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FINAL REPORT

DEVELOPMENTAL TEST

OF THE

HONEYWELL LASER INERTIAL NAVIGATION SYSTEM (LINS)

PREPARED BY

CENTRAL INERTIAL GUIDANCE TEST FACILITY

6585TH TEST GROUP

HOLLOMAN AIR FORCE BASE, NEW MEXICO

NOVEMBER 1975

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Honeywell Laser Inertial Navigation System (LINS), an engineering model of a ring laser gyro strapdown inertial navigation system, was subject to developmental testing at the Central Inertial Guidance Test Facility (CIGTF), 6585th Test Group, Holloman Air Force Base, New Mexico during the period 14 April 1975 to 24 July 1975. The tests were requested by the 666A Program Office, Air Force Avionics Laboratory.

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A total of 20 laboratory tests, 13 flight tests in an NC-141A cargo aircraft testbed and one van test were accomplished. Of these, 12 laboratory tests and 11 flight tests were used in the analysis to determine navigation performance accuracy. The analysis indicated that the LINS appears to be better than a "one nautical mile per hour" navigator when operating unaided, except for barometric altimeter inputs.

The radial position error CEP rate had a value of 0.89 nm/hr for the flight test ensemble used in the computation. The radial position error CEP rate for the laboratory test ensemble was 0.83 nm/hr. The radial position error 90th percentile rates were 1.62 nm/hr and 1.36 nm/hr for the flight and laboratory tests, respectively.

Plots and tables describing position errors and velocity errors for individual tests as well as for test ensembles are presented in the main body of the report or Appendix B.

The LINS was operated for a total of 229 hours with 42 turn-on's without failure. Navigation time was 207 hours.

Reaction time used was 20 minutes for all tests that were analyzed.

The tests demonstrated the successful application of ring laser gyros to strapdown inertial navigation system technology.

FOREWORD

This technical report documents the results of flight test of the Honeywell Laser Inertial Navigation System (LINS), an engineering model of a ring laser gyro strapdown inertial navigation system. The LINS was developed by the Honeywell GAP Division, Minneapolis. The tests were conducted by the Central Inertial Guidance Test Facility (CIGTF), 6585th Test Group, and were sponsored by the Air Force Avionics Laboratory (AFAL), 666A Program Office.

The purpose of the testing was to demonstrate strapdown laser inertial navigation system advanced technology and to evaluate the LINS as a potential candidate system to meet future, moderate accuracy, medium cost, inertial navigator needs. The testing was considered developmental, rather than verification, within the meaning of applicable DOD/DDR&E directives.

Captain David F. Payne was the project test engineer, Mr. Robert B. Shoaf the project analyst and Mr. Hubert P. Koesters the Test Director.

ABSTRACT

The Honeywell Laser Inertial Navigation System (LINS), an engineering model of a ring laser gyro strapdown inertial navigation system, was subject to developmental testing at the Central Inertial Guidance Test Facility (CIGTF), 6585th Test Group, Holloman Air Force Base, New Mexico during the period 14 April 1975 to 24 July 1975. The tests were requested by the 666A Program Office, Air Force Avionics Laboratory.

A total of 20 laboratory tests, 13 flight tests in an NC-141A cargo aircraft testbed and one van test were accomplished. Of these, 12 laboratory tests and 11 flight tests were used in the analysis to determine navigation performance accuracy. The analysis indicated that the LINS appears to be better than a "one nautical mile per hour" navigator when operating unaided, except for barometric altimeter inputs.

The radial position error CEP rate had a value of 0.89 nm/hr for the flight test ensemble used in the computation. The radial position error CEP rate for the laboratory test ensemble was 0.83 nm/hr. The radial position error 90th percentile rates were 1.62 nm/hr and 1.36 nm/hr for the flight and laboratory tests, respectively.

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The LINS was operated for a total of 229 hours with 42 turn-on's without failure. Navigation time was 207 hours.

Reaction time used was 20 minutes for all tests that were analyzed.

The tests demonstrated the successful application of ring laser gyros to strapdown inertial navigation system technology.

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1.1 Authority

1.1.1 AFAL/RWM-6664 Program Introduction Document, 12 March 1975, Ring Laser Gyro Navigator Developmental Flight Test.

1.1.2 AFSWC Management Plan (AFSWC Form 43), 17 March 1975, RLG NAV DEV FLT TEST.

1.2 Purpose of Test

1.2.1 The purpose of the testing was to demonstrate laser inertial navigation system advanced technology and to evaluate the LINS as a potential candidate system to meet future strapdown inertial navigator needs. The tests were developmental rather than verification tests.

1.2.2 The following quotes from DOD memos emphasize the requirement for the developmental flight test of the LINS system.

1.2.2.1 Deputy Secretary of Defense Clements' memo dated 19 November 1974, subject, "Positioning and Navigation Systems", stated: "A demonstration of the ring laser gyro aircraft navigation capability should be accomplished as soon as possible...".

1.2.2.2 DDR&E's memo dated 21 December 1974, subject, "Advanced Technology Demonstration - Laser Inertial Navigation System", stated: "Air Force, with Army and Navy technical participation, should test any (ring laser gyro) platforms available from industry programs during the last half of 1975. Test(s) should be conducted at Holloman Air Force Base as developmental rather than certification tests."

1.2.3 Recognizing the potential for the laser gyro in strapdown inertial systems, Honeywell developed the LINS, under an in-house program, to use this new sensor and as a potential candidate inertial navigator system to meet future moderate accuracy navigator needs. LINS is the HONEYWELL acronym for the class of navigation systems developed under this program.

1.3 Test Objectives

1.3.1 The primary test objective was to determine the navigation performance of the LINS, operating in an unaided inertial mode, except for barometric-altimeter input; specifically, to evaluate velocity and navigational-position accuracy when subjected to the environment produced by the NC-141A testbed aircraft (performance accuracy was also measured in the laboratory and in one mobile van test).

1.3.2 A second objective was to determine variations in performance with changes in alignment time and warm-up time.

2. TEST ITEM DESCRIPTION

2.1 General Description

The Honeywell Laser Inertial Navigation System, LINS (Figure 1), is an engineering model of a ring laser gyro strapdown inertial navigation system. The system tested at the CIGTF contained an inertial sensor assembly which contained three ring laser gyros, arranged in an orthogonal 3-axis non-redundant set, and three single axis accelerometers as the basic sensing elements, in a strapdown configuration. The system also contained a digital navigation computer, separate memory units for the computer, a control display unit and a non-interruptable power supply. The LINS performance goals set by Honeywell are 1 to 3 miles per hour CEP (unaided) navigation accuracy with a reaction time of 2 minutes, including warm-up and alignment. The inertial sensor assembly is operated heaterless, thus elimininating the usual warm-up requirement for conventional inertial system. (Program time constraints did not permit tests to verify the two minute reaction time capability.)

2.2 Physical Characteristics

The LINS consists of the following pieces of hardware:

(1) Inertial Sensor Assemble (ISA)

(2) Strapdown Navigation Computer (SNC) with separate alterable memory units

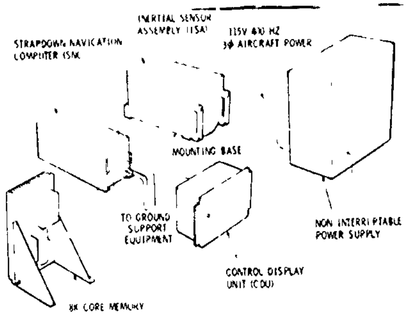
(3) Control Display Unit (CDU)

(4) Non-interruptable Power Supply

Refer to Figure 1 for a block diagram and physical characteristics of the system.

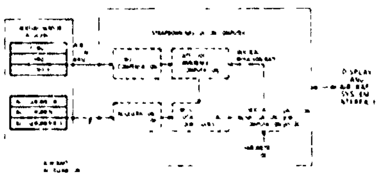
2.2.1 ISA

The ISA contains three Systron Donner 4841F-10 single axis accelerometers and three Honeywell GG1300-AE01 laser gyros in an orthogonal strapdown configuration. The ISA is operated heaterless. Due to the low power dissipation in the ISA (50 watts), ducted air cooling is not required below 130 degrees F ambient air temperature.



HARDWARE	DIMENSIONS (INCHES)	WEIGHT (POUNDS)	POWER
ISA	23.2 x 10.8 x 12.2	102.0	115VAC,400 Hz and 28VDC for system components are supplied through the non-interruptable power supply as follows: 1380VA normally; 3450VA maximum continuous; 6900VA start up transient of 50 milli-seconds.
SNC	23.0 x 7.7 x 7.8	17.7	
8K Core Memory	11.4 x 10.0 x 21.0	22.8	
CDU	7.2 x 19.0 x 12.2	12.0	
Non-Interruptable P.S.	30.0 x 12.0 x 12.8	125.0	

LINS ENGINEERING HARDWARE



BASIC LINS FUNCTIONAL BLOCK DIAGRAM

FIGURE 1. LINS SYSTEM BLOCK DIAGRAMS AND PHYSICAL CHARACTERISTICS

The GG1300-AE01 laser gyro, shown schematically in Figure 2, has the following performance goals which were provided by the contractor.

Accuracy (.01 deg/hr bias, .0005 percent scale factor error, .005 deg/hr $^{1/2}$ random walk in angle)

Instantaneous reaction time (no heaters or warm-up requirement)

Long-term stability (no preflight calibration)

Fine resolution (1.57 arc second pulse size over full operating range of ± 400 deg/sec)

G-insensitive performance

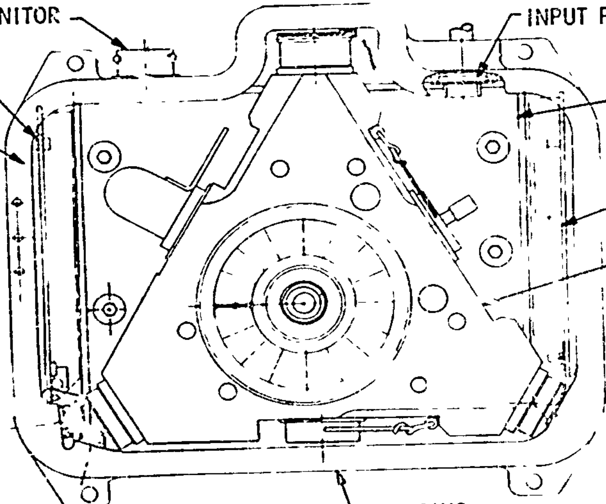
High reliability (few assembly parts and no moving parts)

The outputs of the laser gyros are pulses, each pulse representing a body axis rotation angle increment. The pulses are accumulated by up-down counters and strobed into the LINS computer at 160 Hz.

The 4841F-10 accelerometer is a low-cost inertial grade electrically servoed accelerometer designed for strapdown applications in aircraft and missiles. The off-the-shelf specification for this accelerometer is a reaction time of 30 seconds with 100 G bias stability and .05 percent scale factor accuracy over a wide temperature range (-65° to 160°F) without heaters. A current pulse reset integrator digitizer is used to convert the analog current output signals from the accelerometers into pulses, each pulse representing a body axis velocity increment. The pulses are accumulated by up-down counters and strobed into the LINS computer at 160 Hz. The digitizer circuit has low thermal sensitivity allowing operation without temperature control.

2.2.2 SNC With Alterable Memory Units

The strapdown navigation computer utilizes the HDC-301A processor to perform the strapdown navigation computations.



SIZE:
7 BY 8 BY 2 INCHES

WEIGHT:
6.5 POUNDS

POWER:
6.0 WATTS NOMINAL, 8.0 WATTS MAX.

MAXIMUM INPUT RATE:
± 400 DEG/SEC

SCALE FACTOR:
2^{-17} RAD/PULSE 1.574 ARC-SEC/PULSE

PATH LENGTH:
43.13 CM (TOTAL); 5.66 INCHES PER LEG

NE LASER TRANSITION:
0.6328 MICRON

LOCK-IN COMPENSATION:
CAVITY ROTATIONAL DITHER

FIGURE 2. GG-1300 LASER GYRO CHARACTERISTICS

The HDC-301A is a MIL SPEC qualified, 16 bit parallel digital general-purpose processor with double-precision capability and basic instruction times of 5 micro seconds for add and 21 micro seconds for multiply. It is packaged on a single six-inch square multilayer plug-in card.

In addition to the use of the HDC-301A card the SNC also utilizes a separate alterable 8K core memory unit with its own power supply. Both the memory unit and its power supply are manufactured by Electronic Memories.

2.2.3 CDU

The control display unit (CDU) provides the capability to operate the system in its basic operating modes (standby, align, navigate) either aided or unaided. The unaided mode was used during the CIGTF flight tests covered by this report. The CDU displays latitude, longitude, ground speed and track angle.

2.2.4 Non-Interruptable Power Supply

The non-interruptable power supply, manufactured by Gulton Industries, uses a 400 Hz, 115 volt line-to-neutral, 3 phase input and provides 400 Hz, 115 volts line-to-neutral 3 phase (also 24 VDC) output. This unit contains a battery, battery charger, AC-DC and DC-AC converters. When input line transients, abnormal line voltage or line failure occur, the system output power remains within normal limits of voltage and frequency, with no interruption of output power. The following are the main features of the system:

(1) Sealed, maintenance free nickel-cadmium battery and associated charger and control circuits.

(2) All solid state circuits.

(3) The AC output voltage and frequency variations are less than those present at the input, even when the input is within normal transient free range of voltage and frequency available from conventional aircraft power sources.

(4) forced air cooling with four separate over-temperature sensors (at critical locations) which protect the system by interruption of the appropriate circuit or circuits.

