fast clock must run for 2400/100 ft x 1/3.3 MHz = 7.2μseconds. The clock count of 100 will be obtained in the 7.2μseconds, so that the velocity code aiding counter is operating at a reasonable rate of 14 MHz (100/7.2 useconds).

The relationship between signal power, loop bandwidth, accuracy and pull-in time will be determined as follows. The total time to dwell at a specific code position in order to determine that synchronism (tracking) is achieved, is the sum of the time for carrier acquisition due to doppler (t doppler), the time for carrier stabilization (t carrier), the time for sync decision (t sync), and the time for code settling (t code). The equations for these quantities are:

$$t \text{ doppler} = 4.2 \frac{(f_o v_c / c)^2}{(\sigma_\varphi^2 P_s/N_o)^3}$$

where f_o = 1.6 GHz

v_c = velocity uncertainty (200 fps)

$c = 1 \times 10^9$ fps

$$\sigma_\varphi = \frac{2 \ f_o \ T_1}{c}\left(\frac{\sigma_v}{\sqrt{2}}\right) = 0.707\sigma_v$$

where T_1 = doppler interval (100 msec)

σ_v = standard deviation of velocity error

$P_S/N_o = 1/2 \frac{P}{N_o}$

P = received signal power level

N_o = -168.5 dbm/hz (for noise figure of 5.5 db)

$$t \text{ carrier} = \frac{1}{\sigma_\varphi^2 P_s/N_o}$$

t sync = 5 t carrier

$$t \text{ code} = \frac{5000}{\sigma_r^2 P_S/N_o}$$

where σ_r is standard deviation of range error

A parametric study was performed to arrive at the signal power compatible with the required 21.4 millisecond dwell interval. The results are presented below:

1. Assume code loop phase error of σ_r = 25 ft

   Then

$$t \text{ code} \times \frac{P_s}{N_o} = \frac{5000}{(25)^2} = 8.0$$

2. Assume velocity error of

$$\sigma_v = 1 \text{ fps}$$

$$\sigma_\varphi = 0.707$$

Then

$$t \text{ carrier} \times \frac{P_s}{N_o} = \frac{1}{(.707)^2} = 2.0$$

3. $$t \text{ sync} \times \frac{P_s}{N_o} = 5 \times 2 = 10.0$$

4. Assume velocity uncertainty is 200 fps

Then
$$t_{doppler} = 4\pi^2 \frac{(1.6\times10^9 \times 200 \text{ fps}/(1\times10^9))^2}{(0.6\, P_s/N_o)^3}$$

$$t_{doppler} \times \frac{P_s}{N_o} = \frac{3.45\times10^6}{(P_s/N_o)^2}$$

5. The following table gives the value of t doppler x $\frac{P_s}{N_o}$ for various representative values of input signal.

Input Signal	P_s/N_o	t doppler x $\frac{P_s}{N_o}$
-125 dbm	40.5 db	0.03
-130 dbm	35.5 db	0.28
-135 dbm	30.5 db	2.82
-140 dbm	25.5 db	28.20

6. The following table gives the total time to dwell at each code position:

Input Signal	(t code	+ t carrier	+ t sync	+ t doppler) x $\frac{P_s}{N_o}$	= T x $\frac{P_s}{N_o}$	T (millisec)
-125	8.0	2.0	10.0	0.03	20.03	1.8
-130	8.0	2.0	10.0	0.28	20.28	5.7
-135	8.0	2.0	10.0	2.82	22.82	20.4
-140	8.0	2.0	10.0	28.20	48.20	136.0

It is readily seen that the required dwell interval of 21.4 millisec can be obtained at a signal level of -135 dbm.

The loop bandwidths and the transient performance will now be determined.

7. The carrier and code loop bandwidths during acquisition are given by:

$$B_L \text{ carrier} = \frac{P_s}{N_0} \sigma_\varphi^2 = 560 \text{ hz}$$

$$B_L \text{ code} = \frac{P_s}{N_0} \sigma_r^2 \frac{1}{5000} = 140 \text{ hz}$$

For tracking the bandwidths are (at -135 dbm):

B_L carrier = 22.4 hz (for σ_v = 0.2 fps)

B_L code = 11.2 hz (for σ_r = 7 ft)

In order to accomplish this processing, a fast code clock is applied to the code generator for about 0.5 μsec which advances the code by 150 ft. The processor is permitted to dwell for 20 milliseconds. If no sync decision is obtained at that time, the code is slipped by 1/2 bit and the processor will dwell for another 20 milliseconds. If an in-sync decision is not reached by the time the next channel is selected, a count is incremented. This count is accumulated to a maximum of 8 at which time an indicator is activated to alert the pilot to initiate matched filter sync.

When a sync is detected at the end of a 20 millisecond dwell interval, the loop bandwidths are reduced to improve tracking accuracy and prepare for doppler counting. Depending on whether the range is decreasing or increasing, the processor could acquire the signal from 20 milliseconds to 140 milliseconds after the beginning of the sample interval, thereby giving between 230 and 110 milliseconds for settling and tracking. The following table gives the residual phase transient error at the end of 250 millisecond sample interval depending on relative range rate, for an initial worst case transient error of 50 ft and 2 fps:

	Range Rate (fps)	Remaining Settling Time (ms)	Residual Phase Error (ft)	Residual Doppler Error (fps)
Decreasing Range	200	230	1.2	0.01
	150	230	1.2	0.01
	100	210	4.8	0.02
	50	190	5.5	0.03
	0	170	7.4	0.05
Increasing Range	50	170	7.4	0.05
	100	150	9.3	0.07
	150	130	11.6	0.12
	200	110	16.5	0.17

8. When the signal level is at -130 dBm, the range standard deviation error reduces to 4.0 ft (from 7.0 ft) and the transient error is reduced to 1/2 of that given above.

9. It is interesting to observe the effect of a lower noise figure. An analysis was performed at a noise figure of 3.5 db. It was determined that although the required dwell time at -135 dbm was about 10 milliseconds (compared to 20 milliseconds), that the required 20 milliseconds was obtained at about -137 dbm. Therefore, for the helicopter demonstration, it is not necessary to utilize a better front end with a low noise figure.

Coherent and Non-Coherent Correlation. The code control loop used in the code search can be implemented either by a phase-coherent or a non-phase-coherent loop. The system utilizing the phase-coherent approach incorporates a phase-locked loop.

In the non-coherent approach, a fixed-frequency local oscillator is used to demodulate the input carrier. Bandpass filters having a bandwidth wide enough to accommodate the frequency uncertainty between the received signal and the reference signal must then be used preceding the envelope detectors.

At relatively high signal-to-noise ratios the performance of these two implementations is virtually identical; thereby favoring the non-coherent approach since it is simpler to implement. However, as the signal-to-noise ratio decreases and/or as the frequency uncertainty increases, the performance of the non-coherent loop decreases rapidly due to the suppression effects in the envelope detectors. High performance under these conditions can be maintained only by the use of a phase-coherent system.

Both the coherent and non-coherent loops discussed above can be implemented by either analog or digital means. The analog approach utilizes lumped elements within the loop and a VCO. In the digital approach, filtering operations are replaced by sampling, A/D conversion, and weighted summing. The VCO can be replaced by a fixed-frequency clock with an adjustable time base. The error signal output from the loop is used to select and switch between the various time bases.

The performance of the digital loop will be deteriorated somewhat with respect to the analog implementation due to the various quantizing effects present in both amplitude and timing. However, the relative simplicity of this implementation makes the digital approach attractive.

The advantage of a non-coherent (envelope) correlator for the code tracking loop is that it permits a simple carrier detection means because the code loop is independent of carrier phase. Since high carrier phase accuracy is not required, a phase lock loop is not necessary. If a noise free replica of the carrier is developed for each channel, doppler can be estimated by one of several techniques.

This section contains an analysis of the parameters which are required for a non-coherent code loop. The discussion included here takes into account the operational parameters of satellite motion so that any ensuing design can serve as a realistic prototype for an operational system.

The signal input to the code loop consists of a carrier phase modulated by a PN code. This signal is correlated with early and late signals obtained from a local code generator modulating a convenient carrier. The resulting signals are applied to bandpass amplifiers of bandwidth, sufficient to cover the frequency uncertainty, and then processed either with digital or analog circuitry.
The functions to be performed are narrowband filtering, envelope detection, summation and integration.

The bandwidth of the pre-detection filter will now be determined. Assuming a frequency accuracy of the satellite and user oscillator of 1 part in 10^6, the worst case frequency difference is $\pm 2 \times 1 \times 10^{-6} \times 1.6 \times 10^9$ Hz = ± 3.2 KHz. The satellite motion is a maximum of ± 4000 fps (± 6.4 KHz) and the user motion is assumed to be ± 300 (480 Hz) fps. The total frequency uncertainty is a worst case maximum of ± 10.1 KHz. Therefore a bandwidth of 20 KHz would encompass this uncertainty. The center frequency is unimportant, except that it should be low enough to permit reasonable A/D conversion and sampling rates if digital processing is to be performed, and high enough to avoid spectrum fold-over.

Assuming that the system must operate at a signal level of -140 dBm, the bandwidth of the narrowband filter can be determined. Thermal noise has a value of -174 dBm/Hz which increases to -168.5 dBm/Hz for a noise figure of 5.5 dB. The signal to noise density ratio is +28.5 dB-Hz at a signal level of -140 dBm. The envelope detector must have an SNR of +6 dB to operate satisfactorily so that the bandwidth must be less than 22.5 dB (28.5db - 6db). This corresponds to a bandwidth of 180 Hz (±90 Hz).

The response time of this filter is about 10 milliseconds, and in time-sharing this filter, one would need to wait about 30 milliseconds for past history to subside. This indicates that the shortest cycle interval is of the order of 120 milliseconds. As will be shown later, this sequencing rate is inadequate for a good processor design. If the filter is implemented by digital techniques and storage for each channel provided as digital data, then the response time does not affect the time-sharing rate. Therefore the recommended approach is to perform digital processing for the narrow band filter, envelope detector and loop integrators. The proposed configuration is given in Section 9.1.4.

Accuracy Analysis (Digital Loop). An analysis of the digital envelope correlator was performed and the results are included herein. There are three major areas of consideration for the accuracy analysis. One is the theoretical performance of a hypothetical non-coherent tracking loop as compared with a coherent loop; another is the quantization effect introduced by the A/D converters and the digital computations for the filters; and the third is the quantization effect of the discrete phase selection circuitry. These areas are discussed in the following paragraphs.

The error equations for the code loop outputs are listed below for both the coherent and non-coherent approaches:

$$\sigma_r(c) = 100\sqrt{\frac{B_L}{2P_s/N_0}}\ \text{feet}$$

$$\sigma_r(nc) = 100\sqrt{\frac{B_L}{2P_s/N_0}} \times \sqrt{1 + \frac{2B_1}{P_s/N_0}}\ \text{feet}$$

where σ_r is the standard deviation of range error

B_L is the loop bandwidth

P_s/N_o is the signal to noise density ratio

B_1 is the predetector filter bandwidth

When these equations are evaluated at a signal input level of -135 dBm,* the following errors are obtained:

B_1 (Hz)	$\sigma r(c)$ (feet)	σr (nc) (feet)
100	7.0	7.6
200	7.0	8.2
300	7.0	8.7
500	7.0	9.6

The slight increase in error appears to be a reasonable compromise for a tradeoff of a large error (about 25 ft) for a worse case short delay multipath for the coherent loop.

The effect of quantization errors cannot be rigorously analyzed due to the non-linear operations and the sample data equivalence of the continuous filtering functions. However, some general guidelines can be set down which are used as the starting point for experimentation. At present, a computer simulation of the

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* The comparison is made at B_L of 11 Hz because this is the bandwidth of the analog processors. The digital processor will have B_L equal to about 1 Hz with a $\sigma_r \leq 5$ ft at -140 dbm and $B_1 = 500$ Hz.

code tracking loop is being performed as an IR&D effort at Hazeltine. The simulation is a Monte Carlo exercise of the mathematical functions which would be implemented by actual hardware. As of this time, experimental data indicates that the performance of such a system is in close agreement with the results obtained by first order approximations to the loop. Further computer runs will explore the multipath performance under various transient and steady state conditions.

As a first step at the definition of word length and A/D conversion accuracy, one must consider the maximum dynamic range of the input signals and the theoretical requirements on gain and phase matching in the "early" and "late" processing channels. The effect of permitting a wide dynamic range of the input signal is to provide improved accuracy and response time at high signal levels. An alternate to this is to employ AGC which would maintain relatively constant loop gain, thereby maintaining relatively uniform response time and accuracy regardless of signal level. The most stringent word length requirements are imposed by a wide dynamic range and will therefore be considered.

Assuming the signal level variation is from -143 dBm to -120 dBm, a total range of 23 dB must be accommodated. AGC is provided for signal levels in excess of -120 dBm. This corresponds to a voltage variation of a factor of 14. This alone requires 4 bits of conversion resolution. In order to keep the effect of noise jitter, down to reasonably low values at the lowest signal levels, the phase detector should have a resolution of the order of 1 per cent of maximum value. This gives a resolution of about 0.5 ft for 100-ft chip length, which requires about 7 bits. This brings the total to 11 bits. Adding one more for the sign gives 12 bits for the A/D converter resolution, which results in a quantization error of ± 0.5 ft.

The effect of the phase selection circuitry will now be determined. The basic phase delay will be obtained from the timing relations of 10 MHz and 10.05 MHz signals. The resolution is 0.5 nanoseconds (0.5 ft) for the coincident detector and about 2 nanoseconds for the output trigger pulse timing jitter. This sync pulse (which occurs every 20μseconds) synchronizes a 10 MHz oscillator whose maximum error is ± 0.1 per cent. Over the 20μsecond time interval, the timing error could be ± 20 nanoseconds (0.1% x 20μsec) which manifests itself as a bias error of ± 10 nanoseconds. As this error is due principally to temperature variation, the error will be reasonably constant over many minutes of real time. Therefore, the total random error would be of the order of 2.5 nanoseconds and due principally to trigger timing variations of the circuitry.

Rotor Modulation Effects. The signal field at a point shadowed by the rotor blade has been determined in Section 5.5 of this report. The analysis has indicated that an amplitude variation of approximately 1.5 dB will be experienced and an RF phase variation of 0.2 to 0.6 radians. The effect of the amplitude variation is expected to be relatively insignificant because of the averaging action of the code and carrier loop. The phase variation effects on each of the two recommended approaches will be discussed in the following paragraphs.

Single-Channel (Digital) Processor. The digital processor utilizes circuitry which samples the incoming signal for a one millisecond dwell interval for each channel and processes the resulting values in digital filters. Actually the sample rate is about 40 KHz (25μsec) in order to implement digital time shared narrowband bandpass filters which can be rapidly switched between the four channels. The bandwidths have been selected at about 180 to 300 Hz to provide a signal to noise ratio at the inputs to the envelope detectors of about +6 dB. Since the code loop is a non-coherent correlator the RF phase does not directly affect the performance, as is the case for a coherent code loop. Therefore, the RF phase variation of 0.2 to 0.6 radians does not affect the ranging accuracy of the envelope correlator code loop.

The principal effect on the code loop is due to the harmonic content of the phase variation. That is, the bandwidth of the pre-detector filter must be wide enough to pass the significant harmonics of the modulation. In the analysis performed, it was found that significant energy was contained in harmonics as high as the tenth harmonic (100 Hz). It is pointed out in Section 9.1.4 that the actual bandwidth of the predetection filter is unimportant as long as the input to the envelope detector is at least +6 dB since the low pass filtering of the entire loop (about 1 Hz) determines the ranging accuracy. The effect of the harmonic content in the rotor modulation is to impose a lower limit on the predetector filter, and in this case, corresponds to 100 Hz. Therefore, as long as the bandwidth is greater than 100 Hz, the ranging accuracy is unaffected at the signal levels of the order of -140 dBm.

Somewhat different effects will be experienced when the code loop is a coherent correlator as discussed next.

Modified GFE Receiver. The effects of rotor modulation on a coherent code loop are such that the RF phase variations are reflected directly into the ranging accuracy. In the case of the modified receiver, which must search several code positions in order to arrive at a sync condition, the phase variation must be held to small values. The analysis presented in Section 9.1.3 indicates that a sync decision could be made in a worse case time of 20 milliseconds thereby permitting one second sequencing at a signal level of -135 dBm with a 200 fps velocity uncertainty. This has been calculated for an RF phase jitter of 0.7 radians, determined as a reasonable value for stable loop operation. As the rotor modulation has significant energy in the 10th harmonic (50 Hz), the dwell interval of 20 milliseconds corresponds to one cycle. It is conceivable that under the worst case, the total phase error presented to the code loop would be the maximum value of 0.6 radians plus the one sigma value of 0.7 radians or 1.3 radians. This could result in a condition of missed sync or cause a sync to be detected at the wrong code position. One convenient way to circumvent this difficulty is to reduce the bandwidth of the carrier loop to reduce the phase jitter to say 0.35 radians. This will cause a longer search time for the assumed 200 fps velocity uncertainty. Alternately, the velocity uncertainty can be reduced by holding the voltage to the VCXO at the last value which will then be applied at the beginning of the next one second cycle. The search time for $\sigma_\psi = 0.35$ radians will now be computed in the manner of Section 9.1.3.

$$t_{carrier} \times \frac{P_s}{N_0} = \frac{1}{\sigma_\varphi^2} = \frac{1}{(0.35)^2} = 8.2$$

$$t_{sync} \times \frac{P_s}{N_0} = 5 \times 8.2 = 170$$

$$T \times \frac{P_s}{N_0} = \frac{P_s}{N_0}\left(t_{code} + t_{carrier} + t_{sync} + t_{doppler}\right)$$

At a signal level of -135 dBm

$$T \times \frac{P_s}{N_0} = 8.0 + 8.2 + 170 + 2.82$$

$$T = \frac{36.82}{P_s/N_0} = \frac{36.82}{1.12 \times 10^3} = 33.0 \text{ millisec}$$

This only permits 5 code positions to be searched, which encompasses a range rate of ±133 fps (rather than 7 positions for ±200 fps). The carrier loop bandwidth for this case is 140 Hz. In the proposed system, it will be possible to vary the carrier loop bandwidth and code search positions in order to take this modulation effect into account.

A second effect of rotor modulation is the tracking performance during the tracking interval due to the rotation rate. It is desired that doppler information be obtained over an interval of 100 milliseconds which corresponds to one complete cycle of the fundamental rotor frequency. As long as the doppler interval is within about 20 percent of the rotor period, no degradation to doppler or ranging accuracy is expected.

A third effect is the doppler which is induced by the rotation of the blade on multipath signals reflected from the blades. As this phenomenon has not been completely analyzed, the test program will include an experiment to determine the exact extent by using one dedicated channel and recording the performance for various elevation angles of the balloon borne transmitter, both with and without the rotors in motion.

9.1.4 Design Details, Options I and II

There are two promising candidate approaches to a receiver configuration suitable for the Army helicopter demonstration. One of the two approaches is considered because it promises a modest amount of meaningful test data at a minimal cost. It consists of a GFE four-channel receiver modified to accommodate the physical environment and the dynamic characteristics of a helicopter. The modifications consist of using different processor code and carrier loop bandwidths and different reacquisition parameters. Its operation is such that three of the processor channels are disabled, while the fourth is being tracked. The cycle time is set at 1 second per cycle. This approach has previously been designated Option I.

The second approach is to provide a new single-channel receiver which utilizes digital processing in the code and carrier loops that is time-shared and cycled between all four channels at a rapid enough rate so that the output range and doppler data appears "continuously" at a rate of 5 sets of data every second. This approach has been selected and is recommended because it provides a significant advance in tracking loop technology and is a representative prototype for an operational receiver. Additional advantages are that it would be smaller and cheaper than the four-channel system while providing comparable accuracy in a helicopter or groundbased user environment. This approach has previously been designated Option II.

The design details of the two recommended approaches are given in the following paragraphs.

Single-Channel Receiver. The new single-channel receiver consists of a newly designed chassis, processor and self-test circuits. The modules such as RF/IF, frequency source and frequency synthesizer are similar or identical to those provided for the four-channel receiver.

An overall block diagram of the receiver is shown in Figure 9-1. It consists of the following modules:

- RF/IF
- Matched filter and driver
- Frequency/source and synthesizer
- Processor and sequencing
- Code generator (two modules)
- Self-test module

Functional Description. The processor (Figure 9-2) consists of hybrid digital-analog processing circuits, some of which are time-shared among the four channels, to provide essentially continuous pseudo-range and pseudo doppler data.

Since the coarse range data is related to the code generator state relative to the standard clock, the coarse range data must be obtained from the code generator module. The fine range data is obtained from the processor for each channel from storage registers which are updated at intervals of the order of 4 milliseconds.

The pseudo doppler data is also available for each channel from data registers that are updated at five times per second. The proposed approach uses a carrier frequency estimator rather than a closed feedback loop and a non-coherent code loop. The processor incorporates a digital tracking loop for the code estimator and a time-shared doppler frequency estimator for the carrier. The code loop is a non-coherent delay lock loop time-shared among the four channels. Because of the digital processing it is practical to implement narrow band functions (long response times) and yet be able to switch rapidly between channels. The operation of the loop is as follows. The input signal, consisting of noise plus the phase-coded 10 MHz signal, is applied to two analog modulators (multipliers). The other inputs to the modulators are the "early" and "late" signals obtained from the selected code generator. The outputs of the modulators are each applied to analog bandpass amplifiers, whose outputs are converted into digital form for further processing. The purpose of the band pass function is to reject high frequency noise, thus permitting the signal to be sampled at reasonable rates of about 20 kHz to 40 kHz.