3. TEST METHOD

3.1 Test Approach

The LINS system was flight tested under the developmental test concept. Laboratory tests and a van test were conducted to supplement the flight tests. Since this system is an engineering model and the number of tests was relatively small, evaluation of reliability and maintainability was not accomplished other than to point out that no failures occurred during the test program. The reaction time allowed for all tests was 20 minutes, including warmup and alignment. This is a standard reaction time used for CIGTF verification test programs.

With the above concepts in mind and the heavy commitment of the C-141 testbed to higher priority programs, the LINS system was flown "piggy-back" with other systems whenever the aircraft flew. The number and order of aircraft tests were thus somewhat restricted and the flight profile preferred for each LINS test was not always achieved. However, the flight tests did provide data suitable for quantitative analysis of navigation performance.

The standardized laboratory tests were somewhat expanded to investigate effects of various reaction times. Reaction times on the order of two to three minutes were used for special contractor studies pertaining to system alignment. These were not considered valid tests for purposes of this report.

Only one van test was performed. Originally, 10 to 12 van tests were planned but time constraints did not permit extended van testing.

For test results and the various test conditions refer to Section 5 and Appendix B.

3.2 Aircraft Test Configuration

The LINS system was installed on a standardized CIGTF aircraft pallet 73-0030. A description of this generalized pallet is shown in Figures 3 and 4.

Palletization techniques enabled the system to easily be moved between the laboratory, testbed aircraft, and the van without changing the test configuration.

The LINS system utilized its own power distribution unit (Non-interruptable Power Supply) which kept the system isolated from any power anomalies which might be encountered during the test. Refer to paragraph 2.2.4.

A Hewlett Packard 2114 digital computer, a Digidata tape recorder, and a Gulton time code generator were provided by CIGTF to gather the test data.

The aircraft testbed carried a camera which was used to photograph ground check points for aircraft position reference. The camera was used in a vertically stabilized and in a fixed mode of operation.

A detailed list of engineering drawings for the aircraft Class II modification is available at the 6585th Test Group Aeronautical Test Division.

3.3 Laboratory Test Configuration

Laboratory tests were done with the LINS Inertial Sensor Assembly (ISA) mounted on a Scorsby table top. During lab tests, the LINS system was electrically integrated with the aircraft pallet and instrumentation recording system such that the lab test configuration was identical to the aircraft test configuration. The Scorsby table top could be positioned in azimuth to provide any desired heading. It could also be fixed in a level position or made to provide Scorsby action input to the ISA, i.e., the table top axis was forced into a conical motion at a preselected frequency and angular displacement such that the ISA was subjected to an oscillatory rotating-tilt motion while the average system heading remained unchanged.

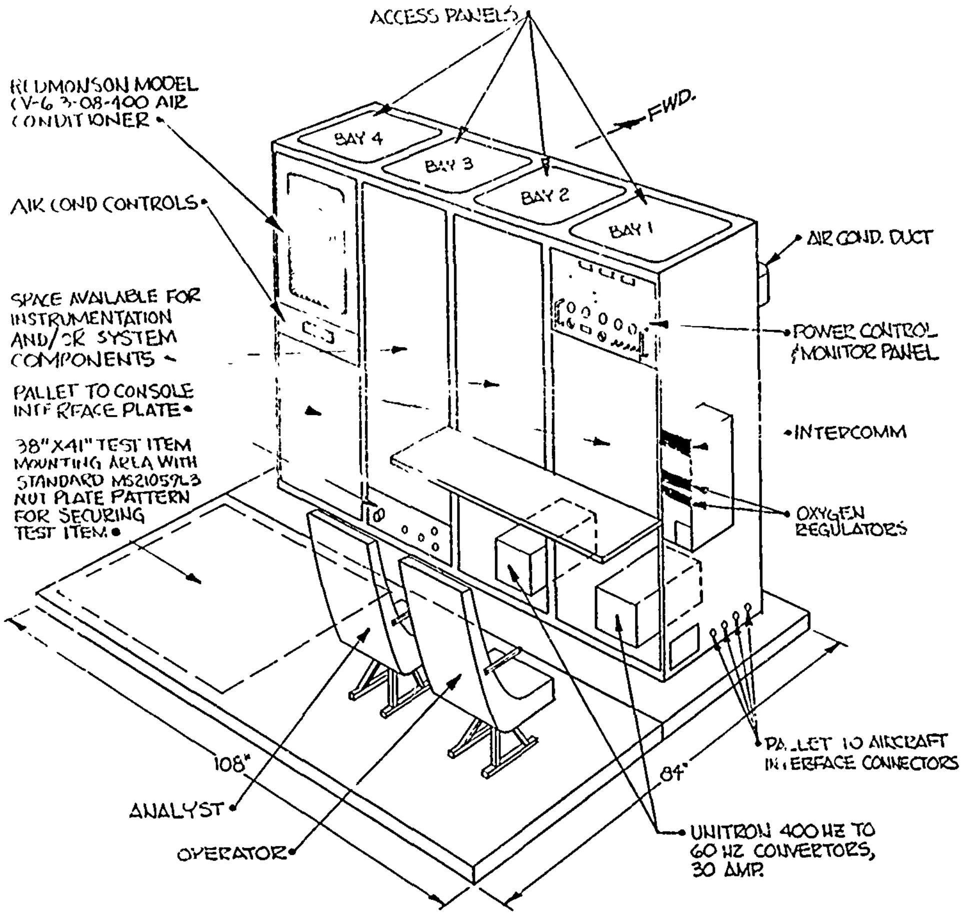


FIGURE 3

AIRCRAFT PALLET SCHEMATIC

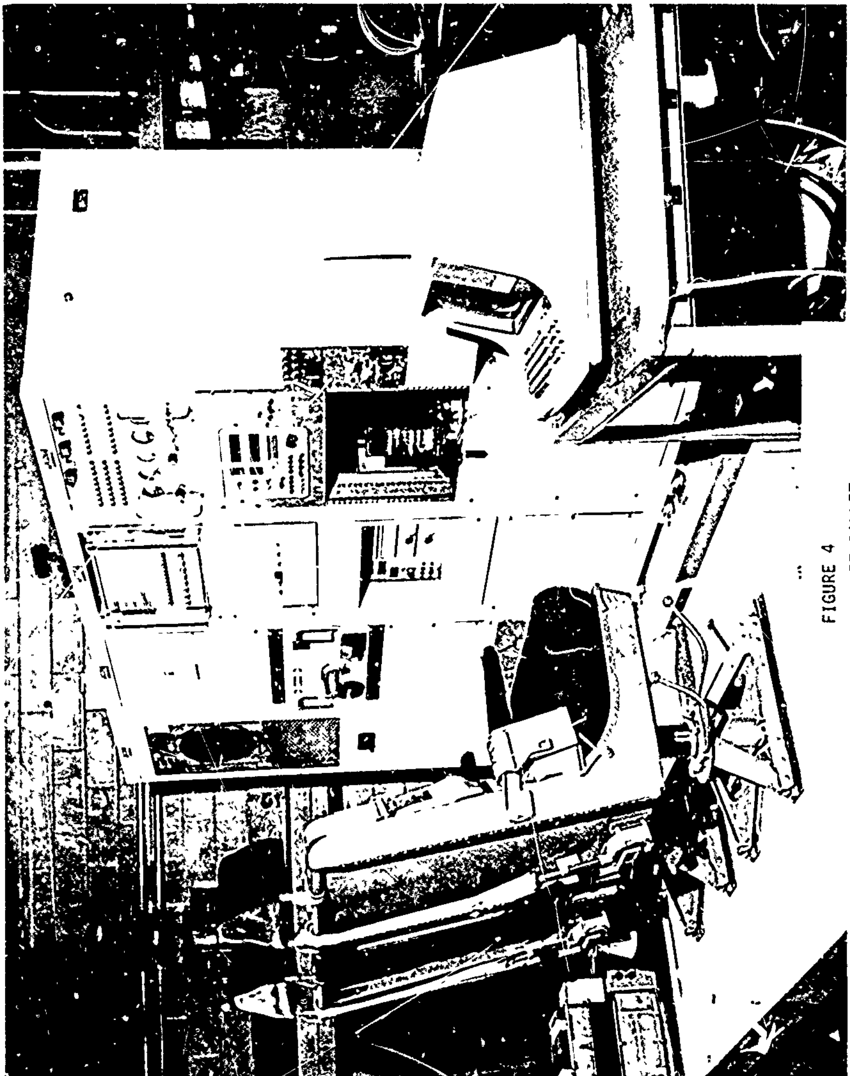


FIGURE 4
LINS AIRCRAFT PALLET

3.4 Van Test Configuration

The one van test that was conducted used a special CIGTF mobile van which was configured to carry the LINS aircraft pallet such that the van test configuration was identical to the aircraft test configuration. The van also contains its own power supplies and carried the CIRIS as a reference system for measurement of LINS performance. CIRIS is the acronym for Completely Integrated Reference Instrumentation System.

4. DATA REDUCTION AND ANALYSIS TECHNIQUES

4.1 The LINS output data and test reference data were time correlated and recorded on magnetic tape. The contents of these tapes were processed on a CDC 6600 computer and subjected to CIGTF standardized analysis procedures described in Appendix A.

4.2 Appendix A presents a discussion of the reference sources (photo-identifiable checkpoints and CIRIS) as well as standardized methods of determining actual position errors and smoothed position errors, for which a smoothing process generates best estimates of position error at times during the tests when position error data gaps existed. Appendix A also shows how estimates of velocity errors were derived from the smoothed position errors, it also discusses two different methods of calculating 50th percentiles (CEP and R50) and the method of determining the 90th percentiles of the distributions of radial position errors and of the radial velocity errors.

5. TEST RESULTS

5.1 Presentation of Results

Plots of the mean, arithmetic median and percentiles of the estimate of the distribution of radial position errors for the laboratory and aircraft tests are presented in Figures 5 through 8. They include two different 50th percentiles (R50 and CEP with 85 percent confidence limits) and the 90th percentiles (R90). The two 50th percentiles, referred to as R50 and CEP, were derived by two different methods as described in Appendix A and in References 1 and 2.

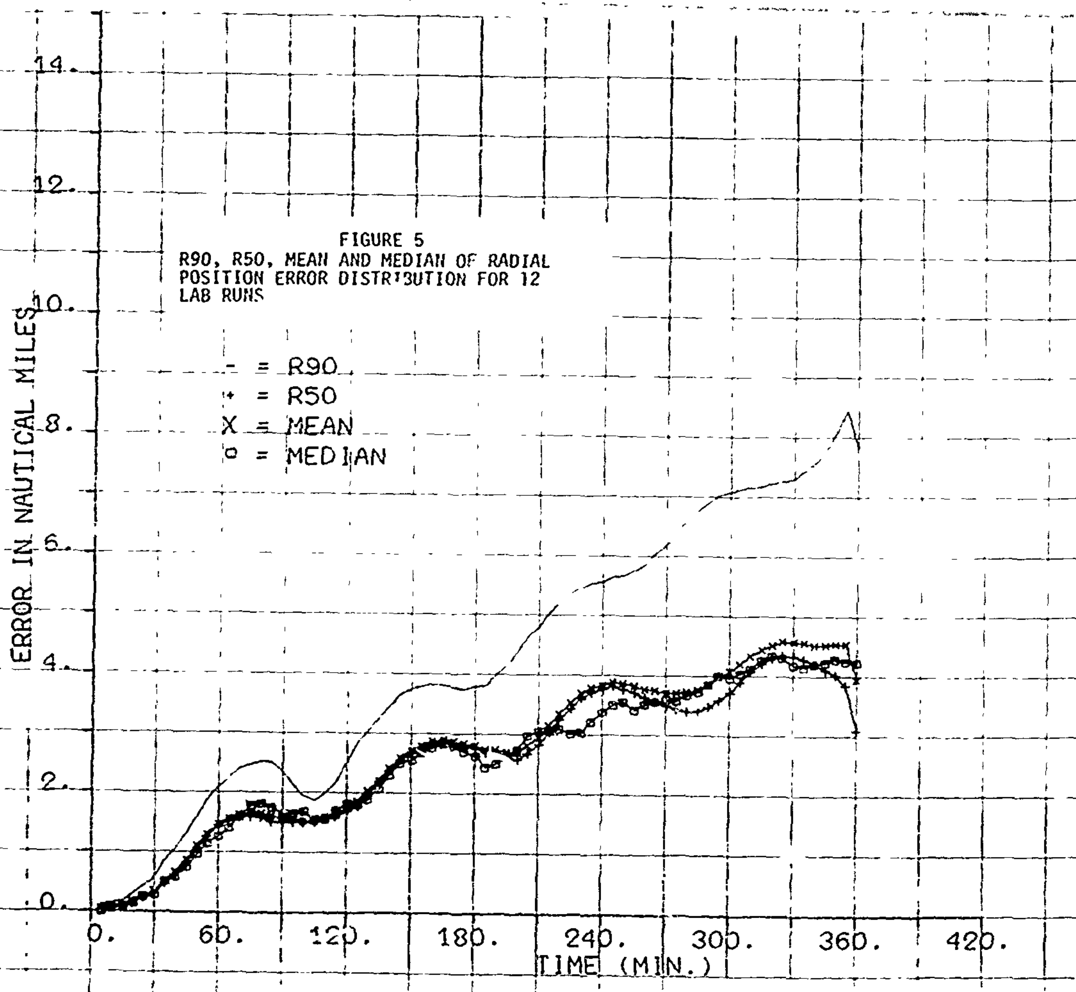
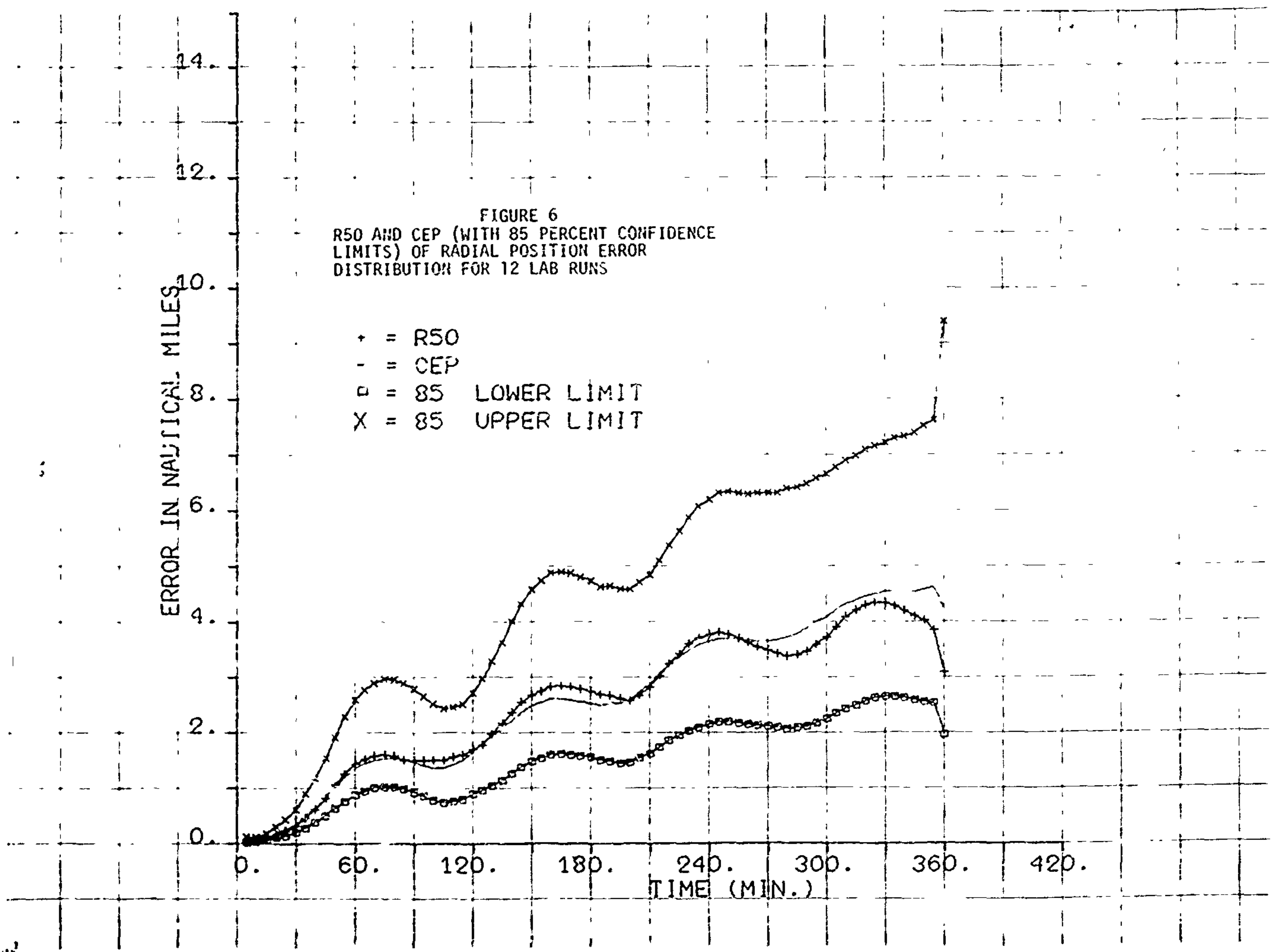


FIGURE 5
R90, R50, MEAN AND MEDIAN OF RADIAL POSITION ERROR DISTRIBUTION FOR 12 LAB RUNS

FIGURE 6

R50 AND CEP (WITH 85 PERCENT CONFIDENCE LIMITS) OF RADIAL POSITION ERROR DISTRIBUTION FOR 12 LAB RUNS



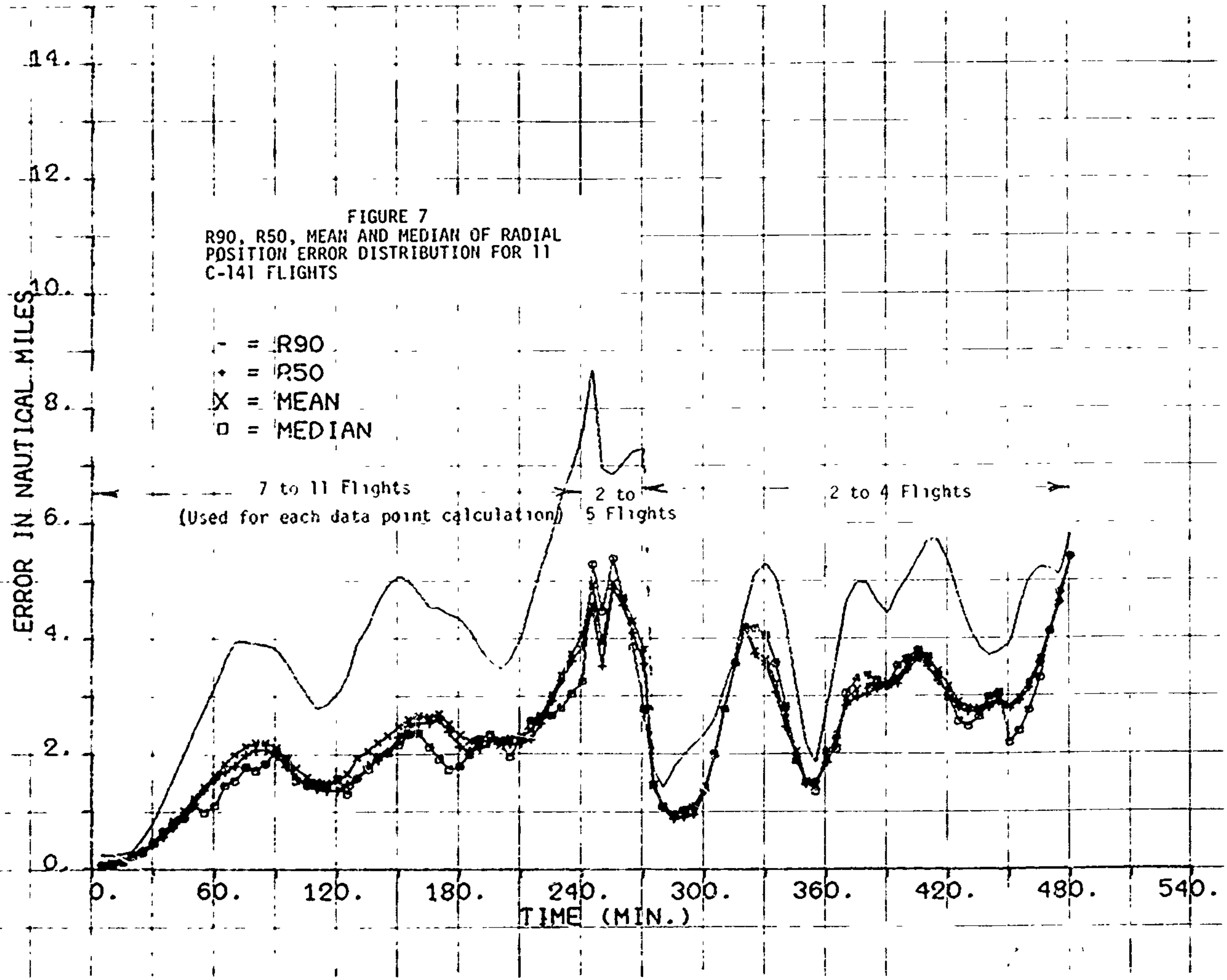
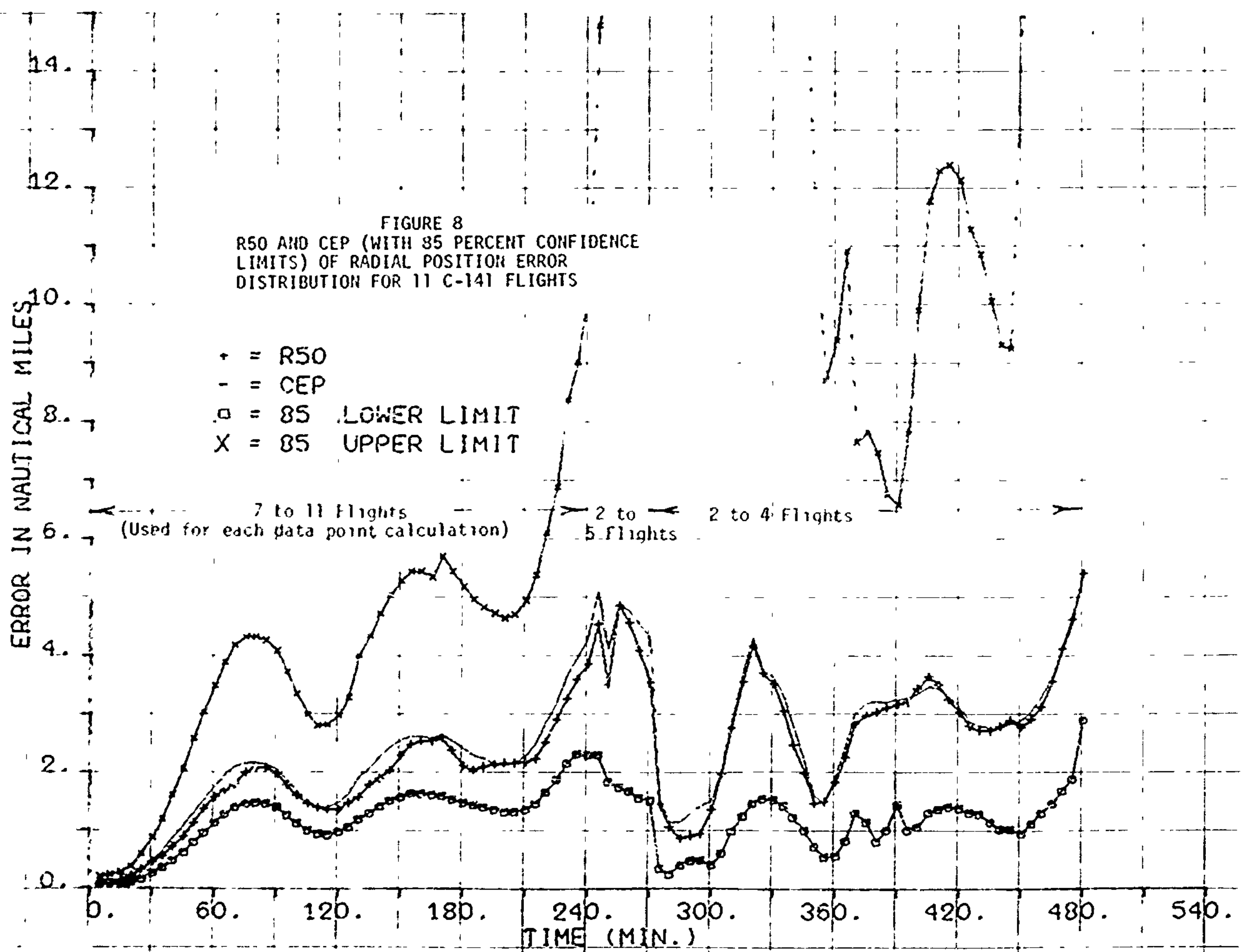


FIGURE 7
R90, R50, MEAN AND MEDIAN OF RADIAL POSITION ERROR DISTRIBUTION FOR 11 C-141 FLIGHTS

FIGURE 8
R50 AND CEP (WITH 85 PERCENT CONFIDENCE LIMITS) OF RADIAL POSITION ERROR DISTRIBUTION FOR 11 C-141 FLIGHTS



Position error CEP rates, R50 rates and R90 rates for the laboratory and aircraft tests that were analyzed are presented in Table I. See Appendix A for analysis techniques used and for definitions of CEP, R50 and R90 and definitions of CEP, R50 and R90 rates.

TABLE I

POSITION ERROR CEP, R50 AND R90 RATES

TYPE TEST	NUMBER OF TESTS	RADIAL POSITION ERROR RATES (NM/HR) CEP RATE	R50 RATE	R90 RATE
Laboratory	12	0.83	0.79	1.36
Flight	See Note	0.89	0.82	1.52

NOTE: Only those CEP, R50 and R90 values for the first 240 minutes of the 11 flight test ensemble were used in calculating CEP, R50 and R90 rates. This is the approximate point in time where the confidence in these values breaks down due to the rapid decrease in the number of flights that produced performance data beyond that time. The number of flights in the flight test ensemble, for the first 240 minutes, varied from 11 to 7 flights. Refer to Figures 7 and 8 and pages B-101 through B-103 in Appendix B.

Additional plots are presented in Appendix B. These include plots of the 50th (R50 and CEP) and 90th (R90) percentiles of the radial velocity error distributions, for the 12 laboratory tests and 11 flight tests that were analyzed, as well as plots of composite and individual position errors and velocity errors for all valid* tests. Velocity errors for flight tests were derived from position errors. Appendix B also presents tables of numerical values describing system navigation accuracy.

* Tests that generated navigation performance data, but not all used in the analysis.

Due to the limited amount of time available no attempt was made to provide computer simulations to identify major error sources.

5.2 Laboratory Test Summary

From test start (14 April 1975) to test completion (24 July 1975), 20 laboratory tests were made. Of the 20 laboratory tests, 12 were analyzed as a group. Of the remaining eight, five were heading sensitivity tests with a realignment after each Schuler period (84 minutes), two were 14 degree Scorsby table tests and one was a seven degree Scorsby table test. Seventeen tests generally ran for about six hours each and the other three from 2.0 to 4.5 hours. Plots of the mean, median and 50th and 90th percentiles of the radial position error distributions for the 12 laboratory tests that were analyzed are shown in Figures 5 and 6. In the legends for these plots, R50 and CEP (with 85 percent confidence limits) pertain to the 50th percentile calculated using the GM/RMS and chi-square methods, respectively, R90 pertains to the 90th percentile calculated using the GM/RMS method (Refer to Appendix A). A radial position error CEP rate, R50 rate and R90 rate, for the 12 laboratory tests analyzed, are listed in Table I. The CEP rate is the slope of a straight line fit through the origin and to the CEP data plotted in Figure 6. The R50 and R90 rates were similarly determined from the data plotted in Figure 5. See Appendix B for a detailed description and listing of laboratory tests and additional test results.