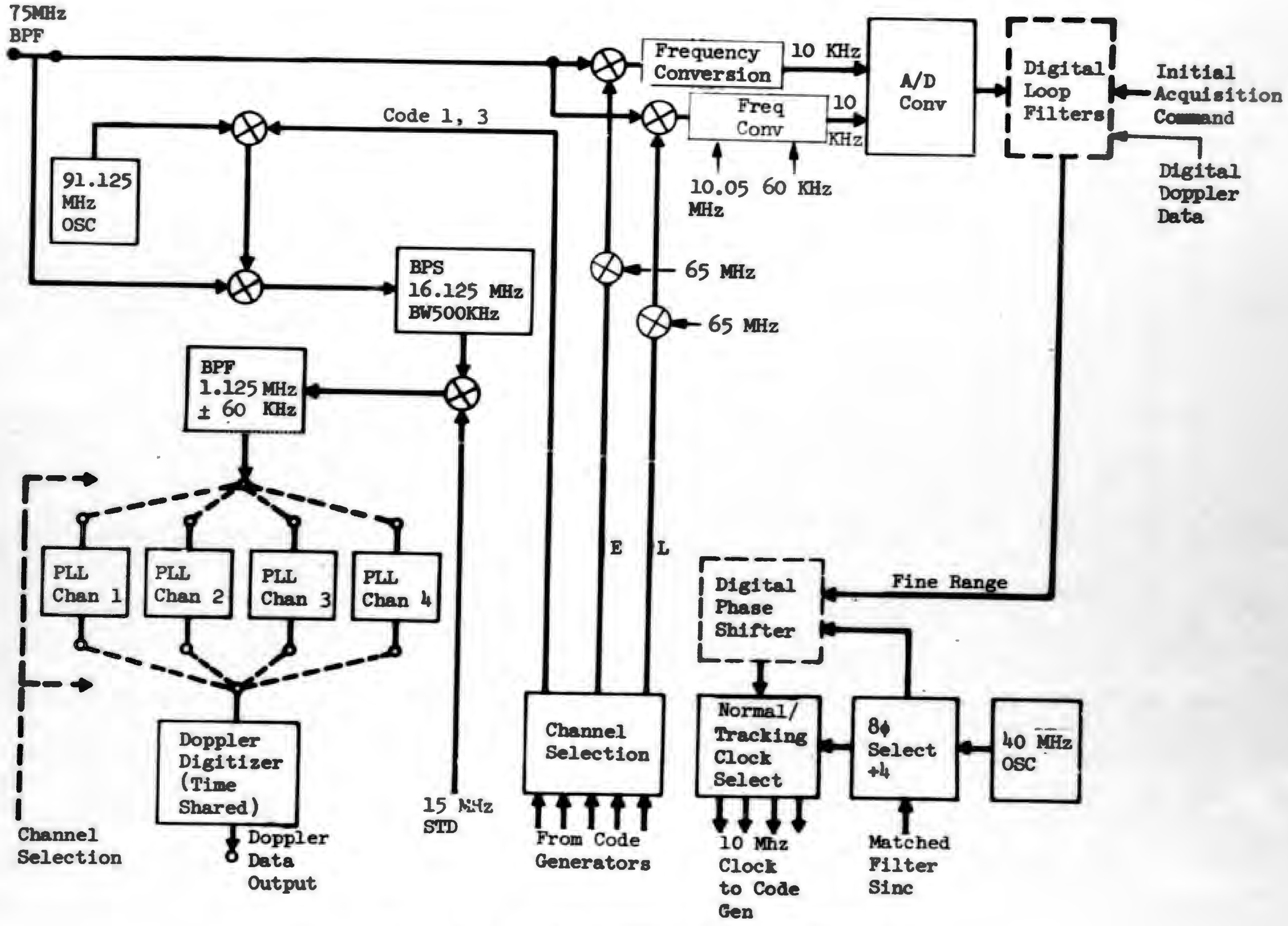


Figure 9-2 Single Channel Receiver Processor

The digital processing to be performed consists of the equivalent of narrow-band filtering and envelope detection in each of the early and late signal paths and integration. When the loops are in the tracking mode, the bandwidth could be of the order of the doppler uncertainty in the signal, which is due only to acceleration. In the helicopter case of 0.5 g acceleration (±24 Hz/sec) and a maximum sample period of 40 milliseconds, the frequency uncertainty only amounts to ± 0.96 Hz.

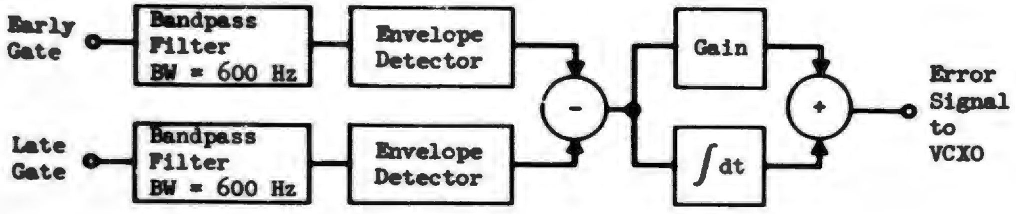
However, in the case of initial acquisition, the doppler uncertainty is equal to dopper due to the helicopter speed plus the speed (range rate) of the satellite, plus the difference in center frequencies of the satellite and receiver oscillators. In the operational environment, the doppler could amount to the order of 10KHz, while in the demonstration tests will only amount to ±300 hz. Therefore, a fixed bandwidth of 600 Hz (±300 Hz) will be implemented. It should be noted that the subsequent low pass loop filter will provide the processing gain to improve the ranging accuracy, so that it is not necessary to reduce the bandwidth of this predetection filter to 0.96 hz.

There are several approaches to implementing a digital filter with its corresponding envelope detector. One approach involves the non-recursive processing of all data samples obtained during the dwell time (of 1/4 of the total sample time); another approach is to recursively process the data as in a fast Fourier Transformer or a sampled data equivalent of a continuous filter. The dwell time determines the number of samples which must be processed non-recursively and at a sample rate of 30 Khz, 30 samples are obtained in 1 millisecond of dwell (300 samples in 10 milliseconds). The dwell time can be determined independently from considerations of code doppler as follows:

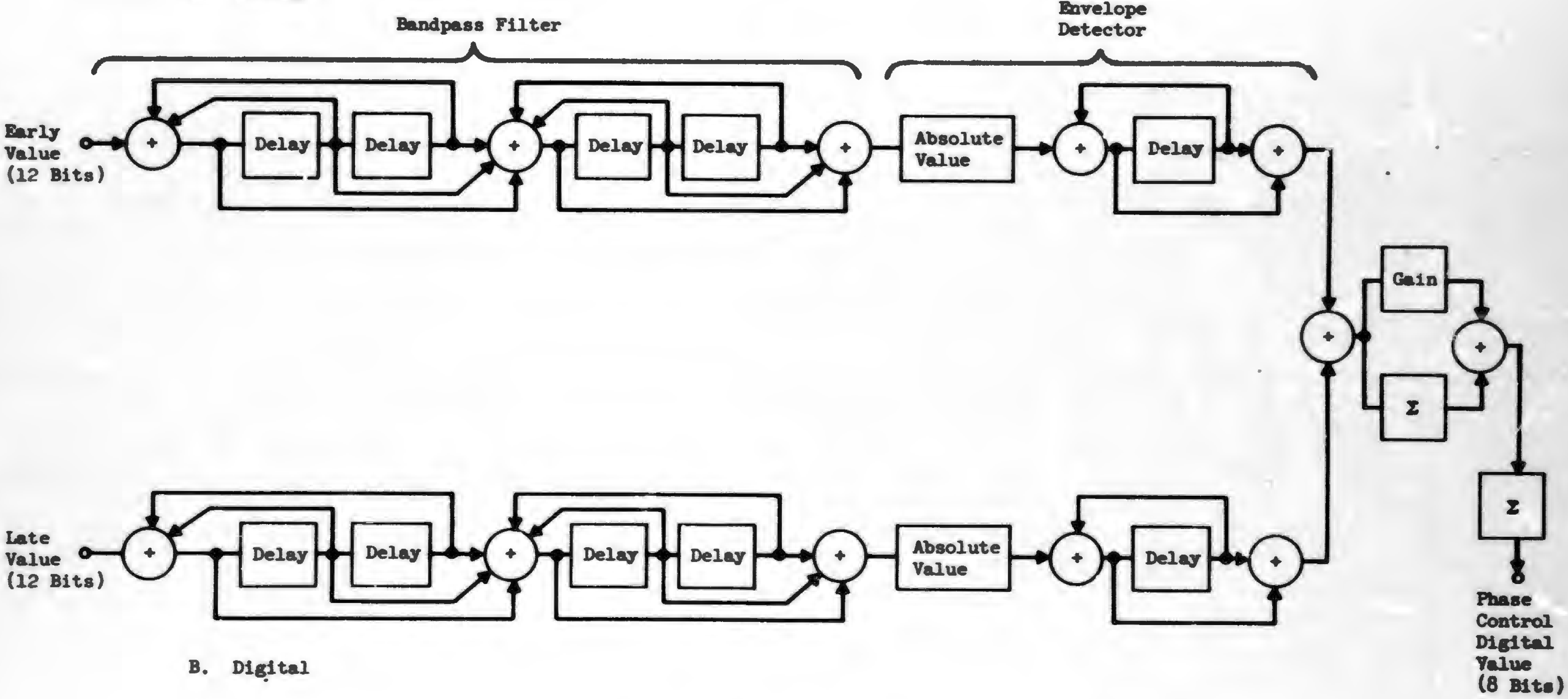
One method of implementing a digital loop is to provide a loop control signal which only controls the phase of the oscillator rather than the frequency or both phase and frequency. As the code doppler is quite low (a maximum of 40 Hz at the operational satellite doppler) it is reasonable to utilize a common 10 Mhz oscillator to clock all four channels, but to introduce a phase delay control to the clock which drives the selected and tracked code generator. Therefore, if it is assumed that the doppler difference of 40 Hz persists during the dwell interval, the phase error introduced at the end of 1 millisecond of dwell is 0.04 cycles of 100 ft or 4 ft. (At 10 milliseconds, the error is 40 ft - which is unacceptable). Therefore, a dwell time of 1 millisecond is selected which results in a 4 millisecond sample interval for all 4 channels.

In the implementation of the digital bandpass filter and the envelope detector (Figure 9-3), it is to be noted that the exact center frequency of the filter should be digitally selectable. Although it will not be required in the demonstration, it is necessary for an operational system. This is because the signal energy could occur anywhere within ±10 Khz, and once determined (after initial search and acquisition) will remain relatively constant for time periods of the order of 5 to 10 minutes. Therefore, there will be a measure of satellite doppler which will be available for internal and/or external use.

The major difference between the digital loop implementation and an analog system is that in the analog system a VCXO is utilized which provides the varying frequency and phase in response to the loop error signal. In the digital system, the VCXO function is performed by a constant frequency oscillator while phase selection logic provides discrete phase shifts in response to the loop error signal. The loop error signal in this case is the output of a double integrator implemented in the digital filter. One of the digital integrators, substitutes



A. Analog



B. Digital

Figure 9-3 Single Channel Receiver Loop Filter for the integrator function of the VCXO.

The digital phase shifter operating at the code frequency of 10 Mhz is the key element in the digital code loop. The main reason for this is that in order to keep the fine range error small the time delays and time differences need to be maintained at around 1 to 2 nanoseconds (1 to 2 ft).

The method which has been selected as the most promising to meet these stringent conditions is to utilize accurate synchronization pulses obtained from the timing relations of two signals (10 Mhz and 10.05 Mhz) to cause synchronization of a free running oscillator. The block diagram of this device is shown in Figure 9-4. The synchronizing pulses are obtained at the difference frequency of 50 KHz (20 μsec).

The operation of the phase shifter is such that a reset signal is generated whenever the 10.0 and 10.05 Mhz signals are coincident to within 0.5 nanoseconds (the value of the LSB of the counter). A count of 256 (8 stages) provides a total delay range of 128 nanoseconds.

The major design considerations for this technique are to keep circuit propagation delays small, repeatable and relatively constant over temperature. When integrated circuits are used in the critical paths, their delay variations must be kept small.

The oscillator is a conventional LC oscillator where temperature compensation is utilized for the L and C to provide the required accuracy of 0.1 percent over temperature. The key factor in the discrete transistor components used therein is to operate them out of saturation to eliminate charge storage effect. This type of oscillator has been built at Hazeltine for use on several programs and

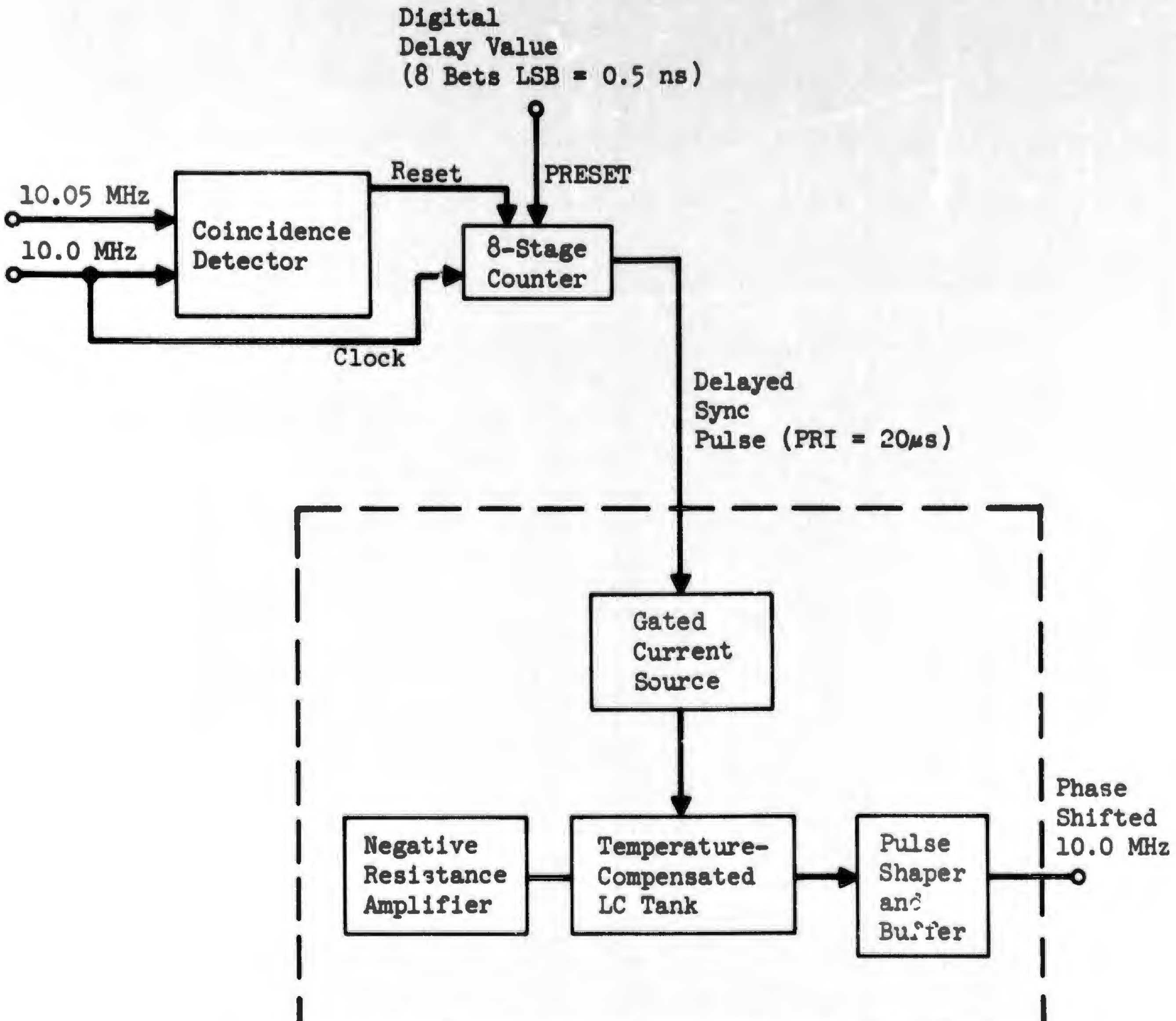


Figure 9-4 Single Channel Receiver Digital Phase Shifter

has been shown to achieve stabilities of the order of three parts in 10^4 (0.03%) over a temperature of -25° to $+70^\circ$C.

Carrier Detection (Doppler Estimation). The "carrier loop" for the helicopter application is reduced to circuitry for the estimation of the carrier doppler frequency. This occurs because the non-coherent nature of the code loop eliminates the code loop dependence on carrier phase. Therefore, as long as the frequency uncertainty in the received code signal is within the capability of the code loop design, in this case ± 10 Khz, then there is no need to close the carrier loop.

The principle of operations is as follows. Assuming a condition of code tracking, the function of the doppler circuits is to estimate the doppler to about 0.2 fps for each of the four channels. To do this, narrow band integrated circuit phase locked loops (PLL) are provided to develop noise free replicas of the received carrier. The input signal to each loop consists of the received signal modulated (correlated) by the standard clock of 15 Mhz which is modulated by the selected code. The code is selected from one of the four generators at the channel sequencing interval of 4 milliseconds. During the one millisecond dwell time on each channel, the selected PLL is updated by the incoming signal. The output of the PLL is then a noise free replica of the incoming signal which is available continuously due to the coasting of the loop during the channel off time.

The degree of noise reduction depends on the loop bandwidth which in turn depends on the frequency uncertainty from sample to sample. In the helicopter application, the frequency uncertainty is due principally to acceleration of 16 fps^2 (24 hz/sec). At the sample cycle of four milliseconds, the frequency uncertainty is

0.1 hz, and if allowance is made for say 5 missed intervals, then the bandwidth could be 0.5 hz. However, such a narrow band makes the initial pull-in time long. The pull-in time can be calculated as follows. The total frequency uncertainty of ± 10 Khz and the noise figure of 5.5 db at a signal level of -135 gives a SNR of -9.5 db at the input to the loop. Assuming that a 6 db SNR is required for the loop, the loop bandwidth (B) must be reduced by 15.5 db to about 560 hz. The pull-in time is given by the following equation:

$$t = 4.2 \frac{(\Delta f)^2}{B_L^3} \qquad \Delta f = 10\,khz$$

$$t = 4.2 \frac{(10,000)^2}{(560)^3} = 2.4 \text{ seconds}$$

However, since each channel is on only 25% of the time, the total pull-in time is 9.6 seconds. Standard deviation of the doppler error for this signal to noise ratio of 6 db is given by the following formula:

$$\sigma_f = \frac{\sqrt{2}}{2\pi T}\left(\frac{1}{SNR}\right)^{1/2}$$

$$\sigma_f = \frac{\sqrt{2}}{2\pi(0.100)}\left(\frac{1}{4}\right)^{1/2} = 1.1\,hz\ (0.7\,fps)$$

Once the carrier loops achieve lock, their bandwidths are reduced to about 56 Hz, providing a + 16 db SNR for an "in lock" doppler error of 0.36 Hz (0.22 fps). The bandwidth of 56 Hz still provides adequate bandwidth for a signal dropout for one to two seconds.

There are several means of implementing the frequency counters in order to obtain a measure of the doppler. The technique which has been selected is the same one employed in the basic 621B 4 channel receiver. It consists of doppler counting circuits which count the number of cycles of a signal of approximately 125 Khz occurring in a specified interval of about 50 milliseconds. This gives the coarse doppler. The fine doppler is determined by a count of the 10 Mhz clock pulses proportional to the fractional portion of a cycle of the 125 Khz signal required to complete the 50 millisecond doppler interval. A block diagram of the doppler digitizer is given in Reference 1 .

The doppler data is obtained on all four channels, sequentially, thereby requiring 0.2 seconds (4 x 50 msec) of real time. The doppler difference over 0.2 seconds corresponds to ± 3.2 fps so that the doppler data will be provided from a single set of registers, time shared among the four channels. The sample for any specific channel will be the average value for the 50 millisecond time period immediately preceding the readout signal.

The code generator modules are two identical modules, each of which contains two identical code generators similar to those contained in the four channel receivers. In addition to the code generator boards, each module contains six boards (5" x 5") to perform the coarse range counting, timing and early-late gating for each channel.

Mechanical Configuration. The single-channel receiver, excluding the power supply, is packaged in a volume that is 14 in. wide, 16-$\frac{1}{4}$ in. deep (including connectors), and 10 in. high. It consists of an upper and a lower section divided by a central air plenum. This air plenum, much like that used on the four-channel 621B receiver, acts not only as a manifold for the cooling air but as the main support structure for the modules. The packaging concept for this prototype receiver is generous of space in order to provide adequate space for future modifications and additions. The design of such a receiver for operational usage would be of the order of half the size of a four-channel receiver.

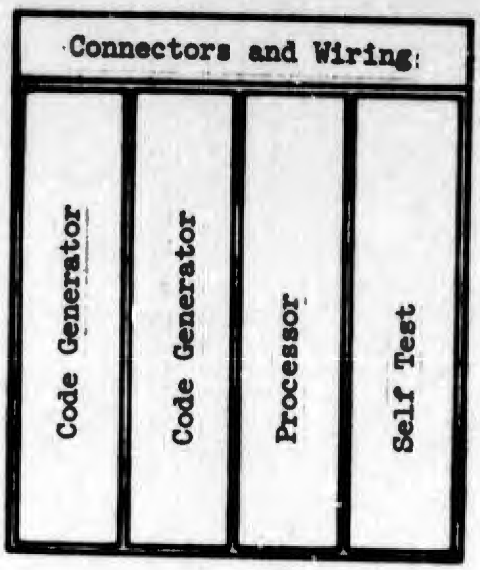
The two code generators, the processor and the self-test module are located on the top; the RF/IF, frequency synthesizer, and matched filter are bolted underneath. Figure 9-5 illustrates the configuration of the single channel receiver.

A bolt hole pattern is located along each side of the chassis to tie in the mounting brackets that will be used to support the receiver.

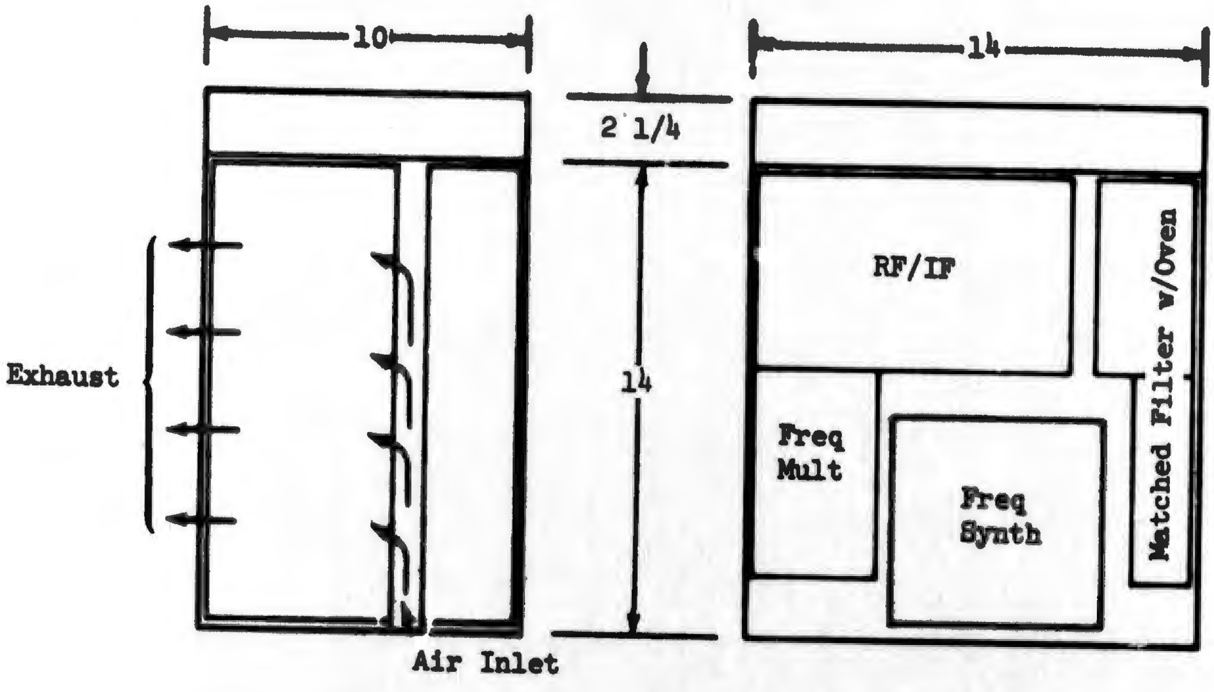
The design of the chassis is rugged. Because of the nature of the equipment, it is designed to withstand rough handling. Due to the acceleration sensitivity of the oscillator, however, the receiver must be supported for operation on vibration isolators which will attenuate the vibration of the aircraft to that described in Curve II of MIL-E-5400.