5.3 Flight Test Summary

Cargo aircraft flight testing was conducted from 14 May to 27 June 1975. A total of 13 NC-141A flights were flown. Six were staged from Holloman AFB, NM, three from Elmendorf AFB, Alaska, and four from Eielson AFB, Alaska. Of the 13 flights, 11 were analyzed as a group. Only quick-look position error data is available for the 25 June 1975 flight (1C021) from Eielson AFB, Alaska to Holloman AFB, NM, because of a tape recorder malfunction. The 27 June local shakedown flight (1C022) had no reference data because the Completely Integrated Reference Instrumentation System (CIRIS) was inoperative. Flights 1C021 and 1C022 were not included in the ensemble of 11 flight tests that were analyzed as a group. Plots of the mean, median, and 50th and 90th percentiles of the radial position error distributions for the 11 flight tests that were analyzed are shown in Figures 7 and 8. A radial position error CEP rate, R50 rate and R90 rate, for the 11 flight tests analyzed, were calculated in the same manner as for the laboratory tests and are listed in Table I. See Appendix B for a detailed description and listing of flight tests and additional test results.

5.4 Van Test Summary

Van testing consisted of one van test, 1VC033 (18 July 1975), on White Sands Missile Range using CIRIS as a reference system. See Appendix B for a detailed description of the one van test and test results.

5.5 Overall Test Record

Table II summarizes the number of system turn-on's, operating hours, flight hours, navigation hours, valid tests and system chargeable failures for all tests. Refer to Appendix B for detailed test records and system performance and analysis results.

TABLE II

OVERALL TEST RECORD

	LAB	FLIGHT	VAN	TOTAL
Number of System Turn-on's	25	15	2	42
Number of System Operating Hours	133	90	6	229
Number of Flight Hours	N/A	66	N/A	66
Number of Navigation Hours	118	84	5	207
Number of Valid* Tests	20	11	1	32
System Chargeable Failures	0	0	0	0

*Tests from which navigation data was obtained, but not all used in the analysis

5.6 Maintainability

There were no LINS failures or maintenance actions during the period that the LINS was under test at the CIGTF. Therefore, it is not possible to assess the ease of maintenance. However, the major units (CDU, ISA, SNC and power supply) are line replaceable units. The LINS is an engineering model and a one-of-a-kind item. Built in test equipment (BITE) indicators to isolate malfunctions were not incorporated within the LINS that was tested but are planned for future production versions.

5.7 Reliability

This test program was conducted in accordance with controlled reliability testing techniques. Success and failure criteria were established at the onset of testing. During the course of the test program, a total of 229 hours of system operating time were accumulated with no system oriented failures. No recalibrations were necessary, which demonstrated good component stability. Bias changes, had they occurred, could have been calibrated and inserted into the software on site. It was not necessary to return the LINS to the contractor's facility during the test program.

5.8 Operational Suitability

The LINS, tested at the CIGTF as an engineering model in a C-141 aircraft, exhibited potential operational suitability for cargo type aircraft.

6. PROGRAM SUMMARY AND CONCLUSIONS

6.1 Summary

The Honeywell LINS, an engineering model of a ring laser strapdown inertial navigation system, was subjected to developmental testing from 14 April 1975 through 24 July 1975. Twenty (20) laboratory tests, 13 flight tests in a NC-141A testbed and one (1) van test were accomplished. Twelve (12) of the 20 laboratory tests and 11 of the 13 flight tests were analyzed in groups. The LINS system was operated for 229 hours and navigated for 207 hours.

Since the LINS system tested was an engineering model and the tests were developmental and relatively small in number, reliability and maintainability were not evaluated; however, no failures occurred during the test program.

Further detail of the tests and detailed test results are presented in the preceding Section 5 and in Appendix B.

6.2 Conclusions

The tests, though developmental rather than verification, demonstrated the successful application of the Honeywell GG-1300 ring laser gyros to strapdown inertial navigation system technology. The tests demonstrated that the LINS, as an engineering model of a strapdown inertial navigation system, is a potential candidate system to meet future strapdown inertial navigator needs.

Based on limited test data, the LINS appears to be better than a "one nautical mile per hour" navigator when operating in an unaided mode, as it was during the CIGTF tests. The slope of a straight line, fit to the 50th percentiles (CEP's) of the radial position error distribution and forced to pass through the origin of the 50th percentile versus time plot, is referred to as CEP rate and had a value of 0.83 nm/hr for an ensemble of 12 laboratory tests used in the computation. The CEP rate for an ensemble of 11 flight tests was 0.89 nm/hr, evaluated over the initial 240 minutes of navigation time (See Note in Table II). The slopes of similar straight lines fit to the 90th percentiles were 1.35 nm/hr and 1.62 nm/hr for the 12 laboratory and 11 flight tests, respectively. The 85 percent upper confidence limits for the radial position error CEP rates for the lab test ensemble and for the initial 240 minutes of the flight test ensemble were 1.58 nm/hr and 1.91 nm/hr, respectively.

The radial position error rate for the one and only van test (of 3.7 hours) was 0.75 nm/hr.

Reaction times of 20 minutes, including 10 minutes alignment, were used for all tests that were analyzed. The design goal is for a reaction time of two (2) minutes. Program time constraints did not permit sufficient tests to evaluate the two minute reaction time capability.

APPENDIX A
DATA REDUCTION AND ANALYSIS TECHNIQUES

1. INTRODUCTION

This appendix presents brief descriptions of the references, used to determine test system position errors, and the data reduction process.

It also contains a description of the analysis techniques used in (1) determining position errors, (2) deriving velocity error estimates from the position errors, (3) estimation of test ensemble distribution of radial errors in terms of 50th (CEP and R50) and 90th (R90) percentiles of the distribution, (4) determining test ensemble CEP, R50 and R90 rates of radial errors, and (5) determining the radial position error rates for individual tests.

2. REFERENCES AND POSITION ERROR DETERMINATION

2.1 Laboratory Tests

No position reference instrumentation was required for laboratory tests of the LINS since the navigation runs were conducted with the system in a fixed geographical location. Position and velocity errors were obtained directly from the test system. Test system output data was recorded on the same instrumentation system used for flight tests.

2.2 Photo Checkpoint Flight Tests

Aerial photographs of surveyed ground checkpoints were made with either a vertically stabilized or a fixed camera aboard the aircraft. At the instant the photo was taken, an electrical pulse from the camera system was recorded on the instrumentation recording system which also recorded IRIG time information. Checkpoint miss distances were later obtained from the camera film. Checkpoint number, time of the camera pulse occurrence, and miss distances were input into a computer program containing a master checkpoint file.

Test system latitude and longitude and aircraft pitch, roll and altitude, all referenced to IRIG time and recorded on the aircraft instrumentation system magnetic tape, were also input into this computer program. Fixed camera checkpoint miss distances were corrected for the effects of aircraft pitch and roll errors and altitude. The output tape from this program contained the test system actual latitude and longitude position errors and the resultant radial* position error referenced to IRIG time. Test system velocity errors were then derived from these position errors as explained in paragraph 3 below.

2.3 Van Tests

The Completely Integrated Reference Instrumentation System (CIRIS) was used as the position and velocity reference for the one and only van test conducted. The CIRIS is a self contained highly accurate reference system which can be carried aboard the aircraft or van. It provides position, velocity and attitude reference data real time and contains its own recording/display system.

3. ANALYSIS TECHNIQUES

3.1 Calculation of Smoothed Position Errors and Derivation of Velocity Errors

Smoothed position errors were produced from the actual position errors measured during a flight test. Since a velocity reference was not available for direct comparison to system output velocity during flight tests, velocity errors for flight tests were derived from the smoothed position errors.

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* Radial position error is the root sum square value of the latitude and longitude position error.

The inputs to the computer program used for the derivation of test system velocity errors were the actual position errors determined for each test. The following two conditions had to be met to produce smoothed position errors from which velocity errors could be derived.

(1) At least four actual position error points were needed to calculate one smoothed position error point.

(2) A fit interval of 60 minutes was used for calculation of each smoothed position error point. In the event that four data points were not found to satisfy the 60 minute fit interval requirement, the interval was expanded to satisfy condition (1). If more than four points were found in a 60 minute interval, all points were used in the calculation. The value of 60 minutes was chosen to satisfy the flight test conditions where data gaps occurred quite frequently. The equation,

$$y = B_1 + B_2\,\omega t + B_3 \cos \omega t + B_4 \sin \omega t$$

where ω = $2\pi/84.4$

and y = position error (latitude or longitude)

was chosen to be fitted to the data since it best approximates the propagation of position error, taking into account the Schuler Period (84.4 minutes). The first derivative of the above equation, after the "B" coefficients were obtained from the fit, produced the smoothed north or east velocity errors, V_N or V_E.

For each smoothed latitude and longitude position error, a radial position error was also calculated. The radial velocity error was derived by taking the root sum square of the derived north-south and east-west velocity errors. (Note that the derived radial velocity error is not the time derivative of the radial position error.)

3.2 Estimation of the Distribution of Radial Errors

Two methods were used to estimate the 50th percentile of radial position and radial velocity errors and are described below. The first method was used to estimate the 90th percentile as well as a 50th percentile. The second method was used to estimate a 50th percentile only.

3.2.1 GM/RMS Method

The first method involves a maximum likelihood estimate of the distribution of radial errors made at fixed time intervals. For this report, the interval was selected as five minutes. The estimate for each five minute point in time is based on all of the samples of radial error at that time, for a particular test ensemble, i.e., laboratory or aircraft test. From the estimate of the distribution, calculations were made to determine the percentiles of radial error, R_p, where p indicates the percentile of the distribution. Each calculation yielded the best estimate of the radial error for that time into the test and for that percentile level. Calculations were made for the 50th and 90th percentiles. The 50th percentile represents the geometric median value of the distribution of radial errors at the time in question, and hence indicates that 50 percent of the time the expected radial error will be less than that value obtained for the 50th percentile. In this report, the 50th percentiles and 90th percentiles calculated by this method are referred to as R50 and R90 respectively. This first method, referred to as the GM/RMS method, is described in detail in Reference 1.

3.2.2 Weighted Chi-Square Method

A second method used to calculate the 50th percentiles of the radial error distributions is a weighted Chi-square method based on a paper by Rosen and Harmer titled "Inertial Systems Performance Evaluation" (Reference 2). This method also uses five minute intervals for the estimates and provides upper and lower 85 percent confidence limits of the 50th percentiles. That is, based on the number of samples, there is an 85 percent confidence that the 50th percentiles lie between these limits. In this report, the 50th percentiles calculated by this method are referred to as CEP's.

3.3 Calculation of the Radial Position Error CEP, R50 and R90 Rate

The radial position error CEP rate, for a particular test ensemble (laboratory or flight test), is the slope of a straight line, fit in a least squares sense to the CEP's of the radial position error distribution and constrained to pass through the origin of the CEP versus time plot. The radial position error R50 and R90 rates are calculated in a similar manner.

3.4 Calculation of the Radial Velocity Error R50 and R90 Rates With Y-Intercept

The radial velocity error R50 rate, for a particular test ensemble, is the slope of a straight line, fit in a least squares sense to the R50's of the radial velocity error distribution. Note that this straight line fit is not constrained to pass through the origin and therefore produces a Y-intercept value as shown in Tables B-II and B-IV in Appendix B. The radial velocity error R90 rate is calculated in a similar manner.

3.5 Calculation of the Radial Position Error Rates for Individual Tests

The radial position error rate for each test is the slope of a zero-"Y"-intercept-linear-least-squares fit to the smoothed radial position errors generated by the test.

APPENDIX B

LABORATORY, AIRCRAFT, AND VAN TEST RECORDS AND RESULTS

This appendix contains a tabulation of all tests conducted, test results and a generalized diagram (Figure B-1) of the flight paths utilized for the cargo aircraft test flights. See Section 5 of the main body of this report for additional test results. See Appendix A for analysis techniques.

1. LABORATORY TEST RECORDS

1.1 Test History

Three basic types of laboratory tests were conducted by CIGTF project personnel. They were static tests, Scorsby table tests, and heading sensitivity tests.

The static tests were totally static, i.e., no motion during or after alignment, for tests up to six hours. The Scorsby table tests consisted of static alignment followed by a navigation run while the IMU was subjected to a rocking motion in which the table vertical axis described a cone, while system average heading remained unchanged. For one test, this "rotating-tilt" type of Scorsby motion occurred at the normal rate of six cycles per minute (CPM) and with the normal peak-to-peak tilt of six degrees. Laboratory tests 1LC037 (23 July 1975) and 1LC038 (24 July 1975) used a rate of six CPM with a peak-to-peak tilt of 14 degrees. Test 1LC039 used a rate of six CPM with a peak-to-peak tilt of seven degrees. Several variations of the heading sensitivity tests were used. In each case, a 90° azimuth rotation of the IMU was accomplished after one Schuler period (84 minutes). Heading sensitivity lab tests 1LC009, 1LC028, 1LC029, 1LC030 and 1LC032, which included a realignment after each Schuler period, were not analyzed (No CEP's, etc), although position, velocity and radial error plots were generated.