The power supply unit, in the interest of maintaining a cost-effective program by utilizing an existing design is identical to the power supply provided for the four-channel receiver. A design for an operational single-channel receiver will be significantly smaller. The power supply which is provided is 14 x 14 x 9 in. high, and is capable of withstanding the vibration environment as specified by Curve IV of MIL-E-5400 both while operating and non-operating.

Both the Receiver and Power Supply need auxiliary cooling to maintain a reliable operating condition. Each is supplied air by an external blower via an inlet air duct while the internal chassis distributes the air. Using Class 1A conditions, 65 cfm of ambient air is required for the receiver and 30 cfm for the power supply. The blowers for each unit are altitude compensating blowers. At 30,000 feet, the blower speeds up to compensate for the reduction in air density.



Top View



Side View

Bottom View

Figure 9-5 Single Channel Receiver

The high heat dissipating modules in the receiver, namely the code generators, the processor, and the self-test, have perforated top and bottom plates. The chassis/plenum to which they are attached has mating holes. The air, blown in from the rear, travels through the plenum, up through the plenum holes and bottom perforated plates of the modules, and then across the vertically oriented printed wiring boards and hot components within each module. Finally the air is exhausted out the top. Cooling is by direct forced convection and a 12°C temperature rise of the cooling air is expected. The modules on the bottom conduct their heat to the underside of the chassis which, in this case, acts as a thermal heat exchanger.

The power supply heat is conducted to a forced convection heat exchanger on the underside of its chassis and eventually removed by the forced air supply.

Testing. An acceptance test will be performed on the single-channel receiver which will verify that the receiver meets the performance characteristics defined in the performance sections of this report. The tests will include pseudo range and pseudo doppler accuracy as a function of signal level and the helicopter dynamics. RF signals which simulate the expected amplitude and doppler variations will be applied, and bias and random errors in range and doppler will be verified.

The receiver will be placed on a vibration table which will impart the vibration profile to be expected in the helicopter installation. This will be accomplished using the actual equipment rack that will be installed in the helicopter. This will also serve to verify that the entire mechanical arrangement has the required integrity to assure of a successful flight test program. The pseudo range and pseudo doppler signals will be monitored to verify that the system accuracies are maintained for various signal levels.

The receiver will be placed in a temperature chamber and operated at normal room temperature and cycled to an ambient of +71°C. The unit will be operated at +71°C, and the temperature will be reduced to +55°C to verify that the accuracies are maintained at +55°C.

When the receiver is delivered to the test site, it will be installed and checked out with the helicopter installation and data acquisition system. The test, instrumentation and diagnostic procedures employed during the NC-135 tests will also be used to verify system operation. Additionally, an indicator unit will be provided which will display fine range and fine doppler to verify that the receiver is operating properly. This unit plus the internal receiver self test provides a high degree of confidence in operational readiness.

Modified Four-Channel Receiver. Functional performance modifications:

- Channel sequencing gates will be added to the processor or in place of an RF/IF module to permit disconnecting the input signals to three quiescent channels.
- Channel sequencing control circuits will be added to permit sampling each channel for an interval of 0.25 seconds. There will also be an override control to permit continuous dwell for a specific channel.
- Reacquisition circuitry will be modified to be inoperative during quiescent channel off time, and to step ahead at a fast rate to a point 150 ft ahead of the present location and to search backwards to a point 150 ft prior to the starting value. An alternate arrangement of the reacquisition circuitry will permit stepping ahead only one bit and instituting the search.
- The processor code and carrier loop bandwidth will be modified to accomodate the dynamics of the helicopter. An alternate arrangement will provide for discharge of the quiescent loop integrator capacitors rather than coasting at last value.
- The coarse range counters' clock signals will be modified to permit continuous counting during the "out of sync" condition which will occur during the channel "off time."

- A discrete signal will be provided for recording that indicates when channel #1 is selected for tracking. This will provide a baseline timing signal in the event RF signals are lost and channels are not locked on.

- The timing circuitry will be modified to generate a doppler counting interval of approximately 100 milliseconds immediately prior to the occurrence of the transfer pulse (interval of 0.25 seconds). Range and doppler data will be available for recording at the time of occurrence of the transfer pulse.

- Additional circuitry will be provided to detect the repeated occurrence of "missed sync" situations for each channel due to signal loss for an extended interval and to cause the sync indicator on the control box to be activated.

- The self test module will be modified to be compatible with the new modes of processor operation and channel sequencing.

- An indicator box identical to the indicator box in the Mobile Calibration Station will be provided which will be used as an overall check when the helicopter is on the ground. This will provide a rapid means of determining that the fine range counters and associated circuitry are operating properly.

Modifications for the Environment. Blowers and duct work will be added to the receiver and power supply for cooling purposes. The blowers will use cabin air and provide adequate cooling when the ambient temperature does not exceed 45°C. The blower for the receiver will provide 4.2 lbs/min of air against a back pressure of approximately 2 in. H_2O, while the power supply blower will furnish air at 2.1 lbs/min against a head of about 1 in. H_2O. The cooling effect of this air flow will allow the components to perform well within their reliable operating range. A 12°C temperature rise in the receiver from inlet to exhaust is anticipated.

The 621B receiver vibration requirements are as follows:

0.075 inches D.A.	5 to 20 Hz
± 3.5 g's	20 to 36 Hz
± 1.5 g's	36 to 2000 Hz

The receiver and power supply will be mounted on vibration isolators or in a vibration isolated equipment rack such that the dynamic input to the equipment is equal to, or less than, the vibration envelope described in the above table.

Testing. An acceptance test will be performed on the modified four-channel receiver to verify that the basic unit meets the appropriate specification requirements as well as the new functions which have been added. The test will effectively be run in two parts, namely, those portions of the previous acceptance tests performed on the basic unit and a second part which verifies that the sequencing functions are performed properly as well as a verification of the new loop bandwidths and their performance in the design signal power levels and helicopter dynamics. The test fixtures used during the previous acceptance test will be modified as necessary to conduct this acceptance test.

When the receiver is delivered to the test site, it will be installed and checked out with the helicopter installation and data acquisition system. The test, instrumentation and diagnostic procedures employed during the NC-135 tests will also be used to verify system operation. Additionally an indicator unit will be provided which will display fine range and fine doppler to verify that the receiver is operating properly. This unit plus the internal receiver self test provides a high degree of confidence in operational readiness.

9.1.5 Antenna Vibration Effects on Tracking Loop Performance

A computer simulation of the Hazeltine four channel receiver carrier tracking loop was utilized to ascertain the effects of vibration. It was assumed that the loop was tracking, i.e., the initial conditions were not new. Sinusoidal inputs of the form:

$$r(t) = A \sin 2\pi ft$$

were assumed, where the valves for A and f were taken from MIL-E-5400G for helicopters. For $A = 0.05$ in. and f in the range from 5 Hz to 20 Hz the loop remained locked with a peak phase error of approximately 0.045 radians which corresponds to a $\sigma_{\dot{R}} = .045$ fps.

During the Phase II effort vibration effects will be evaluated over the entire range specified in MIL-E-5400G

9.2 INSTRUMENTATION

9.2.1 Objective

The objective of this study was to select a design of a data acquisition system which would meet the required accuracies and test objectives of the System 621B single channel User Receiver flight test program. The instrumentation system selected meets the above criterion. In addition other factors considered were: minimize design and instrumentation component costs by utilizing or modifying existing equipment. The preliminary design study indicates that the instrumentation being used for the SAMSO four (4) channel receiver, with minor modifications and repackaging can be used for the helicopter flight test program, including all three options.

9.2.2 Instrumentation System

The instrumentation is described in detail in Reference 1 and Figure 9-6. Option I was assumed as a baseline design for this study, that is, a 621B four-channel receiver would be modified into a one-channel receiver. Thus, the block diagram (with the deletion of the analog recording system) would accurately depict the proposed airborne interface unit (IU).

For Option II (single-channel digital receiver), the receiver channel-cycle time is sufficiently fast so that it can be considered as a four-channel receiver and no change to the IU would be required. Option III modifications are addressed in Section 9.2.5.

Test Measurements. The sources for the airborne data and the parameters measured for the HC equipment are as follows:

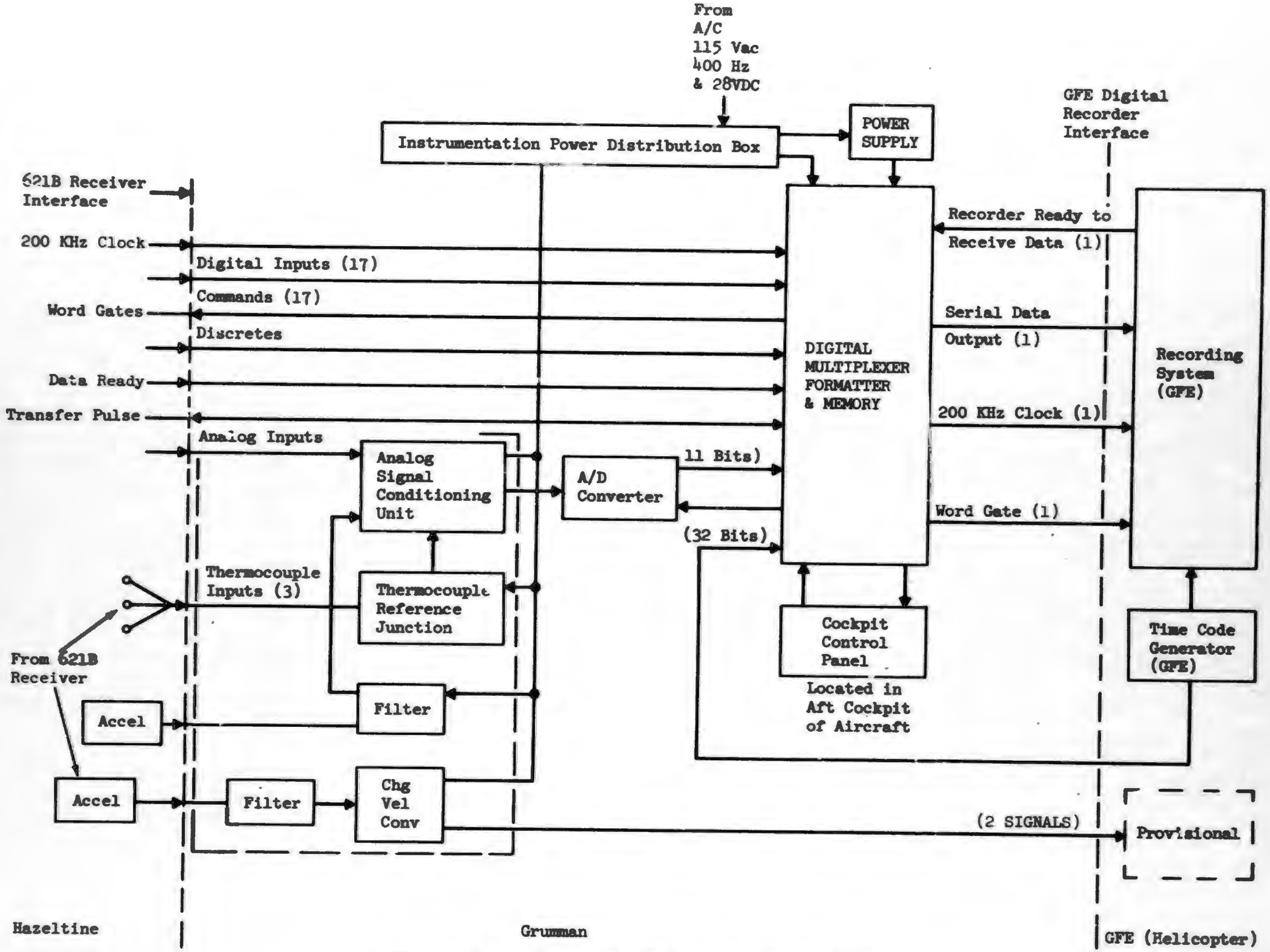


Figure 9-6 Airborne System Block Diagram

- Pseudo Range - 4 channels of coarse and fine digital words
- Pseudo Range-Rate - 4 channels of coarse and fine digital words
- Reference Clock Time - 1 Digital Word
- In-sync monitor - 4 channels
- Power Monitor - 4 channels analog voltage
- Receiver in Calibrate Mode
- Receiver in Self Test Mode
- 621B Receiver Environment
- Time of day
- Pilot event marker

Purpose of IU. The function of the IU is to acquire the digital and analog data output signals from the user System 621B receiver and record the data in digital form on magnetic tape. In addition, analog signals from the receiver and various analog transducer outputs are digitized and recorded in conjunction with the digital signals. IRIG time of day is also recorded, with various discretes. Refer to Table 9-3 for list of measurements and their respective test requirements.

9.2.3 Description of IU

The major instrumentation components which comprise the data acquisition system are:

- Digital Recording Systems and Time Code Generator (GFE)
- Digital Multiplexer
- Analog to Digital Converter
- Analog Signal Conditioner

Table 9-3 Instrumentation Measurement List

Measurement	Quantity, Words	Min Sampling Frequency, sps	Test Reqmt	Accuracy
621B Test Receiver				
• Pseudo range, coarse	4 26-bit	4 sps	Sys Acc	N/A
• Pseudo range, fine	4 8-bit	4 sps	Sys Acc	N/A
• Pseudo doppler, coarse	4 15-bit	4 sps	Sys Acc	N/A
• Pseudo doppler, fine	4 20-bit	4 sps	Sys Acc	N/A
• 10 MHz clock time	1 25-bit	4 sps	Sys Acc	N/A
• In-Sync monitor (Acquisition discrete)	4 1-bit	4 sps	Sys Acc	N/A
• Mode Select Switch	1 1-bit	1 sps	Diagnostic	N/A
• Channel Sequence Discrete	1 2-bit	4 sps	Diagnostic	N/A
• P-channel signal strength	4 10-bit + sign	4 sps	Signal Strength	1 db
• RF/IF Select	1 1-bit	4 sps	Rcvr Status	N/A
• Calibrate	1 1-bit	4 sps	Rcvr Status	N/A
• Self Test	1 1-bit	4 sps	Rcvr Status	N/A
Time Correlation				
• IRIG B Time Code	1	4 sps	Time Correl	1 ms Res
Environment				
• Receiver case temperature	2	0.1 sps	Airborne Envir	± 5°F

Table 9-3 Instrumentation Measurement List (Continued)

Measurement	Quantity, Words	Min Sampling Frequency,	Test Reqmt	Accuracy
• Installation compartment ambient temperature	1	0.1 sps	Airborne Envir	± 5°F
• Case vibration, single axis on the receiver	1	5-500 Hz response must be analog recorded	Airborne Envir	± 0.1 g
• Steady state "G" on the receiver	1	0-2.0 Hz	Airborne Envir	± 0.1 g
<u>Other Signals</u>				
• Pilot event marker	1 1-bit	4 sps	Data Analysis Diagnostic	N/A

Recording System. The airborne data recording system is being supplied by the 6585th Test Group at Holloman AFB. This is a standard unit in their inventory. The essential characteristics of this system are:

- Equipment complement
    - Time code generator
    - Input data synchronizer
    - Data buffer and tape control unit
    - Core Buffer
    - Digital recorder
- Input data signal format
    - Word length 48 bits max.
    - Frame length 127 48-bit words max.
    - Clock rate 1 Mhz max.
    - Synch word Unique repeatable word reqd once per frame
    - Data Format Serial transfer of Manchester, Rz, or NRZ
    - Interface circuitry DTL compatible
- Output data signal format

The output data is in the form of a digital magnetic tape (Figure 9-7) which is IBM computer compatible

- Packing Density 556 characters per inch
- Record head configuration 7 track in-line
- Tape width 0.5 inch
- Reel size 10 1/2 inch IBM type
- Tape capacity 2400 ft., 1.5 mil
- Slew Rate 3 KHz
- Recording technique NRZ Mark (NRZI)

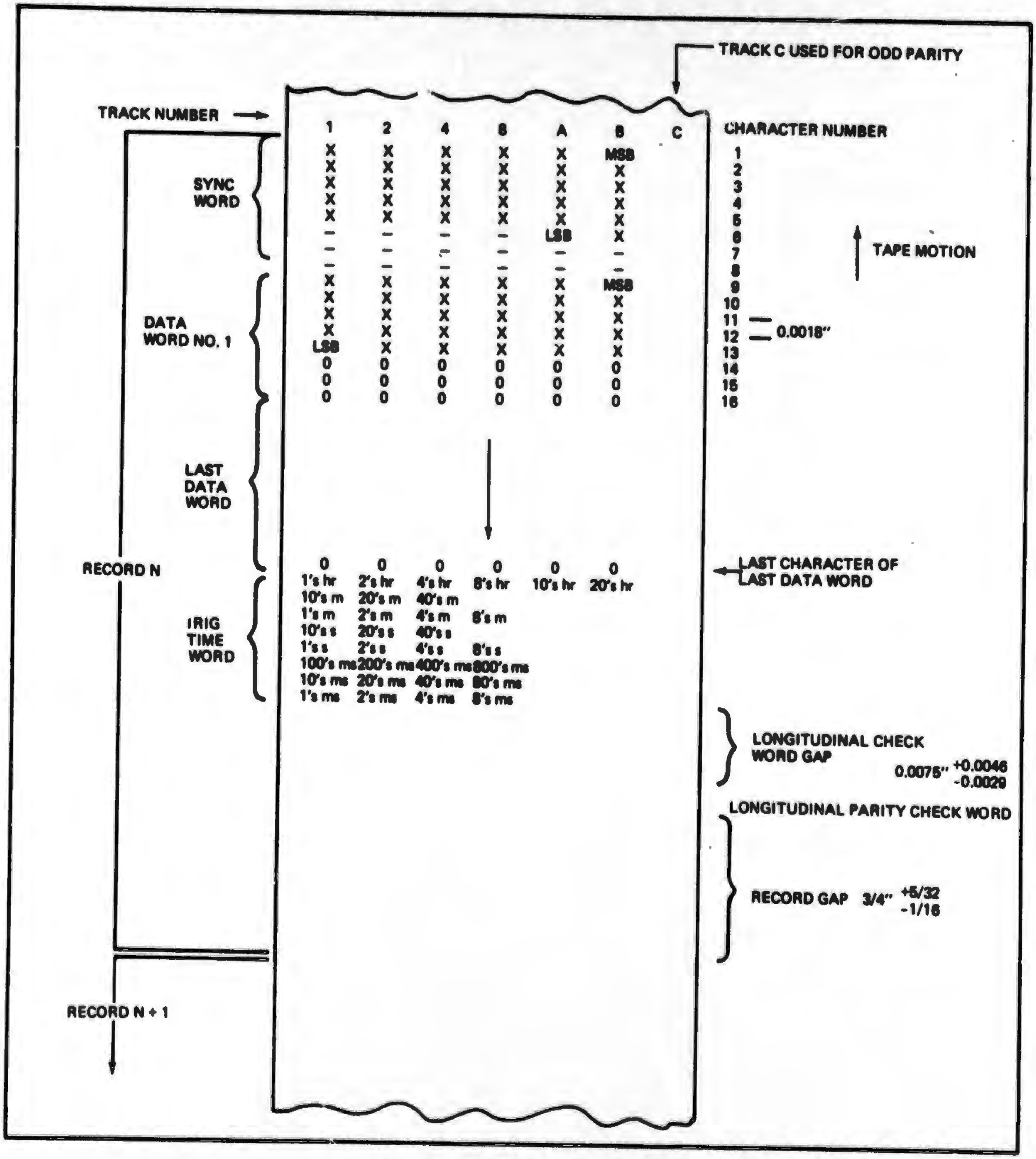


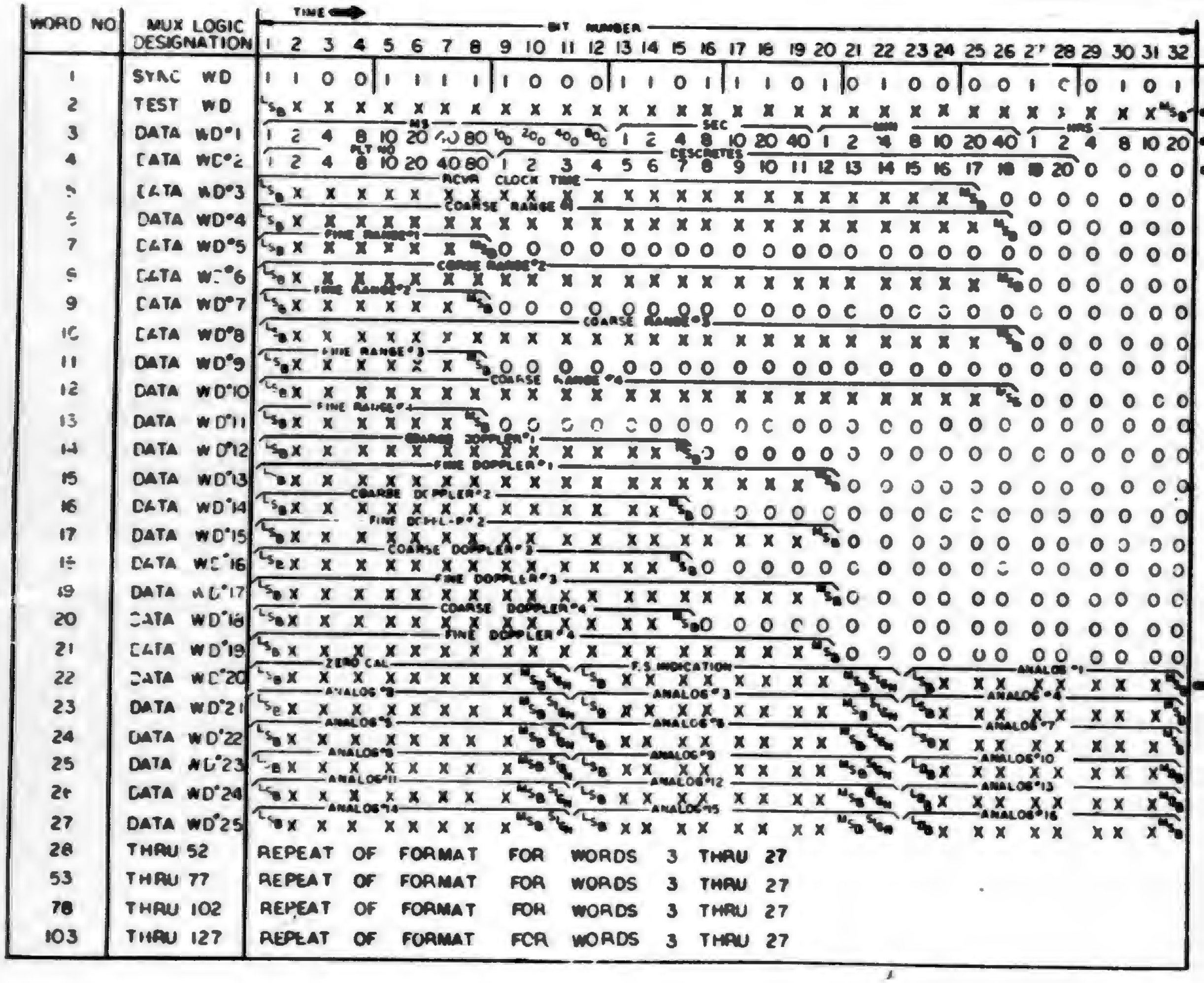
Figure 9-7 Data Tape Format

Digital Multiplexer. The digital Multiplexer and Formatter is the central interface for the digital and digitized analog data. This unit provides the electronics to receive, format and transfer data to the recording system. In addition, the Mulitplexer/Formatter generates transfer pulses which are used by the 621B receiver to initiate transfer of data. Figure 9-8 is the data format.

To summarize the operation of the Multiplexer/Formatter:

- A transfer pulse is generated and sent to the 621B receiver every 250 ms. At this time, data is transferred into the synch word, discrete and time registers.
- After a period of time (50 μs) the 621B receiver returns a "data ready" signal.
- Upon receipt of "Data Ready" signal the sequencer begins a sequence of read commands that will interogate the various data registers in proper order. The sequencer keeps track of word length so only the proper number of bits for each word are accepted. All data registers are self clearing so they are ready to accept new inputs each time a read command ends.
- This data is loaded into the memory as it is received, with guidance from the data gate signal.
- When 4 data groups have been loaded into the memory, it is commanded to unload. The unload is controlled by the word gate signal with the output data being transferred serially to the recording system. The format for the data at the Multiplexer/Formatter to Recording System interface is shown in Figure 9-8.
- The preceding cycle of 1 through 4 is repeated for the duration of the data run.

Analog Signal Conditioner. The analog signals are routed through a unit which provides the electronics required to amplify or attentuate the analog inputs to the A/D converter. The operational amplifiers are selected and designed to have drift and offset characteristics that will allow the maintenance of the required accuracy of the analog signals. The attenuators are constructed of precision resistors.



NOTES

FORMAT SET VIA DIGITAL MULTIPLEXER TEST UNIT

IRIG TIME WHEN THE GROUP T.P. WAS GENERATED

DISCRETE BIT ASSIGNMENT:

1. SPARE
2. MODE (TEST=1, NORMAL=0)
3. SPARE
4. RCRV CAL (CAL=1)
5. RCRV TEST (TEST=1)
6. SPARE
7. SPARE
8. SPARE
9. SPARE
10. SPARE
11. IN SYNC MONITOR#1 (IN SYNC=1)
12. IN SYNC MONITOR#2 (IN SYNC=1)
13. IN SYNC MONITOR#3 (IN SYNC=1)
14. IN SYNC MONITOR#4 (IN SYNC=1)
15. SPARE
16. EVENT MARKER
17. SPARE
18. SPARE
19. AIRCRAFT/GROUND TAPE (AC TAPE=1, GROUND=0)
20. NRL/HAZELTINE TAPE (NRL=0, HAZ=1)

A/D CONVERTER OUTPUTS (NOTE: SOME HAVE NO SIGN BIT)

ANALOG CHANNEL ASSIGNMENTS

A/D CONV ADDRESS	FORMAT DESIGNATION	SIGNAL
0	ZERO CAL	GROUND
1	F.S.IND	12 VDC.
2	ANALOG 1	SPARE CHAN.
3	" 2	SIGNAL STRENGTH #1
4	" 3	" " #2
5	" 4	SPARE CHAN.
6	" 5	SIGNAL STRENGTH #3
7	" 6	" " #4
8	" 7	SPARE CHAN.
9	" 8	SPARE CHAN.
10	" 9	NORMAL ACCELERATION
11	" 10	SPARE CHAN.
12	" 11	SPARE CHAN.
13	" 12	AMBIENT TEMP
14	" 13	SPARE CHAN.
15	" 14	CASE TEMP #1
16	" 15	CASE TEMP #2
17	" 16	SPARE CHAN.

Figure 9-8 AIRBORNE DIGITAL MULTIPLEXER DATA FORMAT SHOWING ONE RECORD

The remaining units in the data acquisition system are the analog-to-digital converter, a power supply, and the time code generator. All of these units are off-the-shelf purchased items. Their operation is standard and will not be detailed here.

9.2.4 Modifications to Existing IU, Options I and II

Electrically for Option I, the modifications are minor. The digital multiplexer unit will be modified to generate transfer pulses at 0.25 second intervals (currently TP's are generated every 200 MS). Also 4 additional discrete signals will be recorded. The multiplexer unit will be modified to accommodate these additional signals. The frequency response of the normal acceleration channel (used for diagnostics) will be reduced, as a consequence of the lowered sampling rate, which does not appear to be a problem. For Option II no electrical changes are required.

The case vibration accelerometer channel will be retained. Since this parameter is for diagnostic purposes only, a strap down visicorder will be used should the need arise to measure the vibration experienced by the receiver.

Mechanically the modifications to the IU consists of repackaging the equipment from a single rack (in the NC 135 aircraft) into three separate racks. Helicopter vibration levels, being greater than those in the NC 135, necessitate a more extensive design of the equipment racks and the associated vibration isolation systems. The isolating effectiveness of the isolation systems (shock mounts) will be verified by a vibration test performed on the rack/isolator assemblies prior to installation. Refer to Figure 9-10 in section 9.4 for the helicopter installation layout of the 621B receiver and the data acquisition system.

9.2.5 Option III - Modification to IU

The proposed airborne computer has a memory capacity of 8192 words. The navigation solution and necessary executive routines are expected to require less than 4000 memory words. The residual capacity will be used as a buffer memory to store the calculated data prior to recording the data on magnetic tape. Utilizing the computer in this manner will preclude the need for an additional recorder. The existing recorder will record the raw measurement data in real-time while the computer solves for the actual navigation data in real time and stores this data in memory. At the completion of the helicopter pass, (about 1.5 minutes or less for the area navigation test) the helicopter will proceed to the starting point of the next pass. During this transit period the computer will dump the navigation data from memory into the tape recorder. Assuming a 90-second pass the memory will have stored some 3000 words. This will have been accumulated from 8 data words every 250 milliseconds over the 90-second period and some additional synch words and identifier words. The data will represent three position components, three velocity components, one oscillator bias, and one bias rate for each 250-millisecond period. With this approach, relatively minor changes to the airborne IU will be required for Option III.

9.2.6 Data Acquisition System (DAS) for the Mobile Calibration Station (MCS)

For the NC-135 tests, the MCS is equiped with a four-channel receiver and the data from the receiver is recorded by a DAS similar to the airborne IU (Reference 1). This data allows for post flight computation of the time biases associated with the transmitters which run asynchronously.

For Options I and II the same configuration is to be used and therefore no modification of the ground based DAS is required. For Option III, the transmitter biases are required in real time by the helicopter computer to permit real time navigation. Therefore, a computer is added to the MCS to compute these biases real time. The data is then voice linked to the helicopter for insertion into the airborne computer where it is used for real time navigation and recorded. The values are also logged at the MCS by the operator.

Should airborne computer capacity be available, the MCS receiver measurements, which should not change, could be voice linked to the helicopter and inserted into the airborne computer where the transmitter time biases could be computed. This would eliminate the need for an MCS computer.

9.3 ELECTRICAL LOAD ANALYSIS

The UH-1H helicopter to be provided for this program is a basic production helicopter. As such, the electrical power available is primarily dedicated to equipment associated with the helicopter primary mission with limited excess capacity for other purposes.

Primary 28 VDC electrical power is provided by a transmission-driven 30 volt, 300 ampere, DC generator which provides 8.4 KVA. In the event of failure of the main generator, an engine driven 30 volt, 300 ampere starter-generator supplies the primary DC electrical power.

AC power is available from a 115 volt, 250 VA, three phase, 400 Hz, main inverter driven from the primary 28 VDC bus. A second 115 Volt, 250 VA, three phase inverter, supplied by the primary DC bus, is provided as a spare.

9.3.1 Helicopter Requirements

An electrical load analysis for the UH-1H helicopter is provided in Ref. 5. This report indicates that the total average power requirements for the helicopter during cruise is 4.6 KVA. This figure is all inclusive and reflects the use of equipment which will not be required during this program. A preliminary review indicates that at a minimum, the equipment listed in Table 9-4 will not be required. From these sources alone, a savings of approximately 1.8 KVA is indicated. Therefore, the helicopter systems will require, at most, 2.8 KVA which allows approximately 5.6 KVA for System 621B equipment.

Table 9-4 Estimated VA of Helicopter Equipment Not Required

Item	VA
Heated Blanket Outlet	560
Internal Rescue Hoist	920
FM Transceiver (AN/ARC-54)	90
UHF Transceiver (AN/ARC-102)	210
Total	1,780

Table 9-5 Estimated System 621B AC Power Requirements

Item	VA
Instrumentation System	370
Recording Systems	380
Receiver	360
Power Supply	360
Rack Blowers	200
Total	1,670

9.3.2 System 621B Equipment

An estimate of System 621B power requirements is tabulated in Table 9-5 for Option I and II. The total AC power required is approximately 1.7 KVA. Clearly, this AC requirement cannot be met by the helicopter 250 VA, AC power system. Therefore, an Army standard 2.5 KVA inverter (PU 545/A) will be required. The installation of this inverter as a supplement to the UH-1H helicopter AC power system is a standard procedure which has been done previously by the Army. See Section 9.4 for details.

Given the efficiency of the inverter of 50%, and the availability of 5.6 KVA from the helicopter primary system, the 2.5 KVA inverter could be run at rated capacity if required. If it is assumed that the power factor of the added equipment is .9 (a pessimistic value) then the requirement for 1900 watts still remains well within the 2500 VA available from the inverter. The above also indicates a greater than 10% power safety margin exists for the helicopter main DC generator at full inverter capacity.

For Option III, the power requirement for System 621B equipment will increase by approximately 250 watts. When added to the nominal 1900 watts required, a 10% power safety margin still exists and the power system modifications as outlined above will therefore suffice for Option III as well.

9.4 EQUIPMENT INSTALLATION

Three equipment cabinets are provided for mounting the HC 621B receiver, power supply, Grumman instrumentation, GFE recorder and time code generator/readout. The arrangement of the cabinets and equipment is shown in Figures 9-9 and 9-10. This arrangement has been selected to provide good Helicopter loading in all configurations (fuel, crew). The equipment installation design provides for ease of maintenance and accessibility, (equipment slides in or out). A prime consideration in the installation design was the requirement for access to the tail rotor gearbox. The tail rotor (90°) gearbox lubrication is accomplished by a self contained wet sump. A visual sight glass gage is provided on the right side of the gearbox to allow for a level check. Due to the preflight inspection requirement on the gearbox oil level indication, an access door and opening in cabinet number 1 has been provided. This will provide easy access to the viewing window and light switch. Other transmission inspection can be accomplished using the opening in the bottom of the helicopter. The installation will therefore, not prevent access to and maintenance of the transmission.

The cabinets will be mounted on an isolation system which will be designed for low frequency, (7-10 cycles/sec resonant frequency), high amplitude isolation (see Figure 9-11). The isolation system base plate will pick up existing helicopter tie down points. The use of an isolation system also gives the floor area that is required to meet the PSI floor loading and provide a safety factor of 3. (Ref TM 55-1520-210-10). On the rear of the cabinets, stabilizing mounts between the cabinets and the bulkhead are provided. These stabilizing mounts limit the cabinet sway and are used in conjunction with the isolation system. The stabilizers also provides a crash safety factor of ± 20 g's. Sufficient clearance has been allotted between adjacent units and structure for the most severe shock condition.

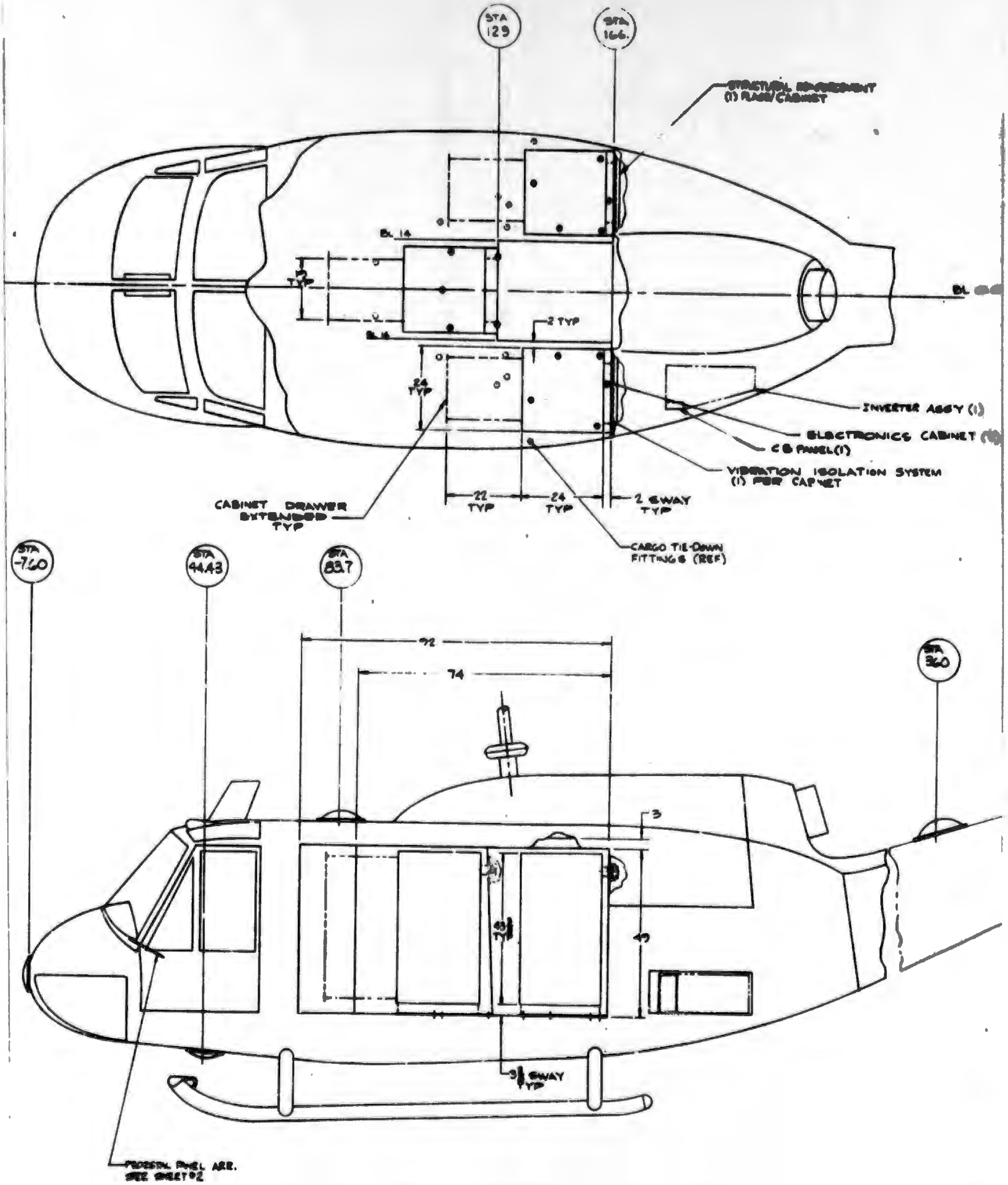
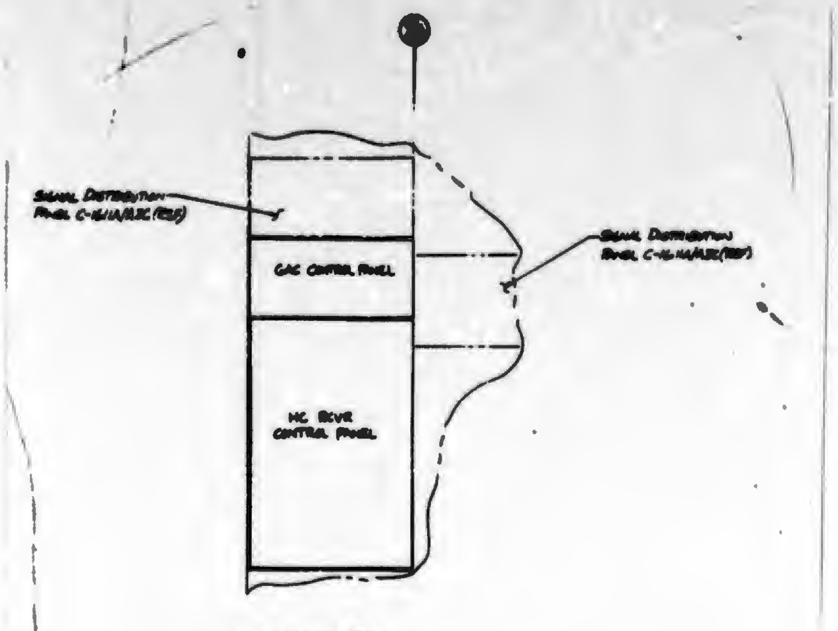


Figure 9-9 621B UH-1H Profile with Cabinet Layout



VIEW LOOKING FWD AT PEDESTAL PANEL

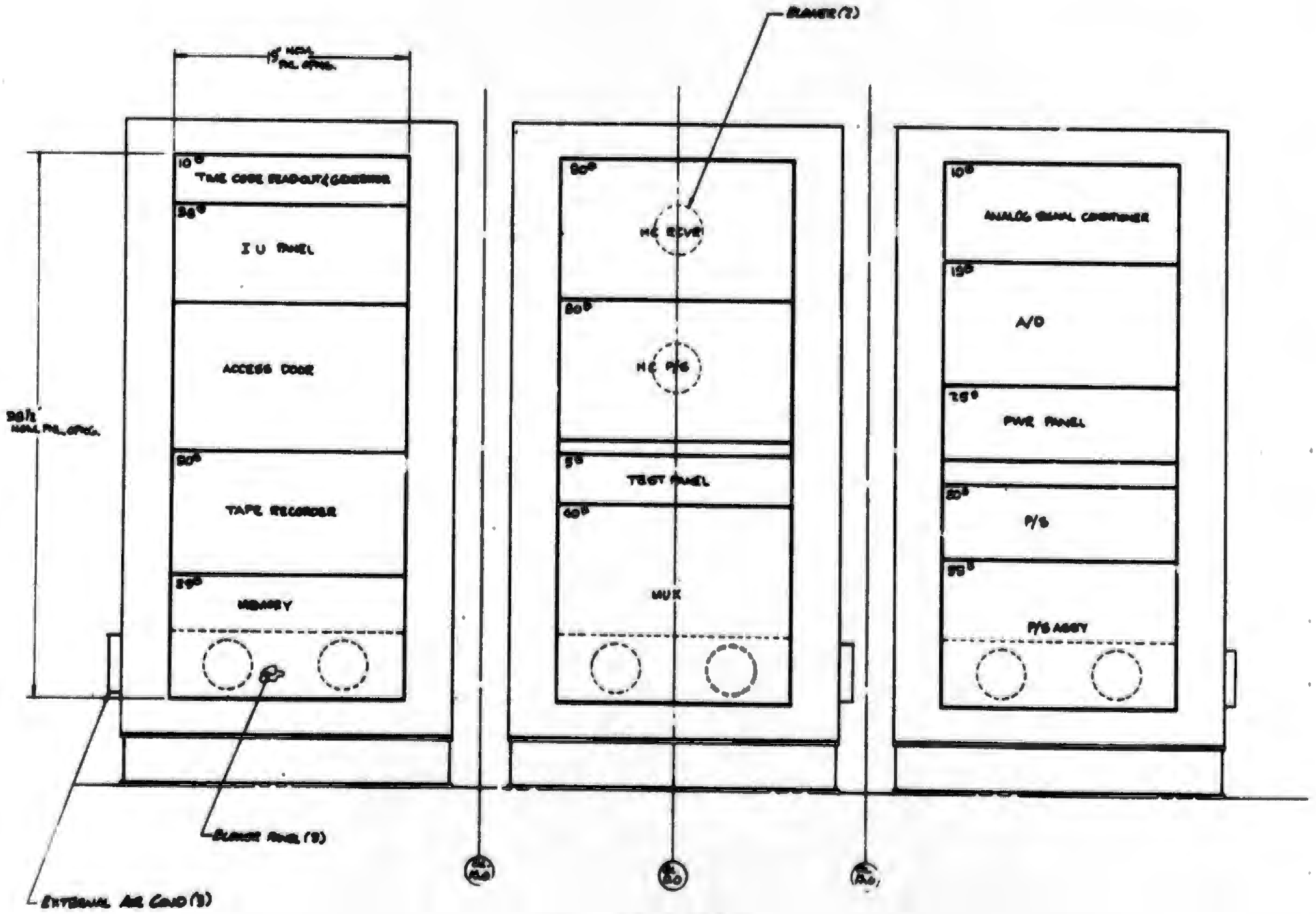


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Figure 9-10 Equipment Arrangement

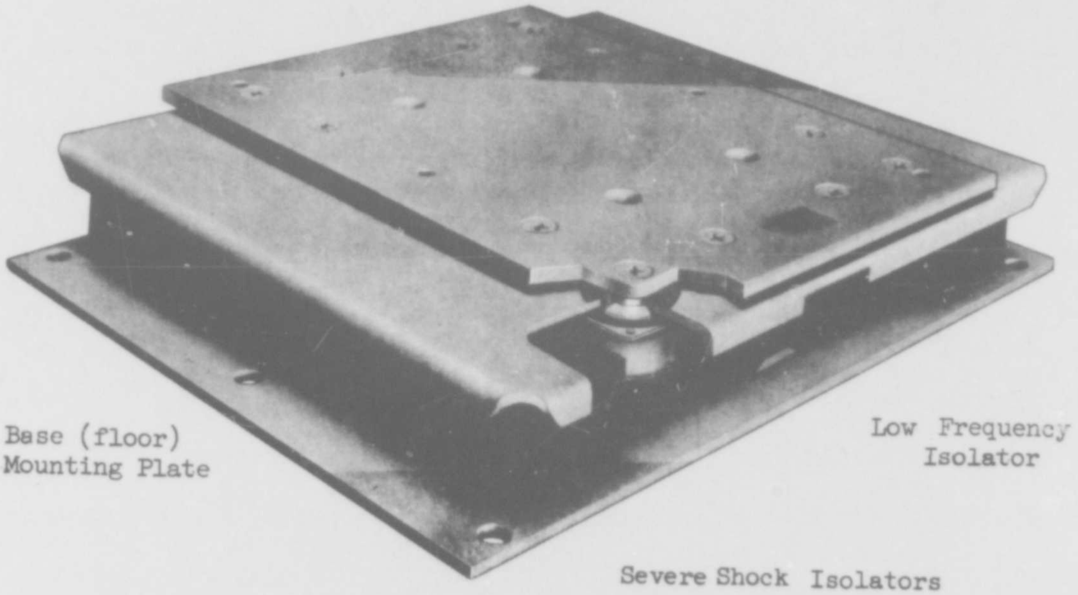


Figure 9-11 Mounting Plate for Cabinet

A 470 CFM blower will be installed in the lower rear of each cabinet to provide a forced air flow through the cabinets. The blower and utilization of natural thermal draft will provide adequate air flow for the equipment mounted in the cabinet. The hotter equipment will also use mounting provisions as heat sinks as the cabinets' heavy aluminum extrusions will provide adequate metallic conduction. The Receiver and Power Supply will also have their own blower, since they have been designed for forced air. Ground cart cooling fittings are being provided on each cabinet to allow for additional cooling while ground tests at Northrop strip are conducted.