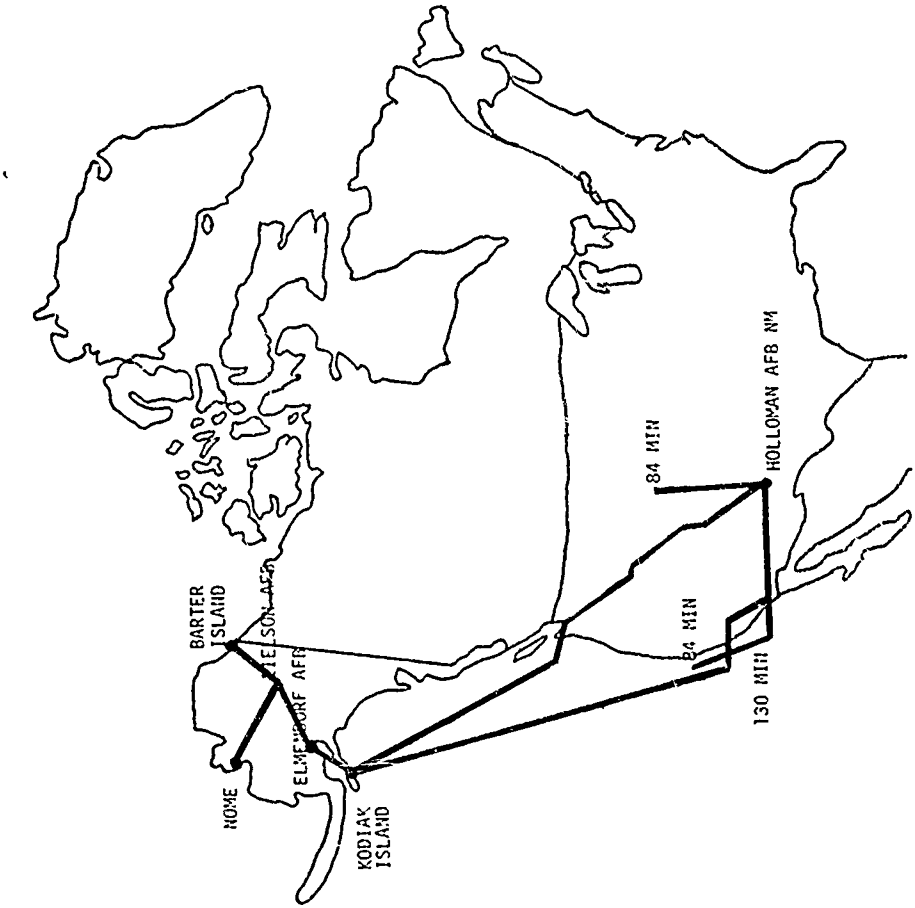


FIGURE B-1. C-141 FLIGHT PATHS

Beginning with lab test 1LC023 (1 July 1975) each lab test was made at the request of the contractor in an attempt to confirm a suspected gyro problem. Lab runs 1LC037, 1LC038 and 1LC039 used Scorsby motions other than six degrees peak-to-peak and were not included in the analysis, although position, velocity and radial error plots were made. All reaction times were 20 minutes including an alignment time of 10 minutes.

1.1.2 System Performance and Analysis Results (Lab Tests)

Table B-I presents the radial position error rate, as well as pertinent test parameters, for each laboratory test. Note in Table B-I that the radial position errors from laboratory tests 1LC037 and 1LC038 are generally much larger than the errors from the other lab tests. These increased errors were no doubt a result of the unusually large Scorsby angular motion, 14 degrees peak-to-peak versus the usual 6 degrees.

Table B-II presents the radial position error CEP rates, R50 rates and R90 rates for the ensemble of 12 laboratory tests that were analyzed as a group. Table B-II also presents the radial velocity error R50 and R90 rates with Y-intercept. The twelve laboratory navigation runs that were analyzed as a group to determine the 50th (CEP and R50) and 90th percentiles of the distribution of radial errors were 1LC002, 1LC003, 1LC004, 1LC005, 1LC006, 1LC007, 1LC023, 1LC024, 1LC025, 1LC026, 1LC027 and 1LC031.

Refer to Appendix A for analysis techniques and definitions of performance values.

Figures 5 and 6 in the main body of this report contain the plots of the R90, R50, CEP mean and median of the radial position error distribution for the 12 laboratory test ensemble.

TABLE B-I

LABORATORY INDIVIDUAL TEST RESULTS

DATE	LABORATORY TEST DESCRIPTION	TEST LABEL	INITIAL ALIGNMENT HEADING (DEGREE)	NAV TIME (HRS)	RADIAL POSITION ERROP RATES (NR/HR)
1 MAY 75	STATIC NAV	1LCØØ2	0^{0}	6.1	0.81
2 MAY 75	SCORSBY (6^{0} P-P)	1LCØØ3	0^{0}	6.1	1.27
8 MAY 75	STATIC NAV	1LCØØ4	180^{0}	6.0	0.77
8 MAY 75	HEAD SENSITIVITY 90^{0} TURN AT 84 MINUTE INTERVALS	1LCØØ5	180^{0}	6.0	0.43
9 MAY 75	HEAD SENSITIVITY WITH 6^{0} SCORSBY. 90^{0} TURN AT 84 MINUTE INTERVALS	1LCØØ6	180^{0}	6.0	1.44
9 MAY 75	HEAD SENSITIVITY WITH 6^{0} SCORSBY. 90^{0} TURN AT 84 MINUTE INTERVALS	1LCØØ7	180^{0}	6.0	0.55
2 JUN 75	HEAD SENSITIVITY 90^{0} TURNS AT 84 MINUTE INTERVALS REALIGN NORTH BEFORE EACH 90^{0} POSITION	1LCØØ9*	0^{0}	5.3	0.29
1 JUL 75	STATIC NAV	1LCØ23	90^{0}	6.0	1.26
2 JUL 75	STATIC NAV	1LCØ24	90^{0}	6.0	0.82
3 JUL 75	HEAD SENSITIVITY 90^{0} TURN AT 84 MINUTE INTERVALS	1LCØ25	90^{0}	6.0	1.09
7 JUL 75	HEAD SENSITIVITY 90^{0} TURN AT 84 MINUTE INTERVALS	1LCØ26	90^{0}	6.0	0.35
8 JUL 75	HEAD SENSITIVITY 90^{0} TURN AT 84 MINUTE INTERVALS	1LCØ27	90^{0}	6.0	0.57
9 JUL 75	HEAD SENSITIVITY 90^{0} TURN AT 84 MINUTE INTERVALS REALIGN EAST BEFORE EACH 90^{0} POSITION	1LCØ28*	90^{0}	4.5	0.14

Table B-I (Continued)

DATE	LABORATORY TEST DESCRIPTION	TEST LABEL	INITIAL ALIGNMENT HEADING (DEGREES)	NAV TIME (HRS)	RADIAL POSITION ERROR RATES (NM/HR)
10 JUL 75	HEAD SENSITIVITY 90^{o} TURNS AT 84 MINUTE INTERVALS REALIGN EAST BEFORE EACH 90^{o} POSITION	1LCØ29*	90^{o}	5.6	0.10
11 JUL 75	SPECIAL HEAD SENSITIVITY. REALIGN EAST AFTER EACH 90^{o} TURN AT 84 MINUTES	1LCØ3Ø*	90^{o}	5.6	0.22
14 JUL 75	STATIC	1LCØ31	90^{o}	6.0	0.89
15 JUL 75	SPECIAL HEAD SENSITIVITY. REALIGN NORTH AFTER EACH 90^{o} TURN AT 84 MINUTES	1LCØ32*	90^{o}	5.6	0.25
23 JUL 75	SCORSBY (14^{o} P-P)	1LCØ37*	0^{o}	5.0	6.55
24 JUL 75	SCORSBY (14^{o} P-P)	1LCØ38*	0^{o}	1.8	6.11
24 JUL 75	SCORSBY (7^{o} P-P)	1LCØ39*	0^{o}	3.0	1.08

* NOT ANALYZED FOR ENSEMBLE PERFORMANCE (SEE TABLE B-II).

TABLE B-II

LABORATORY TEST ENSEMBLE PERFORMANCE VALUES

TOTAL LAB TESTS	RADIAL POSITION ERROR RATES (NM/HR)			RADIAL VELOCITY ERROR RATES, Y-INTERCEPT (FPS PER HR, FPS)	
	CEP RATE	R50 RATE	R90 RATE	R50	R90
12	0.83	0.79	1.36	0.42,2.70	1.27,4.03

NOTES: (1) Radial position error is the root sum square of the latitude and longitude position errors.

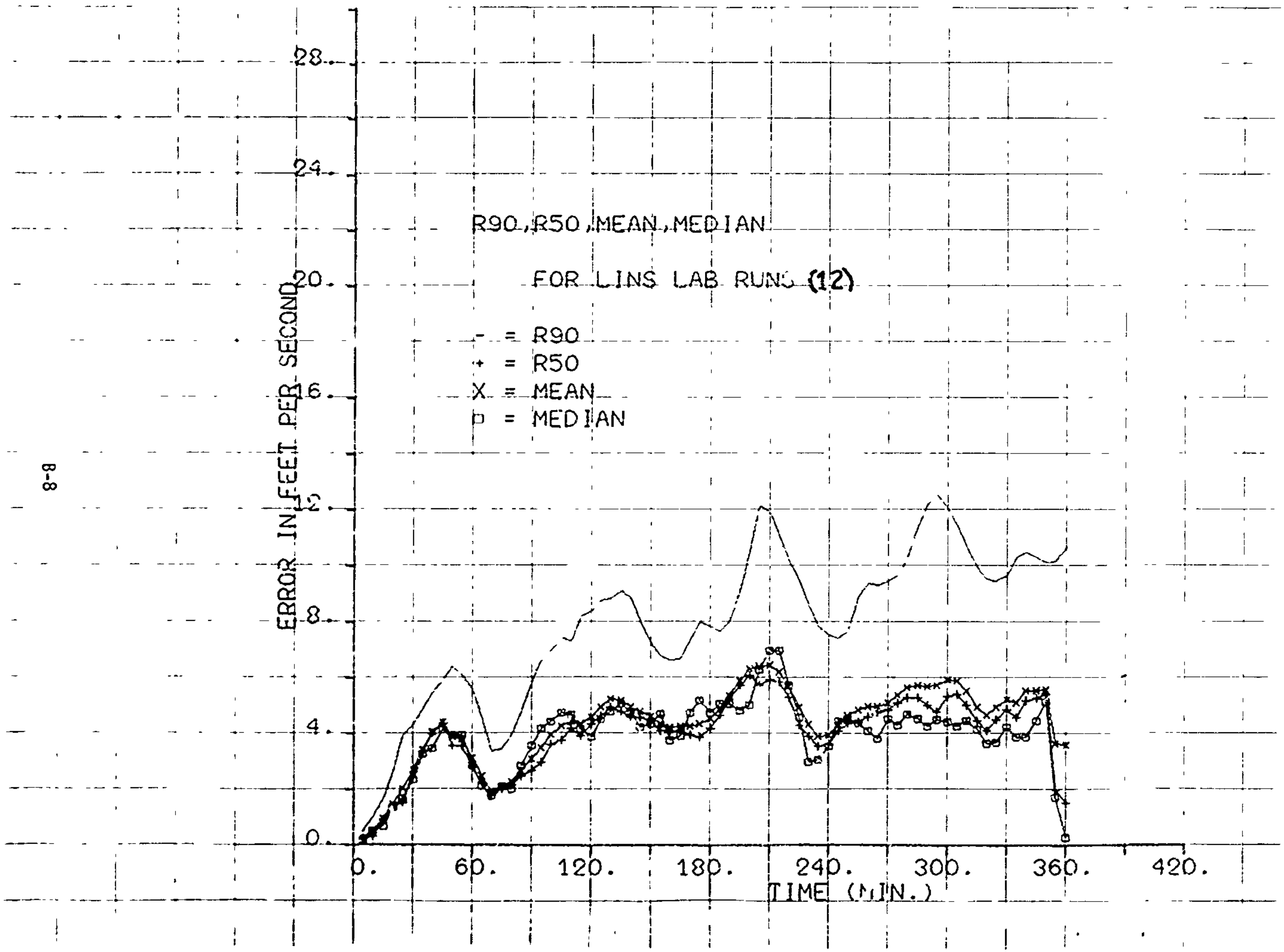
(2) Radial velocity error is the root sum square of the north-south and east-west velocity errors.