The cabinets will have four aluminum extrusion corner posts with aluminum louvered sheet sides and top. Both the basic cabinets and the isolation system, including the base isolator and the stabilizer mounts, are commercially available units which have been designed for military applications.

The cable assemblies will be to the intent of MIL-W-5088, with the addition of an overall shield. The interface connectors will have EMI/environmental back shells on the connectors. The wire will be per MIL-W-81044/2 which is a polyvinlidene flouride jacketed airframe wire. Wire current carrying capacity will be per MIL-W-5088. The interface connectors will be of the MIL-C-26482 or MIL-C-5015 type. Cables will be routed to be easily accessible for inspection and repair. The wires will be marked per MIL-E-5088 and be prefixed with 621B. Cable assemble will be twisted per Grumman specification GSS 13316 to provide maximum flexibility and minimize fatigue due to vibration.

The RF cabling will be RG 214/U coax which is a 50 ohm, double shielded (two single braids with no insulation between them). Cable termination will be with MIL-C-39012 type connectors.

The receiver control and Grumman control panels will be placed on the center console, and will be of the MIL-C-6781 type (no lighting).

The receiver control panel will provide remote operation of the receiver by the operator.

The Grumman control panel will provide power control for the new 115 V 400 Hz inverter, and Blower on-off switches for the cabinet blowers. Two indicator lamps will provide "receiver over temp" and "loss of special equipment power." These indicators should be placed within the operators normal line of sight (30° cone). "Rcvr over Temp" will indicate air over temperature condition internal to receiver (70°C) and that the receiver has been placed in a standby mode. "Loss of special equip pwr" indicator will illuminate when a loss of the 115 V 400 Hz power from the 2500 VA inverter is experienced. The indicators will be of a brightness that can easily be seen in a high ambient condition.

115 V 400 Hz is supplied by a 250 VA inverter with a 250 VA inverter for standby. To satisfy the addition of the System 621B equipment (115 V 400 Hz) a 2500 VA inverter will be added. The inverter will be a GFE MS type. The new AC system will have overload protection, distribution and feeder protection (circuit breakers) as shown in Figure 9-12. An overload controller is provided to protect the primary feeder and inverter. If an overload occurs the controller removes the holding voltage from a toggle switch on the cockpit control panel which in turn removes the holding voltage from the primary contractor which opens the 28 VDC feeder to the inverter. The toggle switch on the cockpit control panel provides the operator with an indication (position of the magnetically held toggle) of power on-off condition. It also provides manual control of the 621B/AC power from the cockpit.

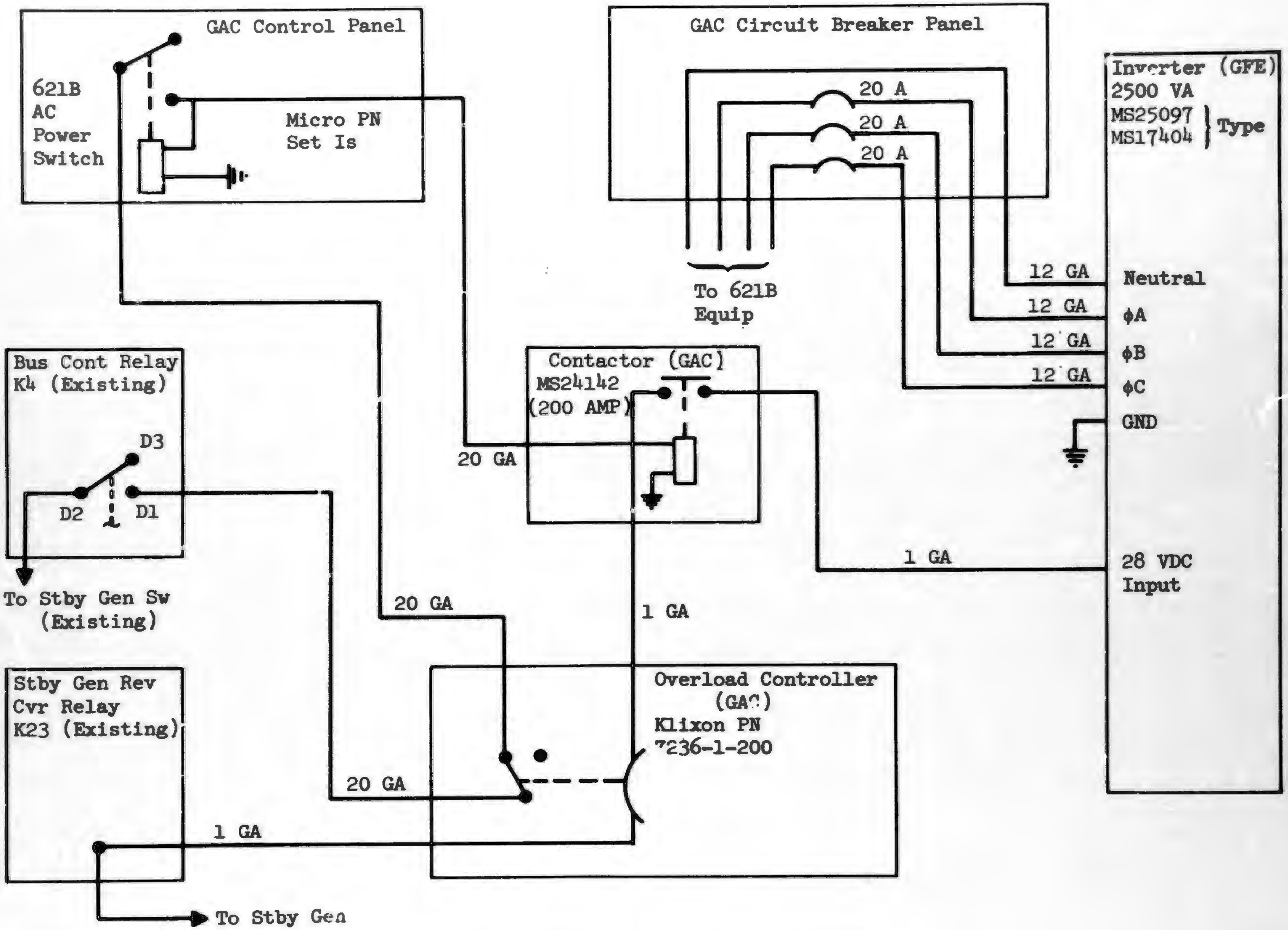


Figure 9-12 Inverter Electrical Interface

The inverter, controller, circuit breaker panel and contractor will be on the single chassis. The single chassis design provides for ease of installation and removal of the modification. The chassis can be installed on the shelf on the left hand side as shown in Figure 9-9.

A circuit breaker panel will be provided for the distribution of the new 115 V, 400 Hz. It will consist of 20 amp circuit breakers and connectors. This circuit breaker panel design will be similar to that of the NC-135 (00371) installation. Using this configuration minimizes changes in connectors, cables and wiring diagrams. The circuit breaker panel will be mounted on the inverter chassis to provide maximum feeder protection (shortest length of unprotected wire).

9.5 ANTENNAS

9.5.1 Helicopter Antenna Assembly Kit

The antenna assembly kit consists of three major subassemblies:

- Antenna with radome and test probe
- Interconnecting R.F. cables
- Structural modifications (designed for minimum modification to the helicopter)

These three subassemblies are required at each of the four helicopter installations:

- Top ADF antenna location
- Bottom ADF antenna location
- Nose location
- Aft rotor boom location

However, only 1 antenna assembly kits will contain antennas (with radome and test probe) since only one antenna installation, at most, will be required at any one time during the program. The antenna will be moved as required.

Antenna Description. The antenna is the compact, lightweight hemispherical radiator developed for the 621B test program utilizing the NC-135 aircraft (Reference 1). As presently fabricated, the antenna/radome is filled with 2 lbs/cu.in. density foam which aids in vibration reduction with no noticeable loss in antenna performance. The general electrical characteristics of the antenna are:

- Antenna input VSWR: 1.4:1 max (with radome and foam)
- Probe input VSWR: 1.6:1 max (with radome and foam)
- On axis antenna gain: +3 dB with respect to an RHCP isotrope

- 3 dB beamwidth: 130° typical, rotationally symmetrical
- Antenna coverage: Greater than hemispherical coverage at 10 dB below isotropic

The antenna, ground plane and low-density foam are entirely covered with a mult-layer fiberglass laminated radome (Reference 1) with a final assembly weight of 1.9 lbs.

The entire assembly was subjected to a number of environmental tests, specifically shock and vibration at temperature on the vertical and one arbitrary horizontal axis. The vibration levels used are a composite of worse case levels from Curve IV, MIL-E-5400G (Equipment Designed for Both Aircraft and Helicopters) and levels actually measured on the NC135 aircraft by the Boeing Company. A comparison of actual test levels and those called out in MIL-E-5400G, Curve IV follows. It should be noted that the test values used are the helicopter levels.

Curve IV Levels		Actual Test Levels	
Frequency (Hz)	Level	Frequency (Hz)	Level
5-20	0.10 inch D.A.	5-20	0.10 inch D.A.
20-33	± 2 g	20-33	± 2 g
33-72	0.036 inch D.A.	33-52	0.036 inch D.A.
		52-80	± 5 g
72-500	± 10 g	80-114	0.15 inch
		114-167	± 10 g
		167-190	Increase to ± 13 g
		190-400	± 13 g
		400-500	± 11 g

A summary of the tests are as follows:

Horizontal Axis

- Vibration at +150°F per above levels for 3 hours
- Vibration at 0° per above levels for 3 hours
- Shock ± 15 g for 11 milliseconds - total 6 shocks

Vertical Axis

- Vibration at +150°F per above levels for 3 hours
- Vibration at 0°F per above levels for 3 hours
- Shock ± 15 g for 11 milliseconds - total 6 shocks

The antenna successfully passed the environmental tests with no noticeable degradation in electrical characteristics.

Interconnecting Cables. Four cable assemblies of two cables each (one to the antenna and one to the self test probe) are required for interconnecting of the receiver and the antenna at the presently intended locations. Nominally, the cable type will be RG-115 A/U with the following characteristics.

- Insertion Loss: 0.1 dB/ft. at 1575 MHz
- Weight: 0.18 lb/ft.

Three cable assemblies will be installed internal to the helicopter by means of standard R.F. cable clamps bolted "piggy back" wherever possible to existing wiring clamps within the constraints of good EMC practices. However, the double cable run from the aft rotorboom antenna for the rotor modulation test will run external to the helicopter and will be attached wherever possible to meet the goals of minimum modifications.

9.5.2 Antenna Locations

The following locations have been selected to allow the system to meet program goals while requiring minimum modification to the UH-1H helicopter (Figure 3-3)

Program Test	Antenna Location	Required Structural Modification
Area Navigation	Bottom ADF Antenna	Addition of Adapter Plate utilizing ADF antenna hole pattern for pickup
ILS	Nose door	Modifications to a spare door utilized during testing only
Rotor Modulation	Top ADF Antenna	Addition of Box Beam Aluminum structure utilizing ADF antenna hole pattern
	Tail Boom	Addition of box beam aluminum structure which straddles the tail boom and attaches to it

Area Navigation Location. With the antenna located in the bottom ADF antenna location, near free space radiation coverage will be realized (+ 3 dBi gain on axis decreasing to approximately -9 dBi gain parallel to the centerline of the helicopter)(Figure 3-3). Since the antenna pattern is basically cardiod in shape and the helicopter is electrically smaller than the RF-4C, for which an intensive pattern study program was conducted, greater than hemispherical coverage is anticipated which will preclude loss of lock with any positive or negative angle of attack of the helicopter.

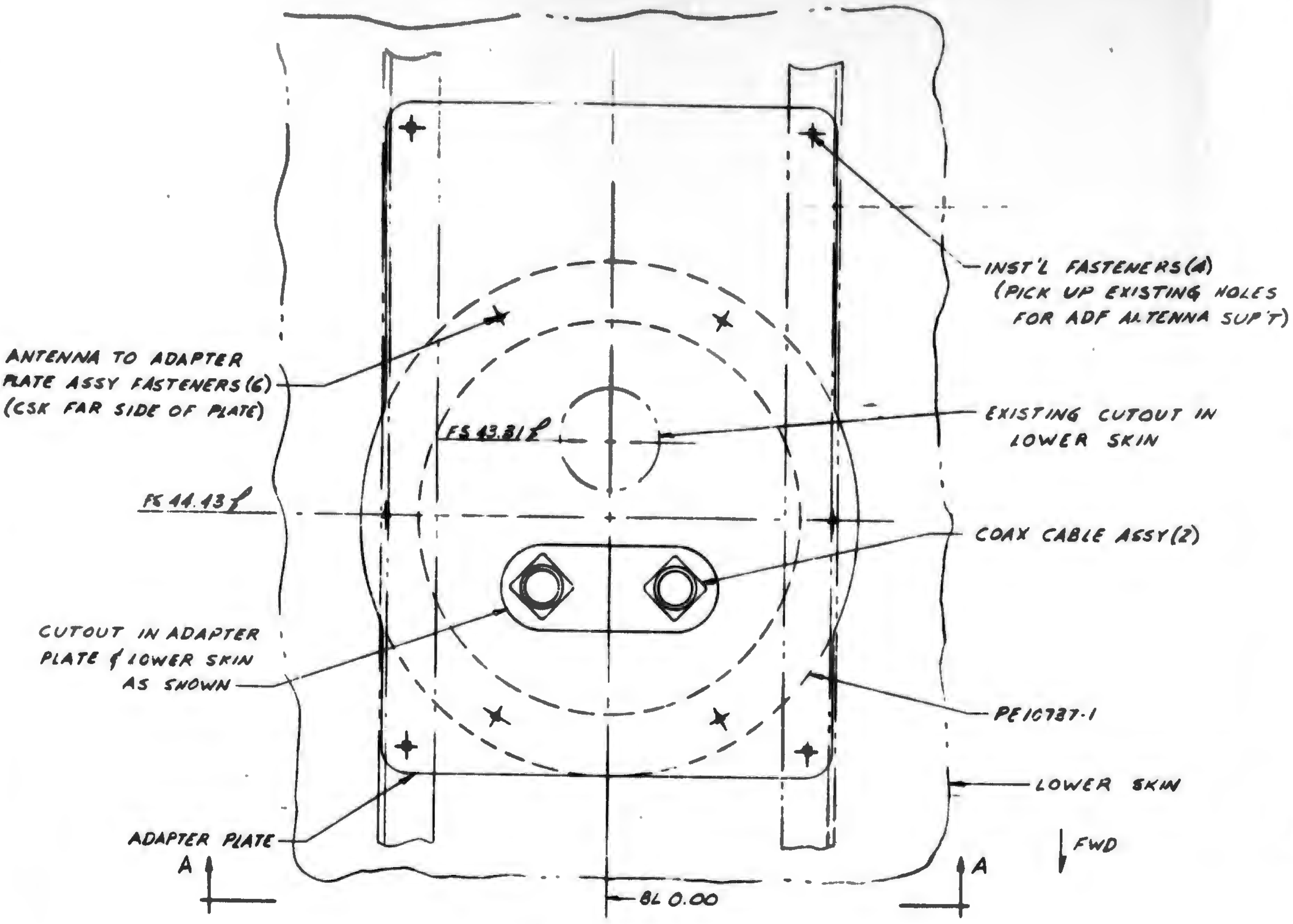
Figure 5-27 shows the total power variation of all four ground stations in the helicopter antenna pattern for an east to west flight.

Of this total the helicopter antenna gain varies by less than 3 dB across the range and would be identical for a West to East run due to pattern symmetry.

To adapt the 621B antenna to the removed ADF antenna mounting hole pattern an adapter plate has been designed (see Figure 9-13). The 621B antenna is attached to the adapter plate and the entire unit is then installed on the helicopter. A hole is cut out of the existing lower ADF hole pattern and at the completion of the flight test program a cover plate is installed over this cutout.

ILS Location. The antenna will be located on the forward equipment access door at Fuselage Station - 7.6 on the centerline at approximately Waterline 30 with the peak of the radiation pattern parallel to the helicopter's Roll Axis. In this location, unperturbed line of sight is afforded for greater than ± 90° about the roll axis. This extensive coverage is required during the ILS landing when angles from the Roll Axis to the transmitters could be greater than 90° (i.e., A 15° "crab" maneuver would be required if experiencing approximately a 15 knct cross wind, causing the LOS to either transmitter #1 or #3 to be greater than 90° when the helicopter is within 1000 ft. of touchdown). At touchdown, transmitters 1 and 3 will be at ± 90° (Figure 3-1).

The modification as designed will allow uninhibited access to the equipment bay with the cables attached to the antenna. A spare door will be obtained and modified to the antenna configuration (see Figure 9-14) and at the completion of the test program, the original door will be replaced. The antenna is mounted to the door, and an adapter ring which matches the outside contour of the door is provided.



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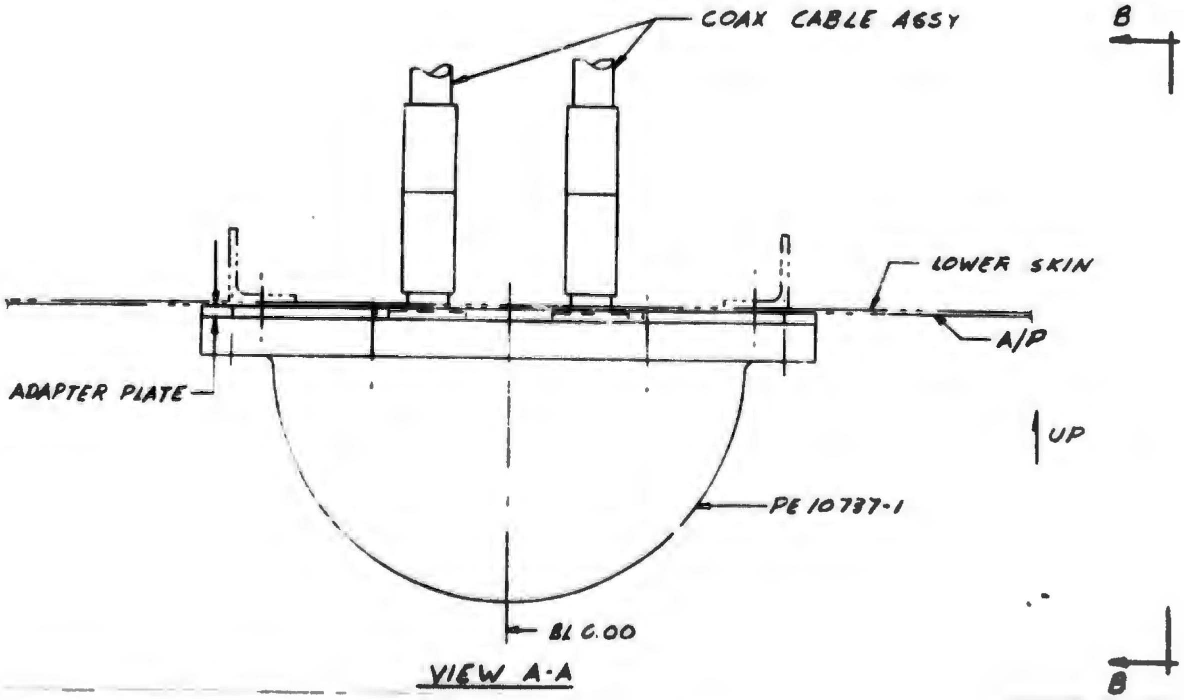
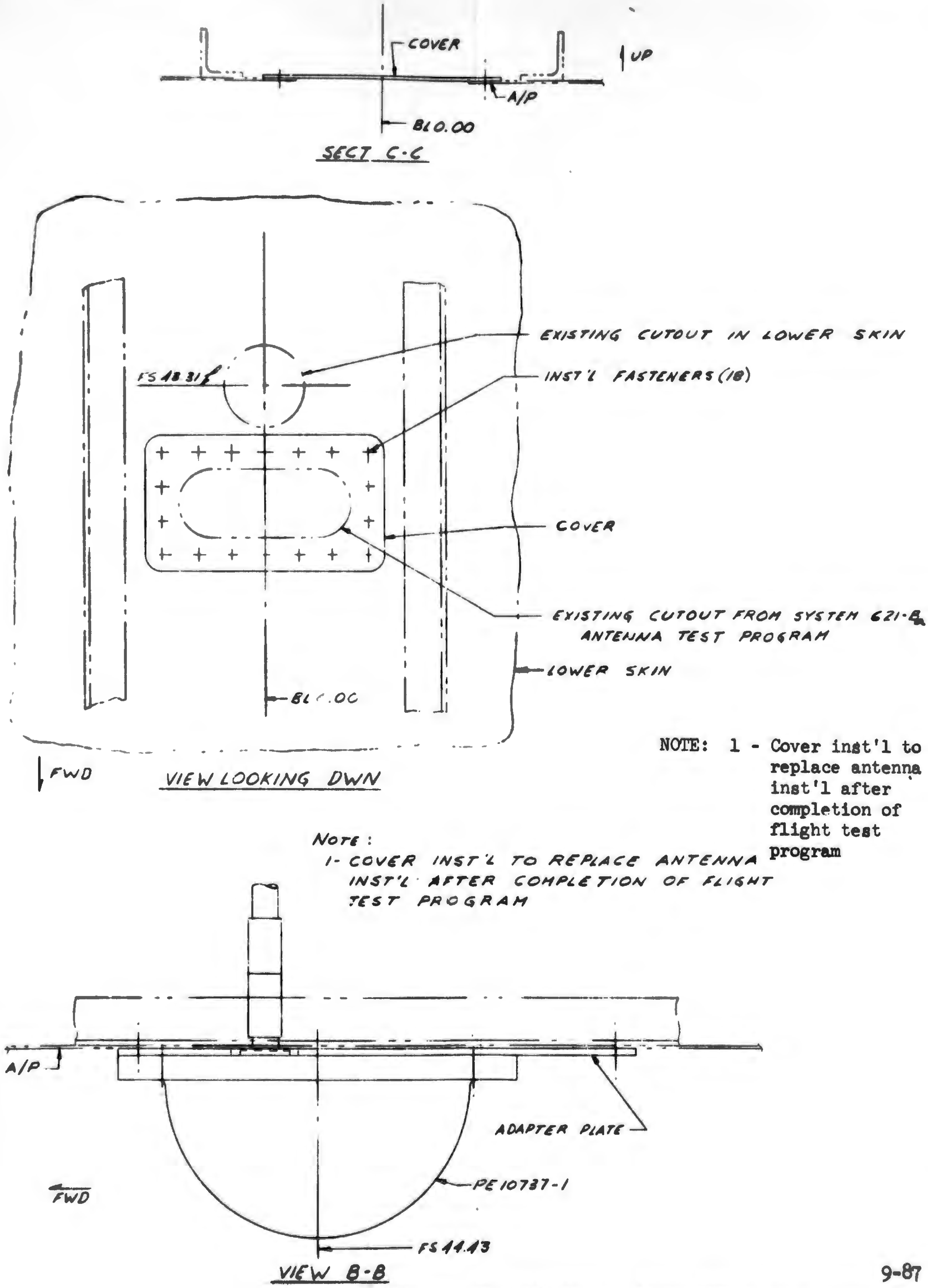
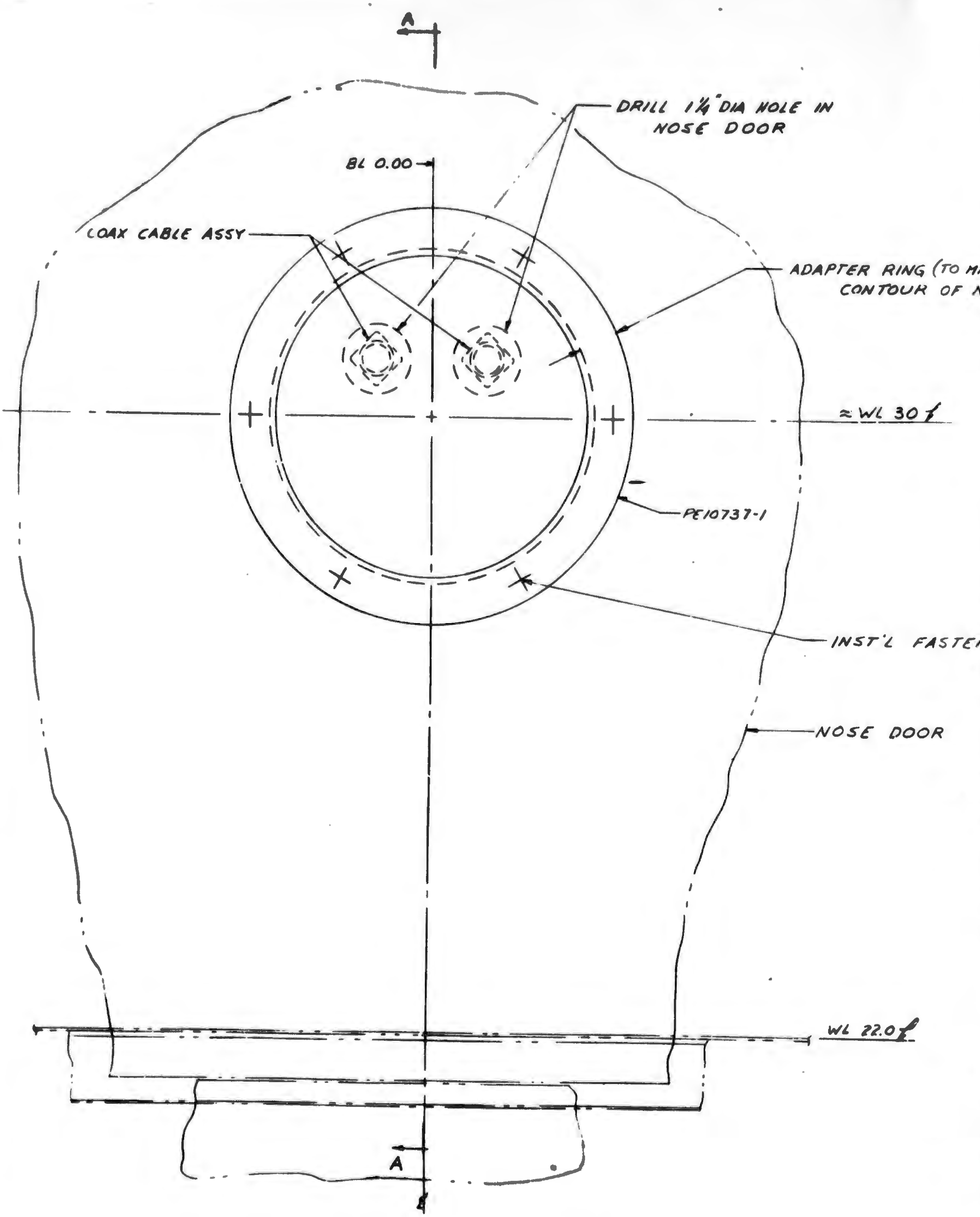


VIEW A-A



NOTE: 1 - Cover inst'l to replace antenna inst'l after completion of flight test program

Figure 9-13 Antenna Installation at Lower ADF Antenna Location



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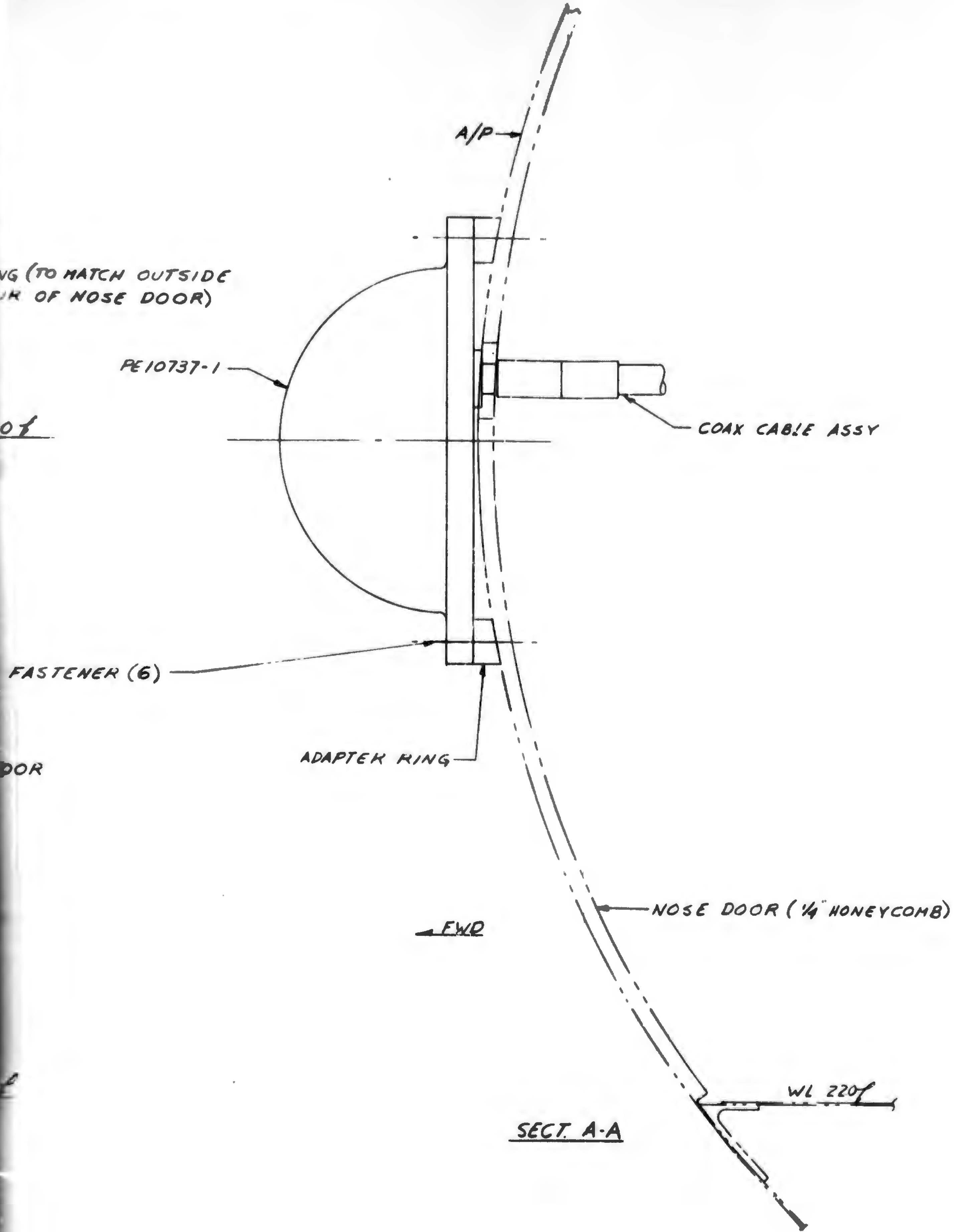


Figure 9-14 Antenna Installation
Nose Door

2

Rotor Modulation Location. (Top ADF Antenna Location) The top ADF antenna location is at Station 81.73 and is approximately 53 inches from the main rotor block shaft. In this location the peak of the antenna beam (antenna vertical axis) is parallel to the helicopter Yaw axis. This allows for maximum signal strength reception normal to the plane of the rotor blades thereby maximizing the modulation effects for the test study.

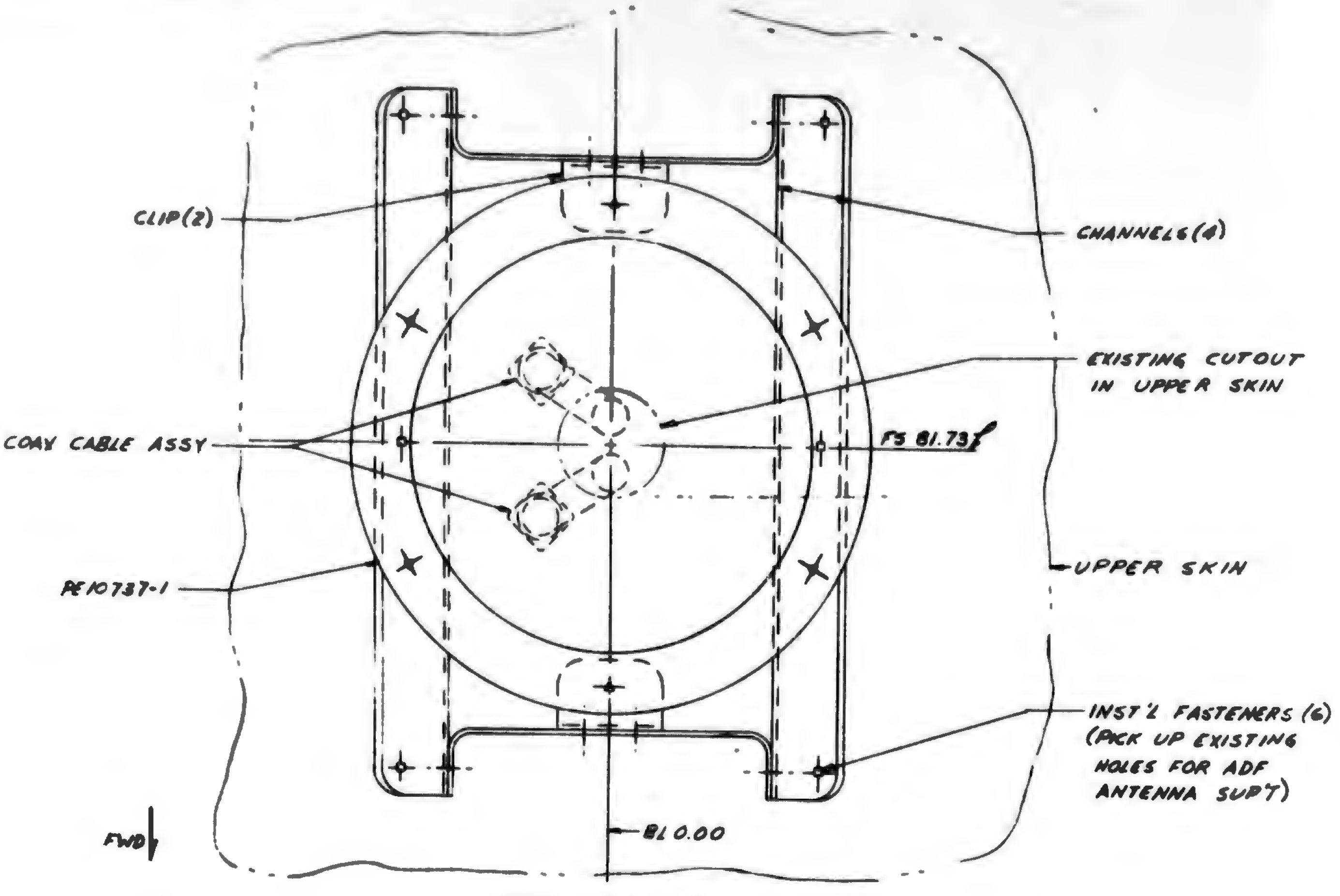
To accommodate the antenna mounting on the aluminum honeycomb structure, a built-up sheet metal section has been designed which picks up the exhisting hole pattern of the ADF antenna. Therefore, no structural modifications are required to the existing upper skin. See Figure 9-15.

The second of the Rotor Modulation Test antenna location is on the aft rotor boom at approximately fuselage station 360. As with the top location, the antenna is directed parallel to the Yaw axis to maximize the modulation effects.

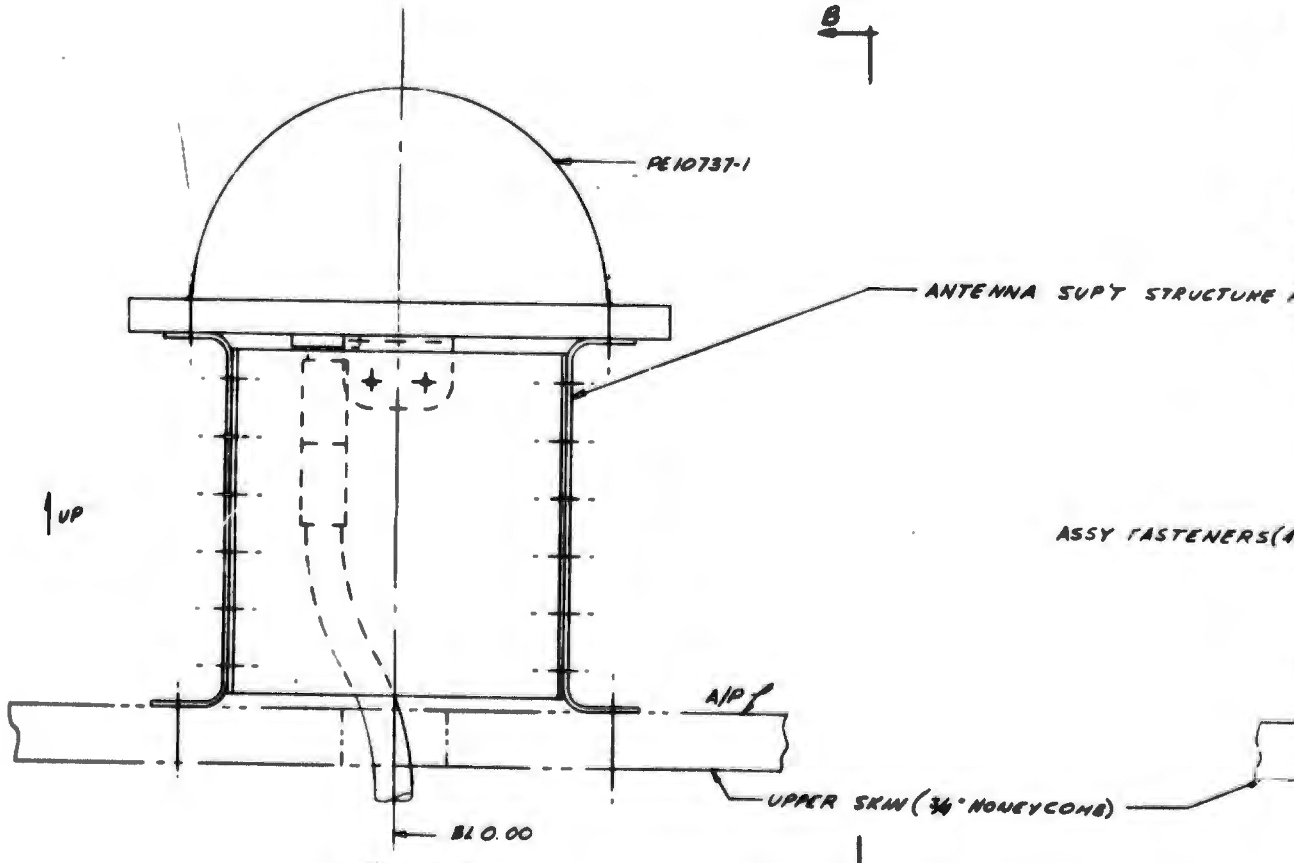
The antenna will be fitted with a right angle connector which allows the cables to be connected perpendicular to the axis of the antenna connectors, eliminating a large cable bending radius that would make the cable connections difficult, and thereby simplifying the design of the structural support assembly (see Figure 9-16).

9.5.3 Ground Transmitting Antennas

ILS Antennas. The ILS test will be performed immediately following the ILS testing for the SAMSO program and will utilize the same equipment configuration. Here the ground and balloon transmitters use the same shaped turnstile design installed on the helicopter without the utilization of the self test probe. The antennas will be mounted on the transmitter sunshield allowing the transmitter/antenna system to be geographically flexible.