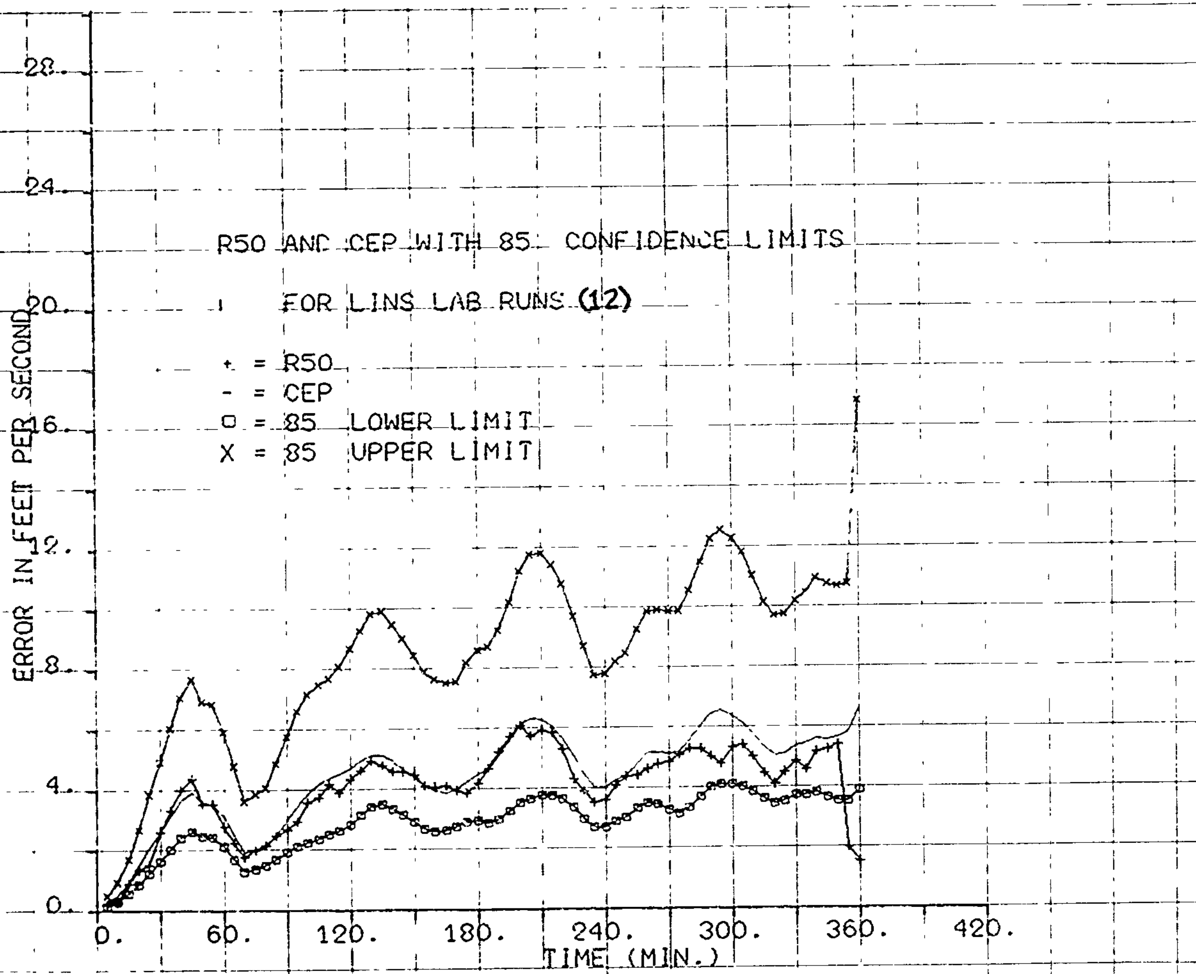
(3) Refer to Appendix A for analysis techniques and to Paragraphs 3.3 and 3.4, Appendix A, for definitions of performance values in Table B-II above.

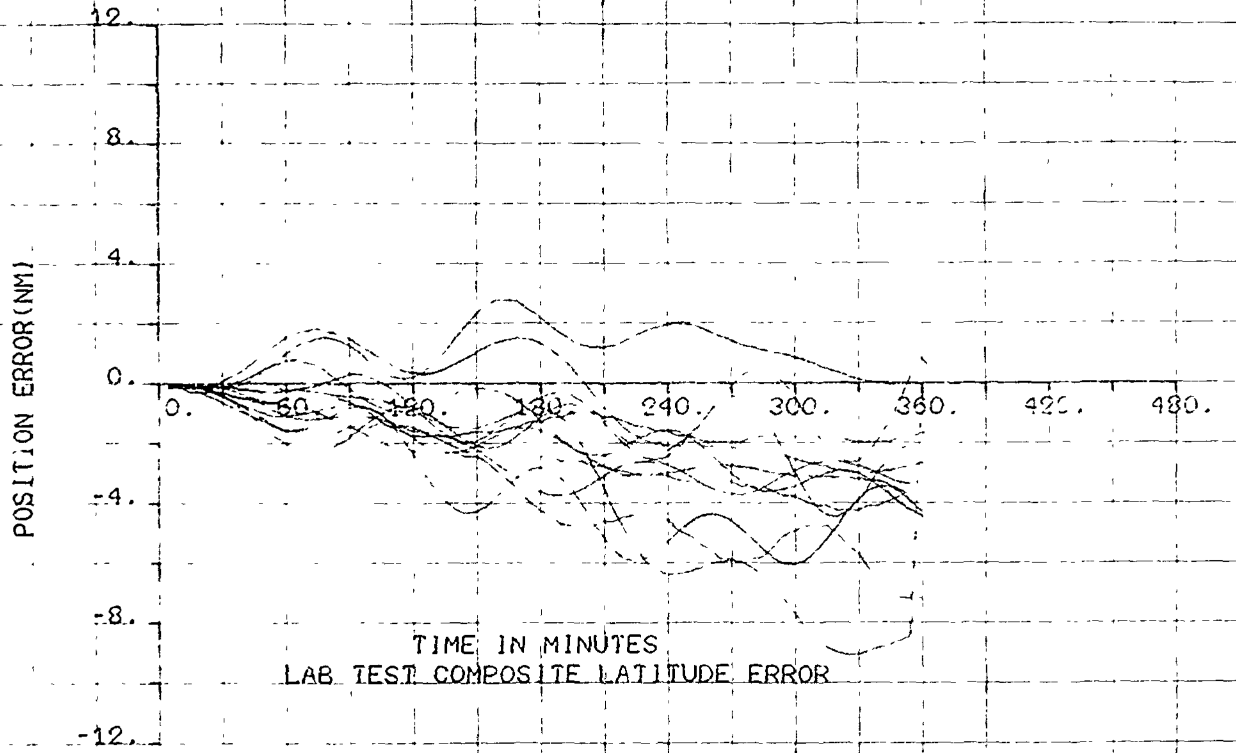
Pages B-8 and B-9 contain plots of the R90, R50, CEP, mean and median of the radial velocity error distribution for the 12 laboratory test ensemble.

Pages B-10 through B-15 contain composite plots of position, velocity, and radial errors from the twelve test ensemble.

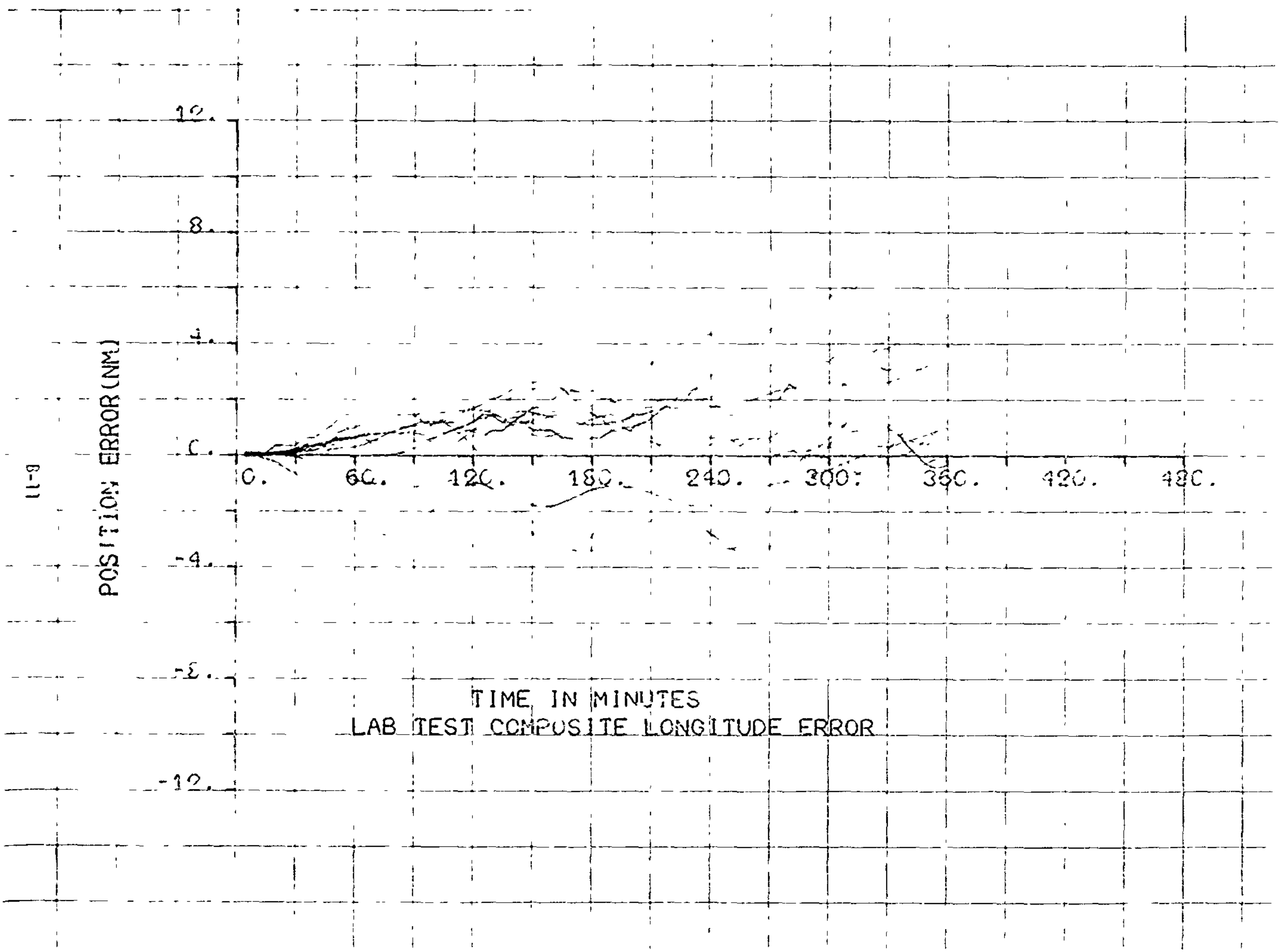
Pages B-16 through B-95 contain the individual latitude/longitude position and north/east velocity error plots and the individual radial position and radial velocity error plots for all lab runs.


R90,R50,MEAN,MEDIAN
FOR LINS LAB RUNS (12)
- = R90
+ = R50
X = MEAN
□ = MEDIAN
ERROR IN FEET PER SECOND
0.
4.
8.
12.
16.
20.
24.
28.
0.
60.
120.
180.
240.
300.
360.
420.
TIME (MIN.)

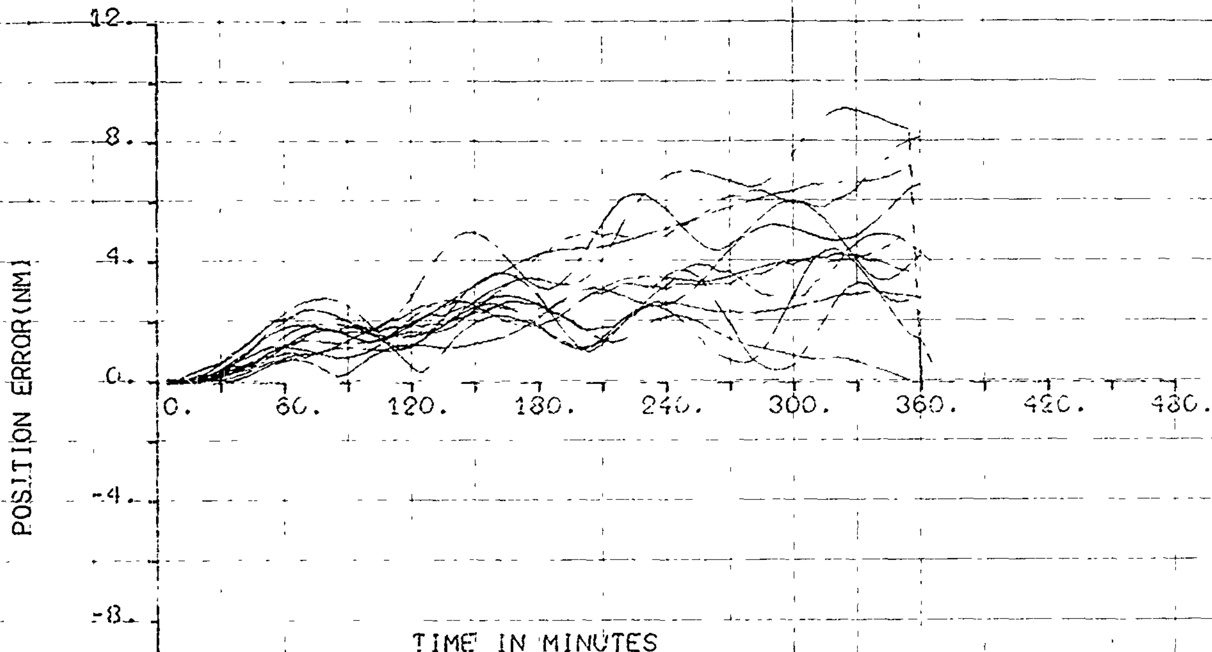

R50 AND CEP WITH 85 CONFIDENCE LIMITS
FOR LINS LAB RUNS (12)
+ = R50
- = CEP
O = 85 LOWER LIMIT
X = 85 UPPER LIMIT
ERROR IN FEET PER SECOND
28.
24.
20.
16.
12.
8.
4.
0.
0.
60.
120.
180.
240.
300.
360.
420.
TIME (MIN.)



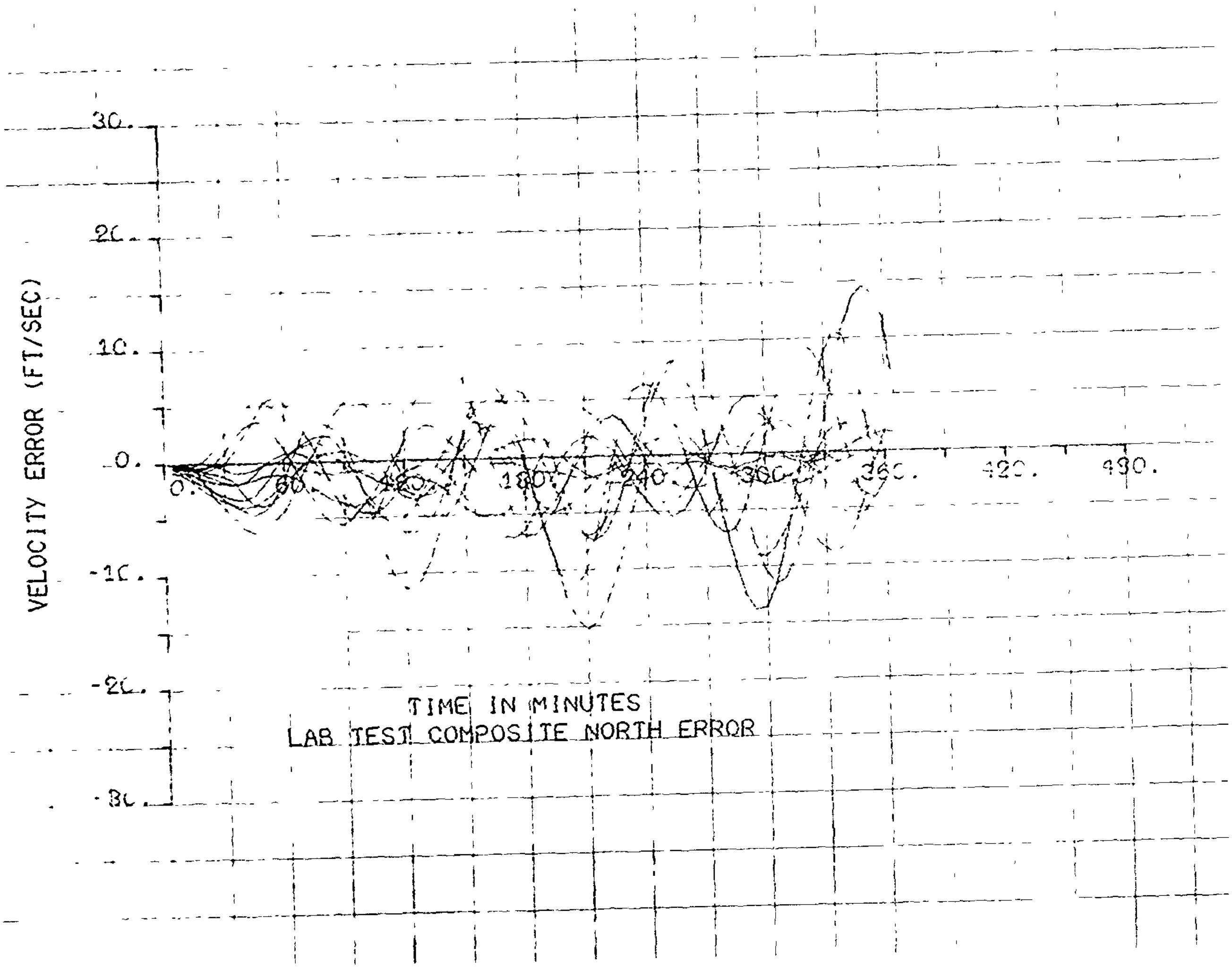
LAB TEST COMPOSITE LATITUDE ERROR



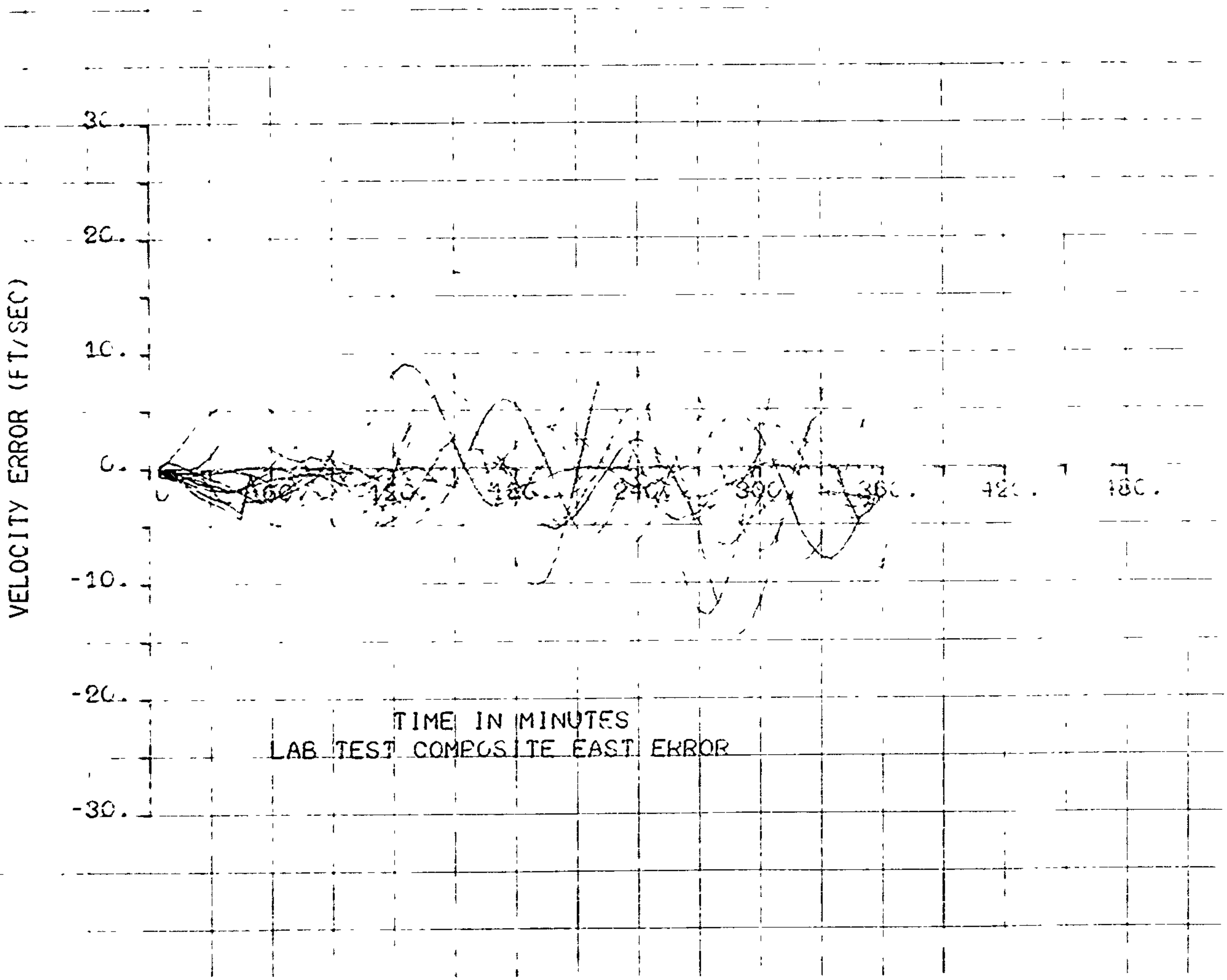
LAB TEST COMPOSITE LONGITUDE ERROR



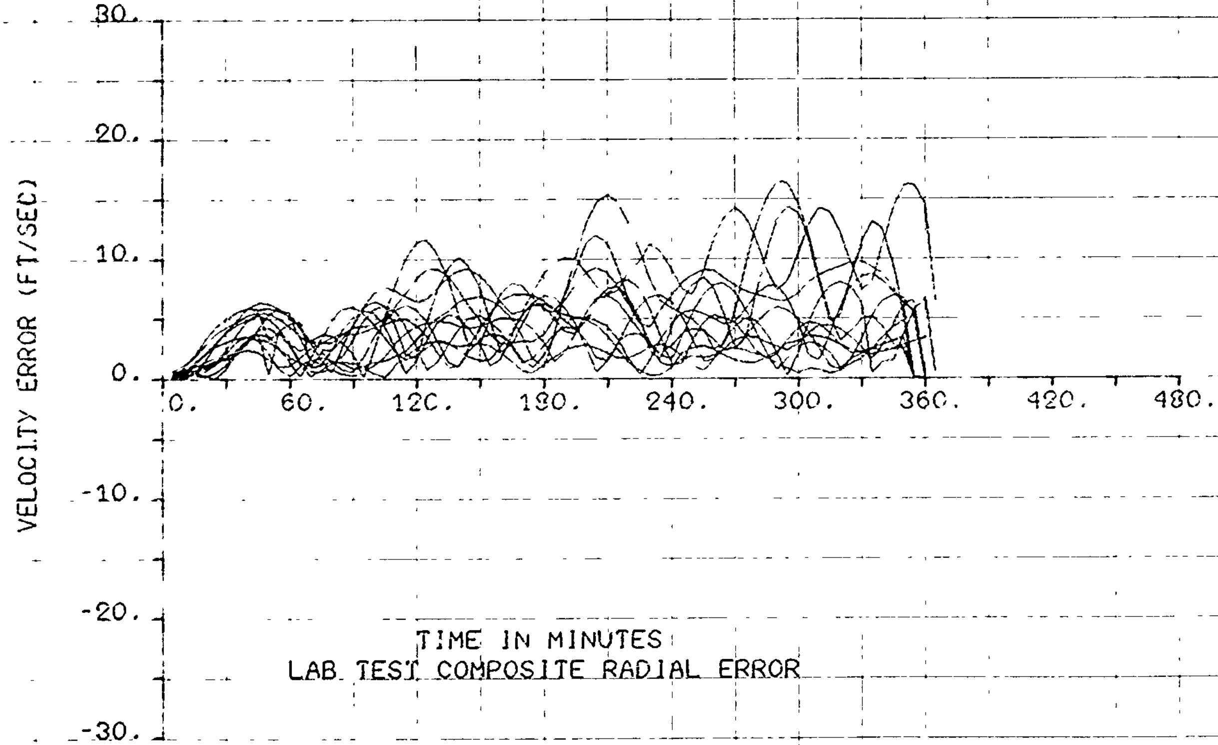
LAB TEST COMPOSITE RADIAL ERROR



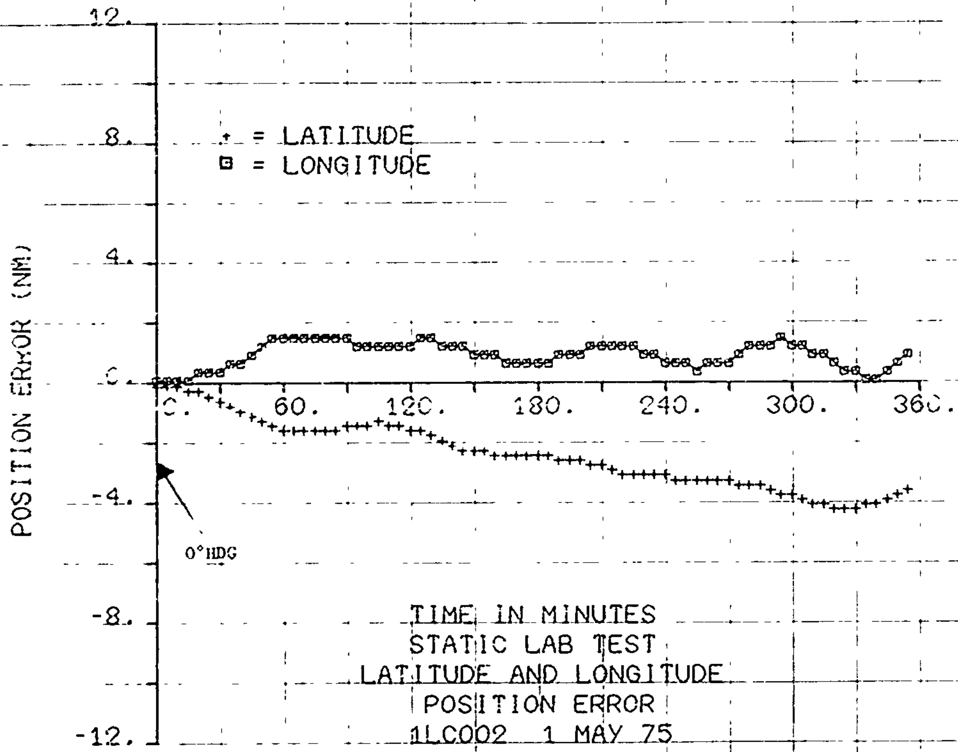
LAB TEST COMPOSITE NORTH ERROR

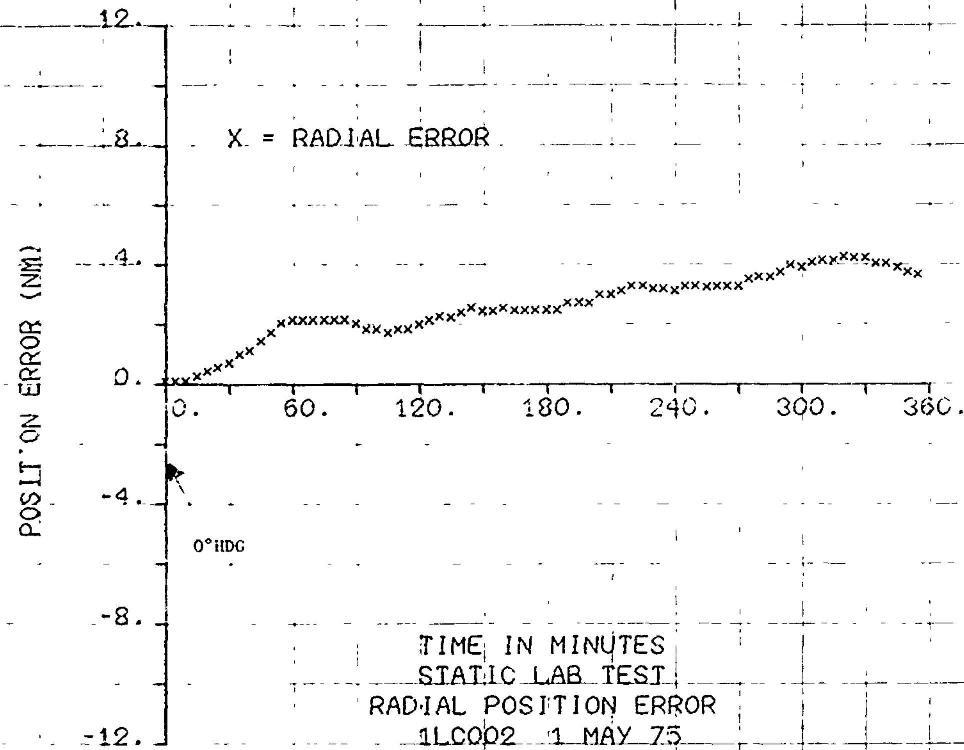


LAB TEST COMPOSITE EAST ERROR

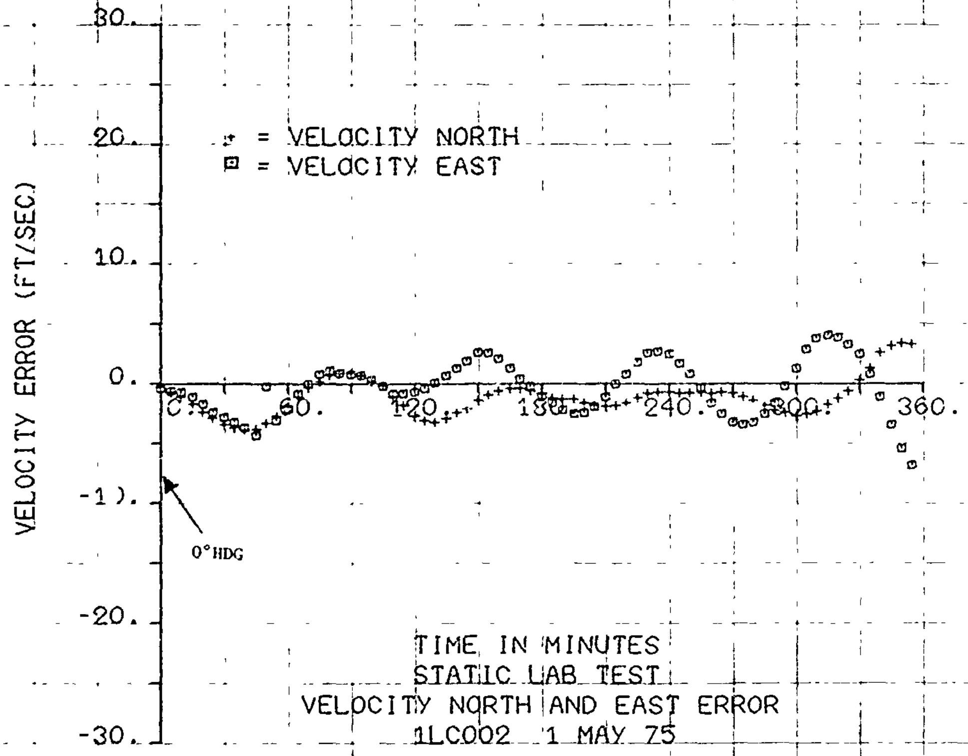


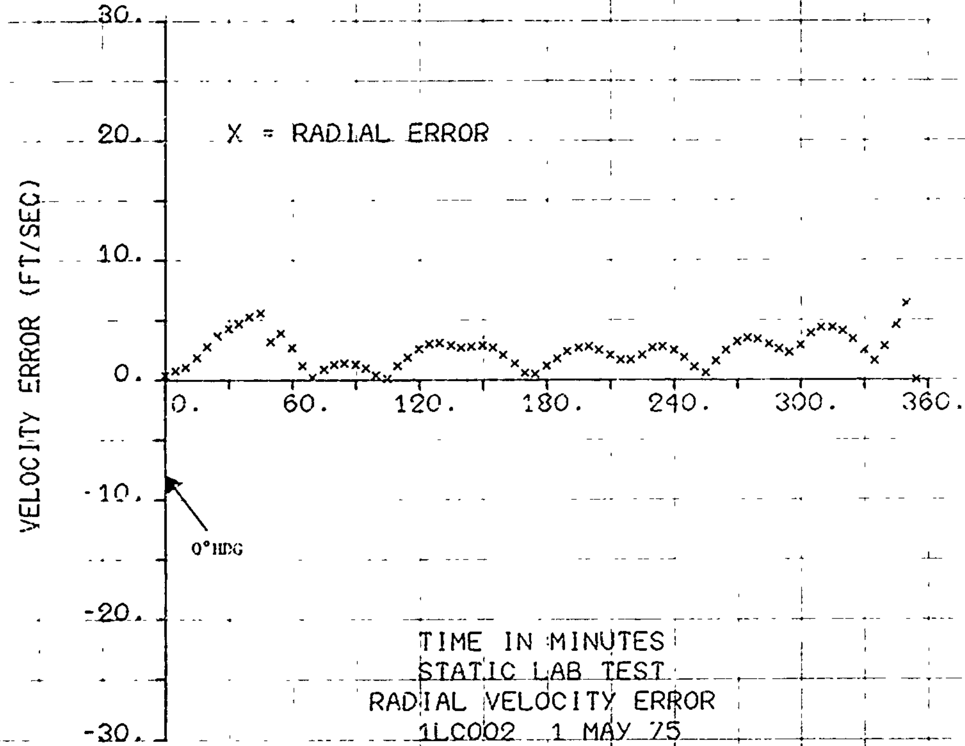
LAB TEST COMPOSITE RADIAL ERROR


+ = LATITUDE
⊡ = LONGITUDE
POSITION ERROR (NM)
12.
8.
4.
0.
-4.
-8.
-12.
0.
60.
120.
180.
240.
300.
360.
0° HDG
TIME IN MINUTES