A
VIEW LOOKING DWN
A



VIEW A-A
B

NOTE: 1 - Cover inst'l to replace antenna inst'l after completion of flight test program

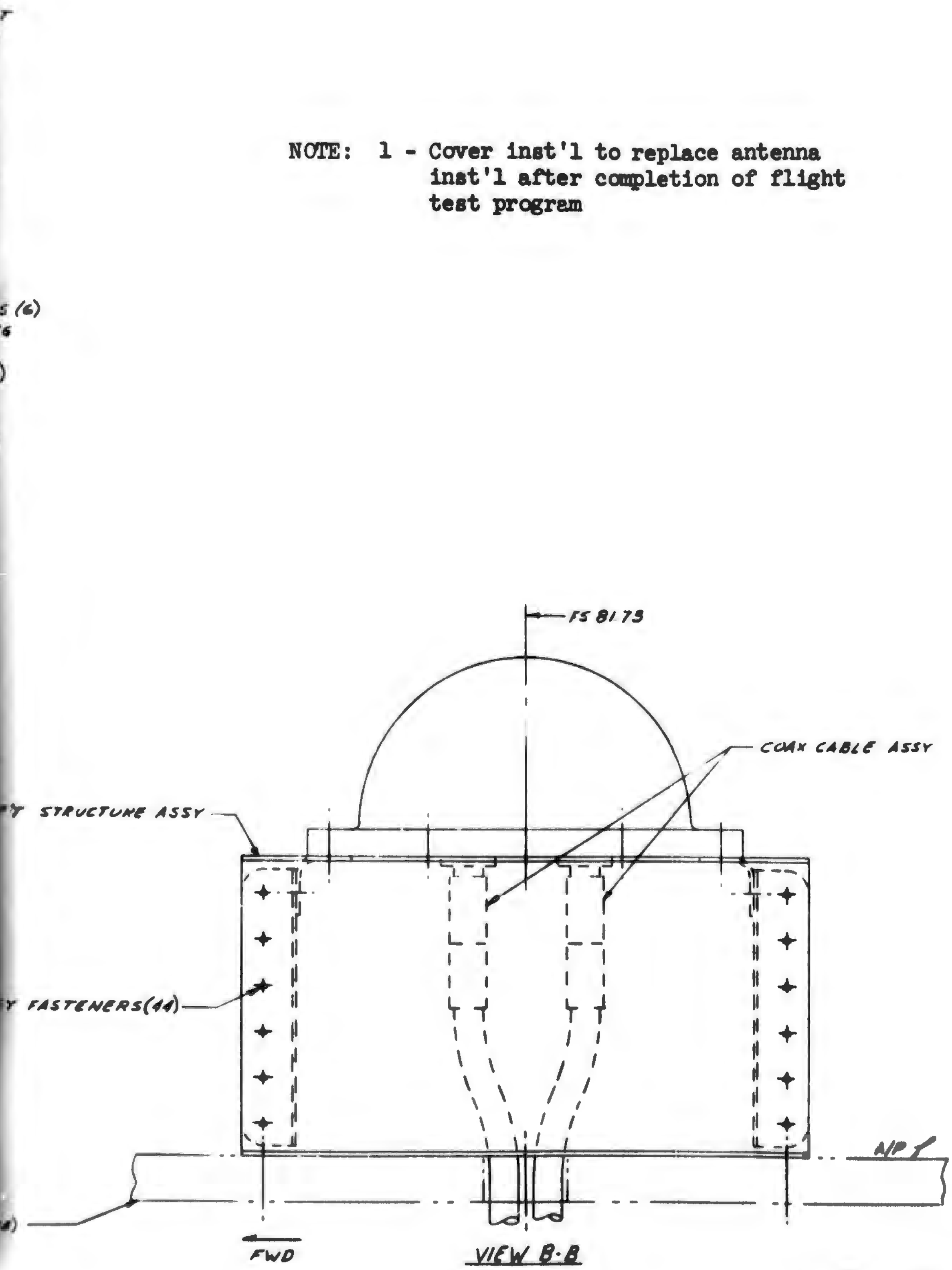
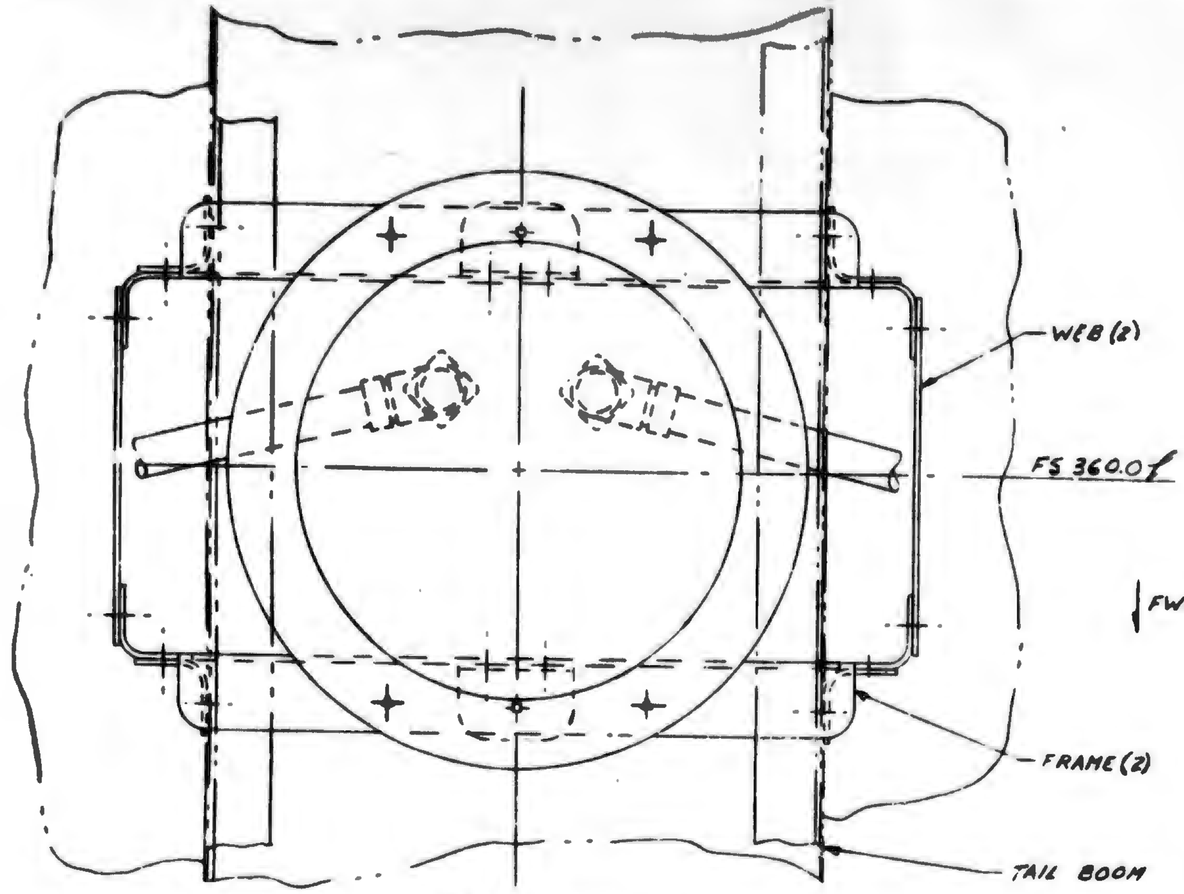


Figure 9-15 Antenna Installation at Upper ADF Antenna Location

2



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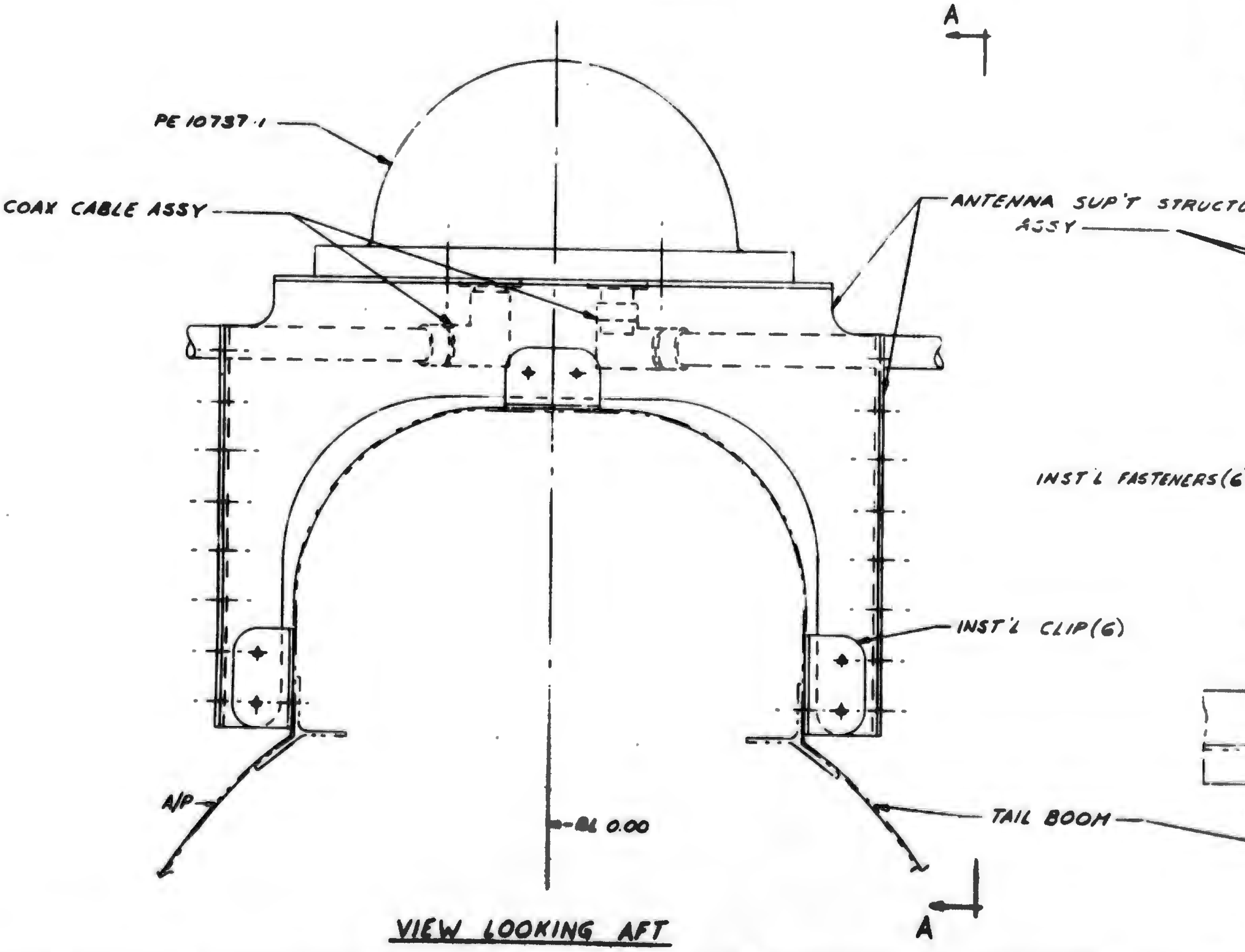

VIEW LOOKING AFT

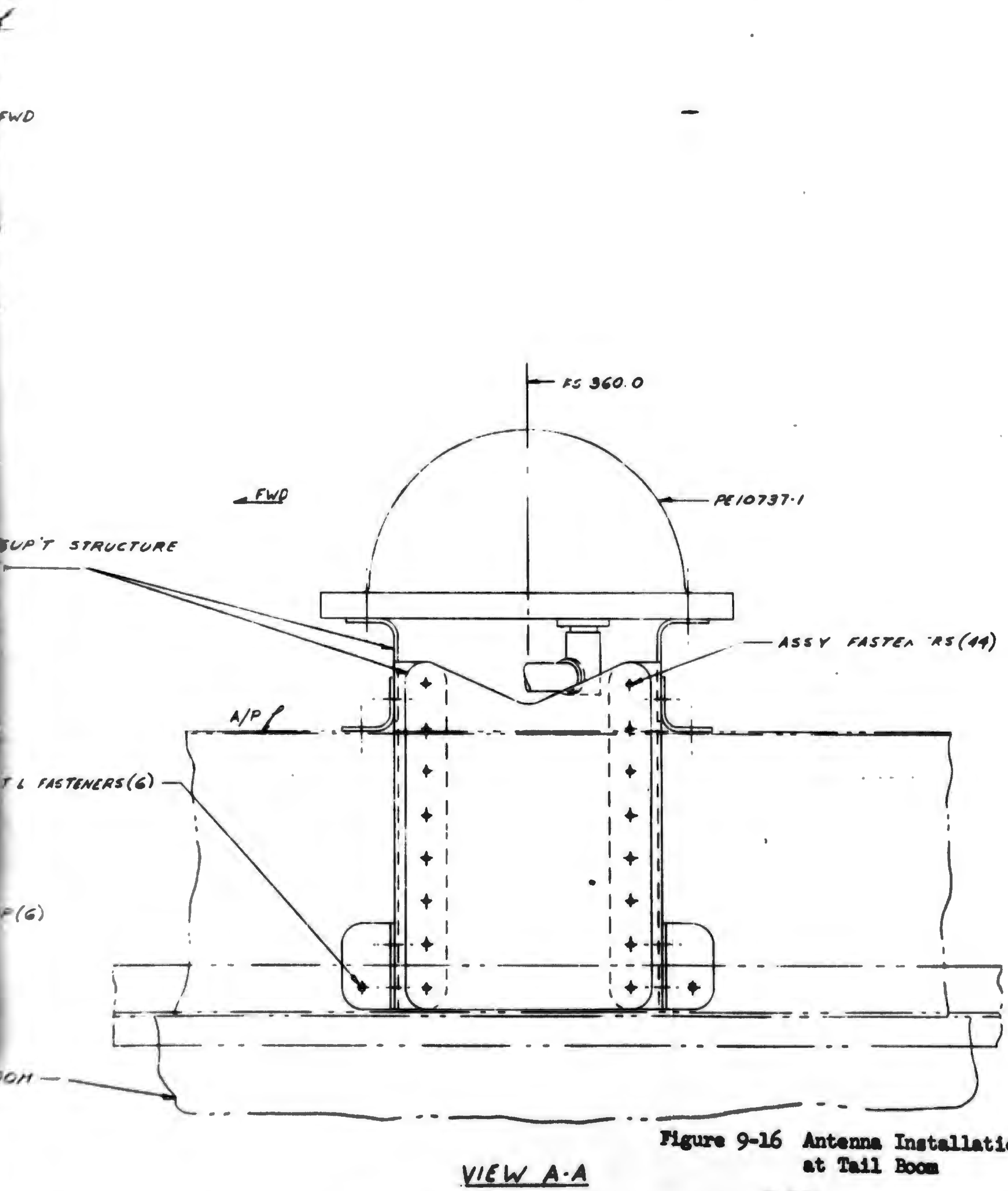

Figure 9-16 Antenna Installation at Tail Boom

Rotor Modulation Tie Down Test Antenna. This test configuration will use the same transmitter configuration, with the ILS antenna, as described in Section 3.1.

Area Navigation Antenna. The Area Navigation flight geometry experiences significant changes in range from the transmitters as the helicopter flies through the transmitter configuration. If the ILS ground antennas were utilized, this changing geometry would reflect itself as a 6 dB change in system antenna gain product and a 4 dB change in space loss. To compensate for the ± 5 dB variation across the range use of the shaped beam antenna used for the NC-135 System Demonstration test may be needed. Here the changing space loss is virtually eliminated so that a minor gain product variation of approximately ± 2 dB is experienced across the range. The antenna is as described in Reference 1.

For these tests, the antennas will be mounted atop the transmitter trailers, which are used in the SAMSO tests and have provisions for the antennas, at three of the sites. The fourth site will require a 15 foot high pipe mount installed and guyed by Grumman at transmitter site #4 (Figure 3-2).

9.5.4 Calibration Link Antennas

The calibration receiving links at the MCS site utilizes four 6 foot dishes mounted on two 20 foot telephone poles (unperturbed SAMSO ILS configuration). These antennas do not require reboresighting for the helicopter ILS test. These receivers will receive the signal transmitted by the uplink omni-directional antenna. However, for the Area Navigation tests, one antenna will require repointing due to the relocation of transmitter #4 in the elongated diamond configuration. This link will be extended to 9000 feet which will require the use of a 6 foot dish for additional calibration link gain for this channel. The dish will be mounted on the existing 4 inch diameter pole on the site and will be fed from a power splitter, not from the delayed output of the receiver. Due to the narrow beam characteristics of the dish, no multipath interference should exist at either the helicopter receiver at any point along the flight path. The 6-foot antenna dish is available from the SAMSO tests.

10. FIELD DATA REDUCTION

Field Site data processing for the helicopter program will closely parallel that for the NC-135 tests. After the flight, the raw receiver data tapes will be validated, converted into engineering units and written on two duplicate engineering units (EU) tapes. One of these tapes, written in a BCD format for computing system compatability, is shipped to Grumman Aerospace Corporation, Bethpage, for fine-grained analysis and comparison to WSMR trajectory data. The other EU tape, written in a CDC binary format, is subsequently processed at KAFB for "quick look" results. The two major components of the field test software package, therefore, are the engineering units conversion and validation program, EUVAL, and the quick look analysis program, NAV/CAL. Only a small amount of modification to the NC-135 programs is required for helicopter test suitability.

10.1 EU CONVERSION

A discussion of the EU conversion/data validation problem is given in Volume IV of the 621B Phase I report (Ref. 1), Section 4.8.1. Basically, the various constraints of the user receiver, data acquisition system and data recording system require that the raw data tapes be written in a hardware-oriented, rather than a software-oriented format. Therefore, it is necessary to recondition and reformat the raw tapes to render them fully compatible to the analytical and applications programs. This process, called engineering units conversion, is performed simultaneously with a valid data check (parity, sync and record length errors) and a short statistical summary of raw data characteristics. The EU data from both airborne and ground sources, along with their statistical characteristics, are written chronologically on the EU tapes for subsequent processing at KAFB and

Grumman, Bethpage. Also, a tabular listing of EU data and validation diagnostics is generated for inspection by field personnel.

The 621B EUVAL program used in NC-135 data reduction includes the tasks listed below. A simplified logic flow diagram is shown in Figure 10-1.

- Record error detection
- Time data validation (software and hardware checks)
- Out-of-limit and diagnostics tests
- Parameter calculations
- Discrete data packing
- Data "time slicing" logic
- Tabular list output of EU data and diagnostics
- EU tape generation
- Statistical calculations

The EUVAL program is presently able to accept data on one, two or three input channels. One channel is for ground site calibration data, one for the Hazeltine user receiver and one for Magnavox Research Laboratories receiver data.

Modification of the EUVAL program for Option I involves the deletion of the Magnavox algorithms and the modification of Hazeltine user receiver processing from a four-channel per sample parallel format to a one-channel per sample serial format. No modification of the calibration site data processing is required. These software changes represent a small programming effort.

10.2 QUICK-LOOK ANALYSIS PROGRAM

The quick look analysis program to be used for the NC-135 tests, NAV/CAL, supports a twofold task: 1) read the EU tape and generate the deterministic navigation solution from the navigation and calibration receiver outputs, and 2) to obtain

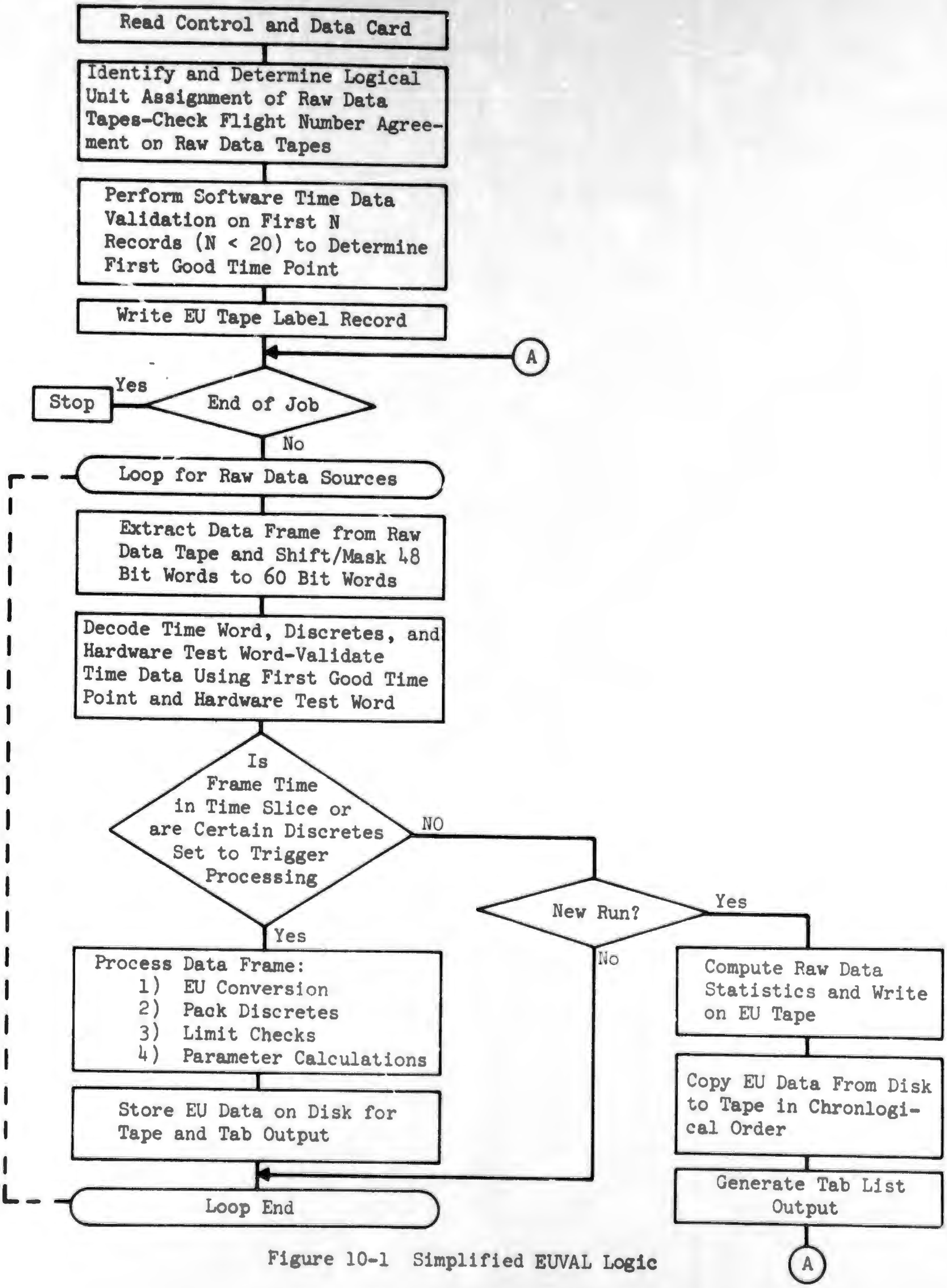

Figure 10-1 Simplified EUVAL Logic

"first cut" statistics for system 621B accuracy. The deterministic (or static) navigation algorithms operate on the four (parallel) pseudorange and pseudodoppler signals available from each data source on the EU tape to produce an x, y, z, $\dot{x}$, $\dot{y}$, $\dot{z}$, t trajectory. This degraded-accuracy (unfiltered) trajectory is written on tab and tape for further analysis. In the NC-135 test program this data is compared with WSMR FPS-16 trajectory date to make a GO/NO-GO decision on further flight test. The quick look WSMR data may not be available in the helicopter test program since all the flights are at low altitutde. Therefore, more reliance will be placed on the NAV/CAL statistical summary for the GO/NO-GO decision.

The NAV/CAL statistical method (variate differences) assumes that the data is composed of a "smooth" trend component and a random error component. By successive differencing of the data the smooth component is attenuated, leaving only the noise component for quantative analysis. The figures thus generated, as well as some results of polynomial regression and serial correlation analysis (also performed in NAV/CAL), are used to determine a GO/NO-GO condition for pending tests. A simplified flow chart is shown in Figure 10-2.

Option I oriented modifications to the Phase II NAV/CAL program are anticipated to be slightly more involved than those performed on the EUVAL program. The major modification will be the conversion of the parallel deterministic navigation solution to a serial solution. In fact, the serial characteristic of the single channel receiver data does not lend itself to a deterministic solution. It is more compatible to a filtered solution. However, the use of a complex filtered solution is neither necessary nor desirable for quick look purposes, and, therefore, the NAV/CAL trajectory will probably be obtained using a linear

Lb1

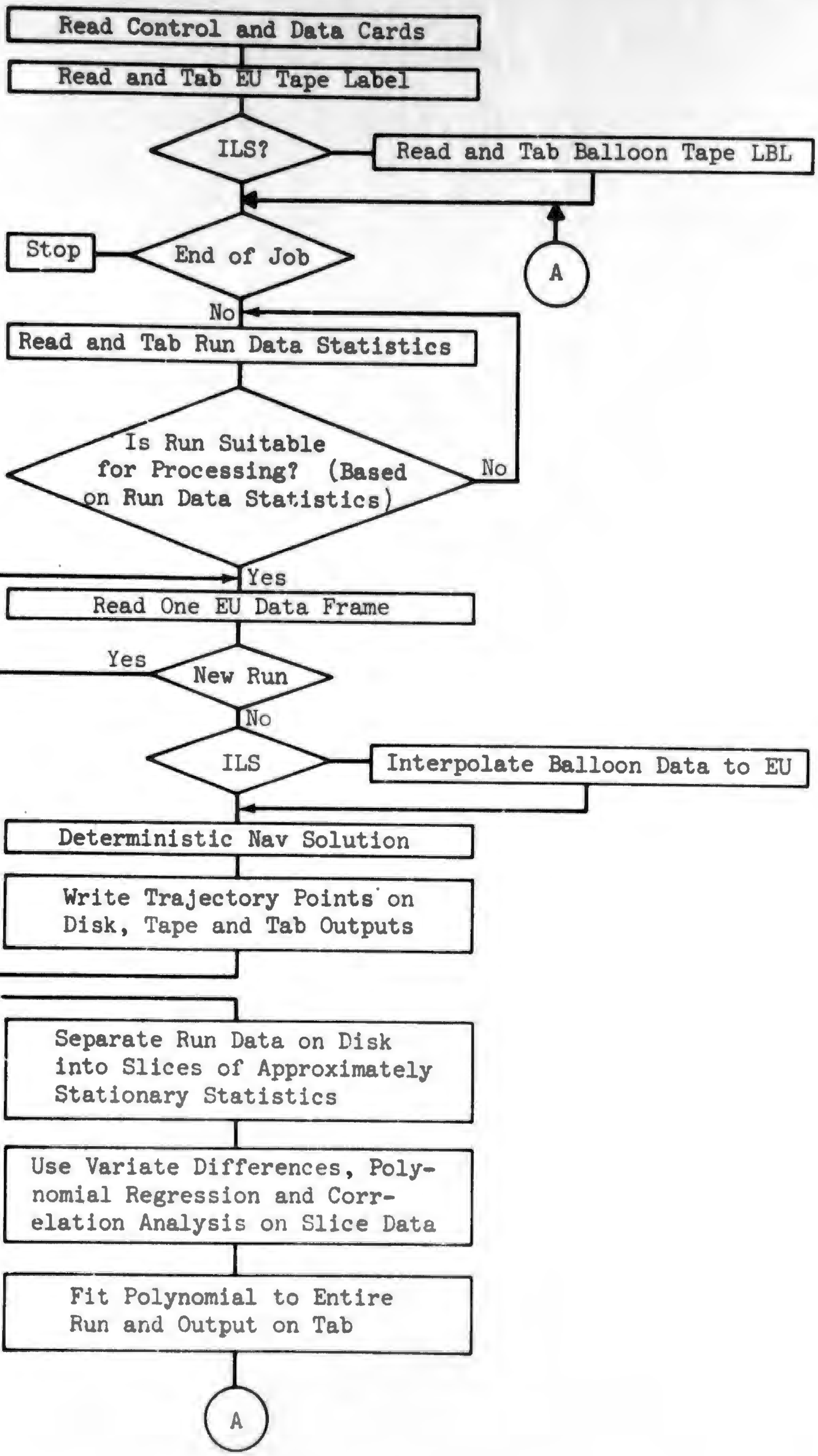

Figure 10-2 Simplified NAV/CAL Logic

extrapolation technique and the existing deterministic solution. This modification, along with a new input routine for reading the serially formatted EU tape are the only foreseeable changes in the NAV/CAL program and do not represent a major programming effort.

10.3 MODIFICATION FOR OPTION II AND III

The impact of the other two options (II and III), digital receiver, and on-board computer, on the field site data processing will now be discussed with respect to the software which has been developed for the NC-135 program. Option II, the digital receiver, will have a minimum impact on existing software. Unlike the GFE receiver, the output of the digital receiver will be identical to that obtained from the four-channel receiver in the NC-135 program. Therefore, the tape formats and EU program are unchanged. Minor changes, if required, such as additional receiver discretes have essentially no impact on the software. Since the digital receiver looks like a four-channel receiver as far as the software is concerned, no modifications to the NAV/CAL program are necessary.

Option III, on-board computer, requires that data processed by the on-board computer as well as the receiver be recorded for post flight analysis. This ncessitates a modification to the airborne recorder tape format. A preliminary investigation has shown that the best approach is to record the receiver data as described above for the proposed program during the flight data run. At the same time, the on-board computer will be sampling the receiver outputs, computing a navigation solution, and storing the results in memory. After the flight data run has been completed, the recording system will stop sampling receiver outputs and connect to the computer to unload the stored computer solution onto the data tape. Thus the tape would consist of two major data blocks per run. One data block consists of receiver data and the other consists of computer data. The post flight analysis software must separate this data into two tapes. The receiver tape would then be processed by the EU and NAV/CAL programs. The computer tape would be processed by a new program which performed any tape decoding necessary to obtain a tab list of data and obtain a tape suitable for further analysis programs. The solution obtained on-board will then be compared to that generated by the NAV/CAL program to determine the validity of the on-board solution. The remaining data analysis and comparison to WSMR reference trajectory data remains unchanged from that established in the NC-135 test program.

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APPENDIX A

AN IDEAL ILS TRANSMITTER CONFIGURATION

SUMMARY. A set of mathematical relations is derived for an idealized ILS configuration. The most significant conclusions are that for a four transmitter configuration with three transmitters constrained to the ground the minimum achievable errors are:

Horizontal Error: $E[\delta y_1^2 + \delta y_2^2] = \frac{4}{3}\sigma_R^2$

Altitude Error: $E[\delta y_3^2] = \sigma_R^2$

where σ_R is the standard deviation of range measurement, assumed equal for each transmitter. These minimum errors occur simultaneously when the three ground transmitter form a symmetric Y about the critical point (landing point for the helicopter, flare for an aircraft) and the fourth transmitter is directly above.

INTRODUCTION. A basic accuracy requirement of an ILS tradeoff study is that errors be small at the critical point, with altitude accuracy being most critical. A logical approach to the overall tradeoff problem is to derive the mathematically optimum solution and then to attempt to achieve this configuration as closely as possible within the practical constraints. In this appendix we present the derivation of the optimum ideal solution.

In order to construct a meaningful math model we list the following observations:

- For the cases of interest the distances between transmitters and the critical point are large compared to the vehicle altitude. The critical point may therefore be treated as if it were in the plane of the ground transmitters.
- With the aid of filtering the pseudorange bias and bias rate should be reduced sufficiently so that the system appears as a ranging system. This assumption is the basis for the utilization of Dynamic GDOP as a useful figure of merit (Ref. 1).

STATEMENT OF THE PROBLEM. Let position at a point, P, be determined from N range measurements ($N \geq 3$) originating from known locations. Let the transmitter locations be constrained as follows:

(a) Transmitters 1 through N-1 must lie in the horizontal plane passing through P.

(b) Transmitter N may be placed arbitrarily.

Assume all range measurements are indepent with equal standard deviation, σ_R.

We will show

(1) The horizontal position error is dependent only on transmitters 1 through N-1.

(2) The vertical position error is minimum when the unit vector from P to Transmitter N is normal to the plane. This minimum corresponds to

$$E\left[\delta y_3^2\right] = \sigma_R^2$$

(3) If N = 4, then the minimum in-plane error occurs when the unit vectors to Transmitters 1, 2, and 3 form a symmetric Y.

This corresponds to

$$E\left[\delta y_1^2 + \delta y_2^2\right] = \frac{4}{3}\sigma_R^2$$

(4) Other solution configurations, equivalent to the symmetric Y, are obtained by rotating any transmitter 180° about the point P.

PROOF OF STATEMENTS (1) AND (2). The system is described by the equations

$$M\delta\bar{Y} = \delta\bar{R}$$

$$M = \begin{bmatrix} \gamma_{11} & \gamma_{12} & 0 \\ \gamma_{N-1,1} & \gamma_{N-1,2} & 0 \\ \gamma_{N1} & \gamma_{N2} & \gamma_{N3} \end{bmatrix}$$

where

$$\delta\bar{Y} = \mathrm{col}\,(\delta Y_1, \delta Y_2, \delta Y_3)$$

$$\delta\bar{R} = \mathrm{col}\,(\delta R_1, \cdots\cdots \delta R_N)$$

The least squares solution is the solution of

$$M^T M \delta\bar{Y} = M^T \delta\bar{R} \tag{A-1}$$

where

$$M^T M = \begin{bmatrix} \sum_{i=1}^{N} \gamma_{i1}^2 & \sum_{i=1}^{N} \gamma_{i1}\gamma_{i2} & \gamma_{N1}\gamma_{N3} \\ \sum_{i=1}^{N} \gamma_{i1}\gamma_{i2} & \sum_{i=1}^{N} \gamma_{i2}^2 & \gamma_{N2}\gamma_{N3} \\ \gamma_{N3}\gamma_{N1} & \gamma_{N3}\gamma_{N2} & \gamma_{N3}^2 \end{bmatrix}$$

and

$$M^T \delta\bar{R} = \begin{bmatrix} \sum_{i=1}^{N} \gamma_{i1}\,\delta R_i \\ \sum_{i=1}^{N} \gamma_{i2}\,\delta R_i \\ \gamma_{N3}\,\delta R_N \end{bmatrix}$$

We solve these equations without using general inversion procedures. Rather we manipulate as follows.

Observe that

$$\gamma_{N3}^{2}\,\delta y_3 = \gamma_{N3}\,\delta R_N - \gamma_{N3}\left(\gamma_{N1}\,\delta y_1 + \gamma_{N2}\,\delta y_2\right)$$

So that, if $\gamma_{N3} \neq 0$

$$\gamma_{N3}\,\delta y_3 = \delta R_N - \left(\gamma_{N1}\,\delta y_1 + \gamma_{N2}\,\delta y_2\right)$$

and

$$\gamma_{N1}\gamma_{N3}\,\delta y_3 = \gamma_{N1}\,\delta R_N - \left(\gamma_{N1}^{2}\,\delta y_1 + \gamma_{N1}\gamma_{N2}\,\delta y_2\right)$$

$$\gamma_{N2}\gamma_{N3}\,\delta y_3 = \gamma_{N2}\,\delta R_N - \left(\gamma_{N1}\gamma_{N2}\,\delta y_1 + \gamma_{N2}^{2}\,\delta y_2\right)$$

Substituting these relationships into equation (1) we can write

$$\begin{bmatrix} \sum_{i=1}^{N-1} \gamma_{i1}^{2} & \sum_{i=1}^{N-1} \gamma_{i1}\gamma_{i2} \\ \sum_{i=1}^{N-1} \gamma_{i1}\gamma_{i2} & \sum_{i=1}^{N-1} \gamma_{i2}^{2} \end{bmatrix} \begin{bmatrix} \delta y_1 \\ \delta y_2 \end{bmatrix} = \begin{bmatrix} \sum_{i=1}^{N-1} \gamma_{i1}\,\delta R_i \\ \sum_{i=1}^{N-1} \gamma_{i2}\,\delta R_i \end{bmatrix} \qquad \text{(A-2)}$$

and

$$\delta y_3 = \frac{1}{\gamma_{N3}}\left\{\delta R_N - \left(\gamma_{N1}\,\delta y_1 + \gamma_{N2}\,\delta y_2\right)\right\} \qquad \text{(A-3)}$$

From (A-3)

$$E\left[\delta y_3^{2}\right] = \frac{1}{\gamma_{N3}}\left\{E\left[\delta R_N^{2}\right] + E\left[\left(\gamma_{N1}\,\delta y_1 + \gamma_{N2}\,\delta y_2\right)^{2} - 2E\left[\delta R_N\left(\gamma_{N1}\,\delta y_1 + \gamma_{N2}\,\delta y_2\right)\right]\right]\right\}$$

From (A-2), δ_{y_1} and δ_{y_2} are indepent of δR_N, so that

$$E\left[\delta R_N\,\delta y_1\right] = E\left[\delta R_N\,\delta y_2\right] = 0$$

and
$$E\left[\delta Y_3^2\right] = \frac{1}{\gamma_{N3}^2}\left\{E\left[\delta R_N^2\right] + E\left[\left(\gamma_{N1}\,\delta Y_1 + \gamma_{N2}\,\delta Y_2\right)^2\right]\right\}$$

Since the second term on the right is always ≥ 0 it is minimized when it is set to zero. We simultaneously minimize this term and maximize the denominator by choosing

$$\gamma_{N1} = \gamma_{N2} = 0$$
$$\gamma_{N3} = 1$$

from which

$$E\left[\delta Y_3^2\right] = E\left[\delta R_N^2\right]$$

or

$$E\left[\delta Y_3^2\right] = \sigma_R^2$$

Thus statements (1) and (2) are proven.

PROOF OF STATEMENT (3). Let T_1, T_2 and T_3 be the three transmitters in the plane. The proof is achieved by utilizing two steps. Step (a): Let T_1 and T_2 be two transmitters in the plane with unit vectors $\bar{\gamma}_1$ and $\bar{\gamma}_2$. Then the best location for transmitter T_3 is so that its unit vector is either along the angle bisector between $\bar{\gamma}_1$ and $\bar{\gamma}_2$ (when the smaller angle between $\bar{\gamma}_1$ and $\bar{\gamma}_2$ is obtuse) or normal to it (when the smaller angle is acute). When the angle between $\bar{\gamma}_1$ and $\bar{\gamma}_2$ is 90°, the choice of T_3 is arbitrary in the plane.

PROOF. Without loss of generality define the coordinate system so that the 1-axis is the angle bisector.

$$\bar{\gamma}_1 = \begin{bmatrix} \alpha \\ \beta \\ 0 \end{bmatrix} \quad , \quad \bar{\gamma}_2 = \begin{bmatrix} \alpha \\ -\beta \\ 0 \end{bmatrix} \quad , \quad \bar{\gamma}_3 = \begin{bmatrix} \gamma_{31} \\ \gamma_{32} \\ \gamma_{33} \end{bmatrix}$$

then equation (A-2) evaluates to

$$\begin{bmatrix} 2\alpha^2 + \gamma_{31}^2 & \gamma_{31}\gamma_{32} \\ \gamma_{31}\gamma_{32} & 2\beta^2 + \gamma_{32}^2 \end{bmatrix} \begin{bmatrix} \delta Y_1 \\ \delta Y_2 \end{bmatrix} = \begin{bmatrix} \alpha(\delta R_1 + \delta R_2) + \gamma_{31}\delta R_3 \\ \beta(\delta R_1 - \delta R_2) + \gamma_{32}\delta R_3 \end{bmatrix}$$

so that

$$E\left[\delta Y_1^2\right] = \frac{(2\beta^2 + \gamma_{32}^2)}{D}\sigma_R^2 \qquad \text{(A-4)}$$

$$E\left[\delta Y_2^2\right] = \frac{(2\alpha^2 + \gamma_{31}^2)}{D}\sigma_R^2 \qquad \text{(A-5)}$$

where D = $2(2\alpha^2\beta^2 + \alpha^2\gamma_{32}^2 + \beta^2\gamma_{31}^2)$

combining (A-4) and (A-5) and using the fact that

$$\gamma_{31}^2 + \gamma_{32}^2 = 1$$
$$\alpha^2 + \beta^2 = 1$$

we obtain

$$E\left[\delta Y_1^2 + \delta Y_2^2\right] = \frac{3\sigma_R^2}{D}$$

where

$$D = 2\left(2\alpha^2\beta^2 + \alpha^2 + \gamma_{31}^2(\beta^2 - \alpha^2)\right)$$

Since the numerator is independent of $\bar{\gamma}_3$, the error is minimized by maximizing D. This is achieved as follows:

If $\beta^2 > \alpha^2$; $\gamma_{31} = 1$; $\gamma_{32} = 0$

$$E\left[\delta Y_1^2 + \delta X_1^2\right] = \frac{3\sigma_R^2}{2\beta^2(2\alpha^2+1)} \qquad \text{(A-6)}$$

If $\alpha^2 > \beta^2$; $\gamma_{31} = 0$; $\gamma_{32} = 1$

$$E\left[\delta Y_1^2 + \delta X_1^2\right] = \frac{3\sigma_R^2}{2\alpha^2(2\beta^2+1)} \qquad \text{(A-7)}$$

If $\alpha = \beta$; the choice of $\bar{\gamma}_3$ is arbitrary in the plane.

COMMENT. The statement $\alpha < \beta$ is equivalent to the statement that $\bar{\gamma}_1$ and $\bar{\gamma}_2$ form an obtuse angle.

Step (b): Given that T_1, T_2 and T_3 are oriented as in (A-6) or (A-7), an optimum choice for β and α is such that T_1, T_2 and T_3 form a symmetric Y. Other equivalent choices are obtained by reflecting transmitters 180°.

PROOF. Consider the case where $\beta^2 > \alpha^2$. The Denominator is given by

$$D = 2\beta^2(2\alpha^2+1) = 2(1-\alpha^2)(2\alpha^2+1)$$

$$\frac{\partial D}{\partial \alpha} = 4\alpha(1-4\alpha^2)$$

and

$$\frac{\partial^2 D}{\partial \alpha^2} = 4 - 48\alpha^2$$

the derivative is zero when

$$\alpha = 0 ; \quad \beta = \pm 1 ; \quad D = 2$$

$$E\left[SY_1^2 + SY_2^2\right] = \frac{3\sigma_R^2}{2}$$

But for this case,

$$\frac{\partial^2 D}{\partial \alpha^2} = 4 > 0$$

and D is at a relative minimum.

The second case is $\alpha = \pm 1/2 ; \quad \beta = \pm \sqrt{3}/2 ; \quad D = 9/4$

$$E\left[SY_1^2 + SY_2^2\right] = 4\sigma_R^2/3$$

$$\frac{\partial^2 D}{\partial \alpha^2} = -8$$

and D is at a relative maximum.

For the case $\alpha^2 > \beta^2$

$$D = 2\alpha^2(2\beta^2 + 1) = 2\alpha^2(3 - 2\alpha^2)$$

$$\frac{\partial D}{\partial \alpha} = 12\alpha - 16\alpha^3$$

$$\frac{\partial^2 D}{\partial \alpha^2} = 12 - 48\alpha^2$$

So that the desired solutions are

$$\alpha = \pm \sqrt{3}/2 ; \quad \beta = \pm 1/2$$

for the minimum error.

APPENDIX B

IMPACT OF BALLOON EPHEMERIS ERRORS ON ILS ACCURACY

This section discusses the impact of transmitter ephemeris errors on 621B navigation accuracy. Of particular interest to the ILS demonstration is the fact that the impact approaches zero as the user position approaches the MCS, provided continuous MCS data is employed by the user algorithm.

The basic equation relating user position and transmitter position to the pseudorange measurement is

$$R_{ui} = \sqrt{(\bar{Y} - X_i) \cdot (\bar{Y} - \bar{X}_i)} + \phi_{si} - \phi_u \tag{B-1}$$

where ϕ_{si} is the $i^{\underline{th}}$ transmitter clock phase (in feet)

ϕ_u is the user's clock phase (in feet)

R_{ui} is the pseudo range measurement output of the user

$\bar{X}_i$ is the position of the transmitter

$\bar{Y}$ is the user position

The analogous equation relating the MCS location and transmitter position to the pseudo range measurement is

$$R_{Ki} = \sqrt{(\bar{Z} - \bar{X}_i) \cdot (\bar{Z} - \bar{X}_i)} + \phi_{si} - \phi_K \tag{B-2}$$

where $\bar{Z}$ is the MCS position

ϕ_K is the phase of the MCS clock

The pseudo range, which is used as an input to the navigation solution is constructed from the relation

$$R_i = R_{ui} - R_{Ki} + \ell_i \qquad \text{(B-3)}$$

where ℓ_i is computed from

$$\ell_i = \sqrt{(\bar{z} - \bar{X}_i)\cdot(\bar{z} - \bar{X}_i)} \qquad \text{(B-4)}$$

Combining (1), (2), (3) and (4) we see that in the absence of errors

$$R_i = \sqrt{(\bar{y} - X_i)\cdot(\bar{y} - X_i)} + \phi_K - \phi_u$$

or

$$R_i = r_i + B$$

where r_i is the true range

B is pseudo range bias, which is independent from channel to channel.

ERROR ANALYSIS. The basic pseudo range measurement equation is

$$(\bar{y} - \bar{X}_i)\cdot(\bar{y} - X_i) = (R_i - B)^2$$

Consider the impact of ephemeris error on position perturbing equations

( ) we obtain

$$\bar{\gamma}\cdot\overline{\delta Y} = \bar{\gamma}\,\overline{\delta X}_i + \delta R_i \qquad \text{(B-5)}$$

where $\bar{\gamma}$ is the unit vector from transmitter (i) to user.

But δR_i is an error caused by contributions by each of the three terms in equation (3)

$$\delta R_i = \delta R_{ui} - \delta R_{Ki} + \delta \ell_i \qquad \text{(B-6)}$$

The errors, δR_{ui} and δR_{ki} are measurement errors; the error $\delta \ell_i$ is caused by using incorrect ephemeris values in the equation (4)

$$\delta L_i = \bar{\gamma}_{Ki} \cdot \delta x_i \qquad \text{(B-7)}$$

where γ_{ki} is the unit vector from transmitter (i) to the MCS

Combining (5), (6) and (7).

$$\bar{\gamma}_i \cdot \delta \bar{y} = (\bar{\gamma}_i - \bar{\gamma}_{Ki}) \cdot \delta \bar{x}_i + \delta R_{ui} - \delta R_{Ki}$$

Thus, the ephemeris error appears to be like an additional measurement error of the form

$$\delta R_{i\epsilon} = (\gamma_i - \gamma_{ui}) \cdot \delta x_i$$

In matrix notation

$$\delta R_{i\epsilon} = (\gamma_i - \gamma_{ui})^T \delta x_i$$

and

$$E\left[\delta R_{i\epsilon}^2\right] = (\bar{\gamma}_i - \bar{\gamma}_{Ki})^T \delta x_i \, \delta x_i^T (\bar{\gamma}_i - \bar{\gamma}_{Ki}) \qquad \text{(B-8)}$$

It is seen from (8) that if $\bar{\gamma}_i = \gamma_{ui}$ then E $(\delta R_{i\epsilon}2) = 0$ and if the magnitude, $/ \bar{\gamma}_i - \bar{\gamma}_{ki} /$, is small then E $(\gamma R_{i\epsilon}2)$ is small.

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13. ABSTRACT

In order to solidify confidence in the predicted performance of the System 621B receiver, this report outlines the tradeoffs that were performed to determine the best field test, for the U.S. Army, of a representative single-channel receiver which would use a helicopter as a test vehicle. Options have been defined including a choice of single-channel receiver and the addition of a real time navigation capability. Also the details of the design and test plan for the selected field test are given, as well as the requirement for the test range. This effort was done in sufficient range and depth to allow the immediate initiation of the test hardware procurement and/or fabrication.

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