STATIC LAB TEST
LATITUDE AND LONGITUDE
POSITION ERROR
1LC002 1 MAY 75

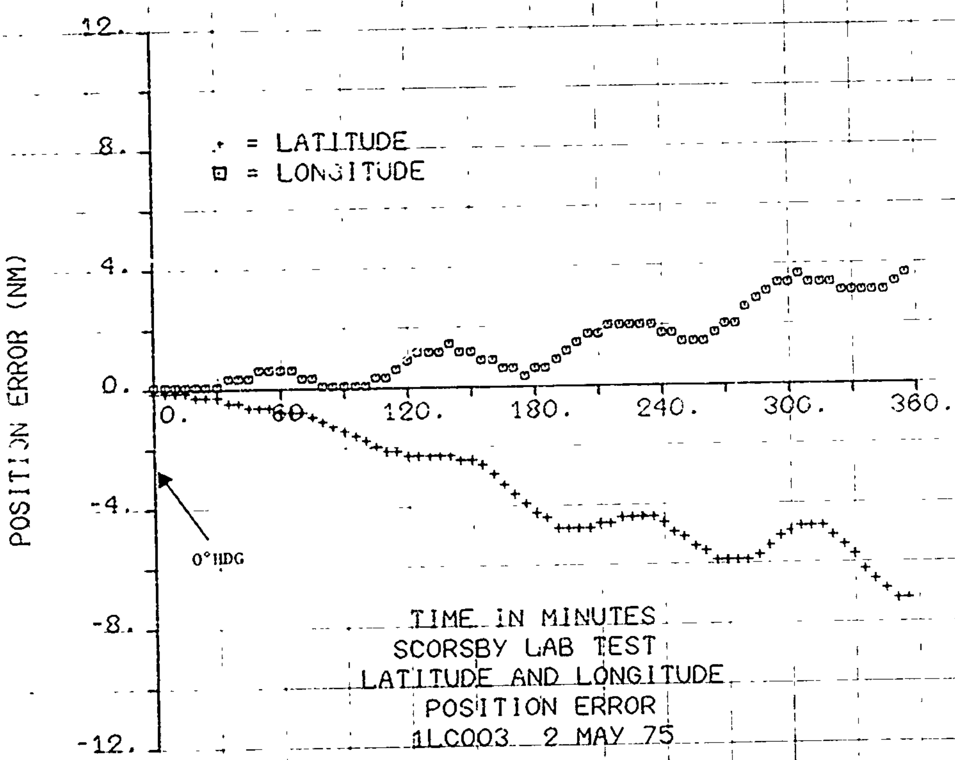


X = RADIAL ERROR
POSIT.ON ERROR (NM)
12.
8.
4.
0.
-4.
-8.
-12.
0.
60.
120.
180.
240.
300.
360.
0°HDG
TIME IN MINUTES
STATIC LAB TEST
RADIAL POSITION ERROR
1LC002 1 MAY 75

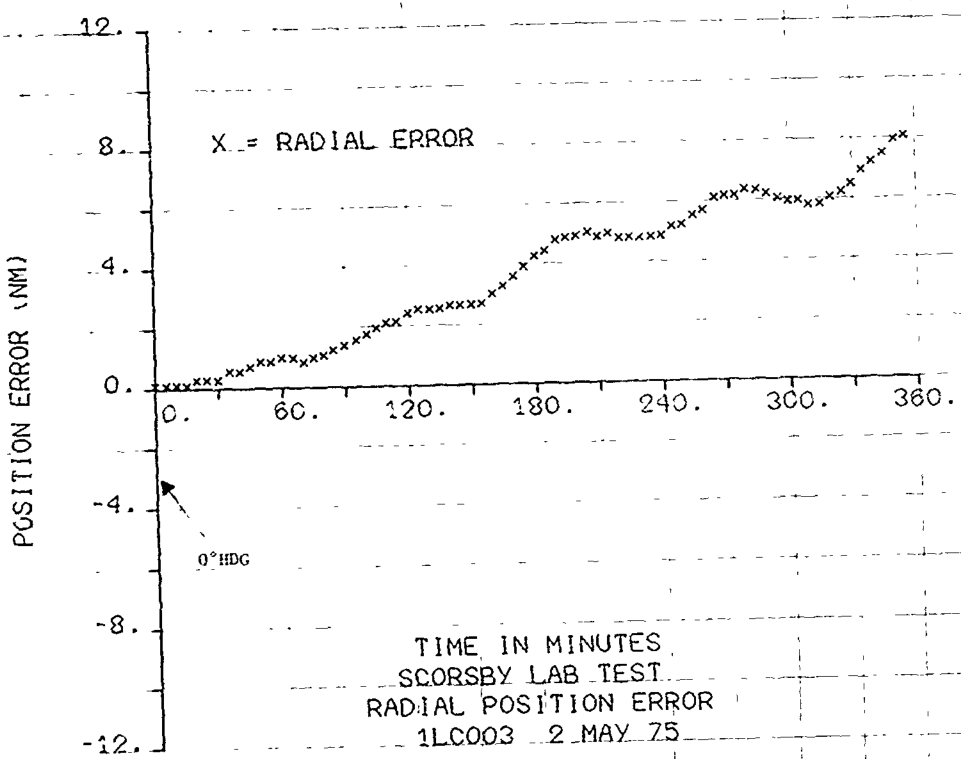

VELOCITY ERROR (FT/SEC)
30.
20.
10.
0.
-1).
-20.
-30.
+ = VELOCITY NORTH
⊡ = VELOCITY EAST
0° HDG
0.
60.
120.
180.
240.
300.
360.
TIME IN MINUTES
STATIC LAB TEST
VELOCITY NORTH AND EAST ERROR
1LC002 1 MAY 75



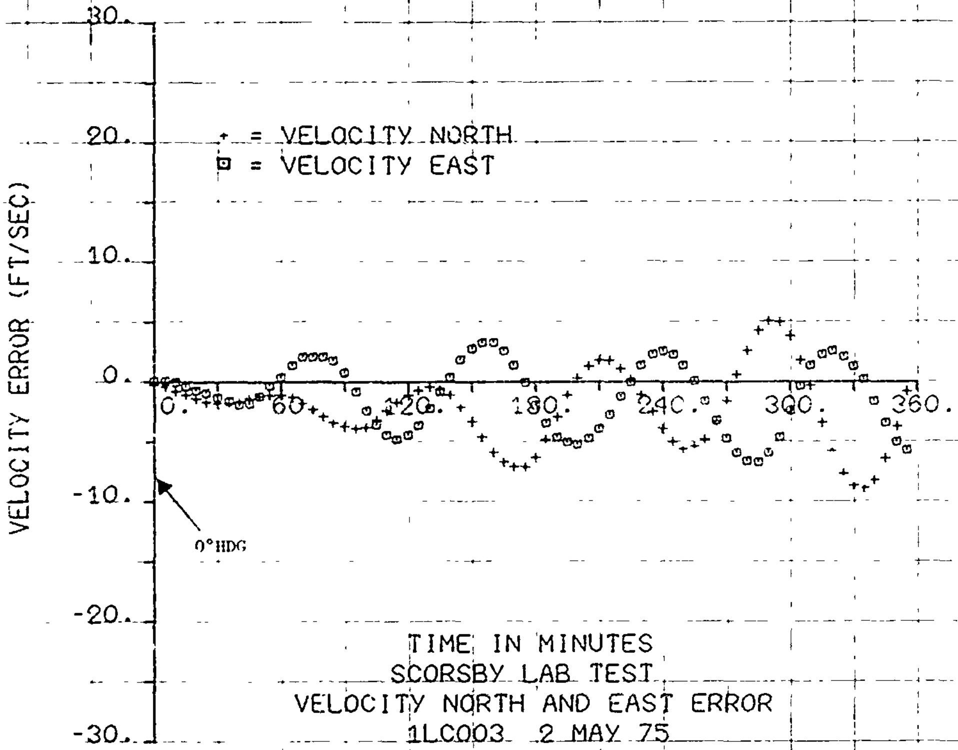
STATIC LAB TEST
RADIAL VELOCITY ERROR
1LC002 1 MAY 75



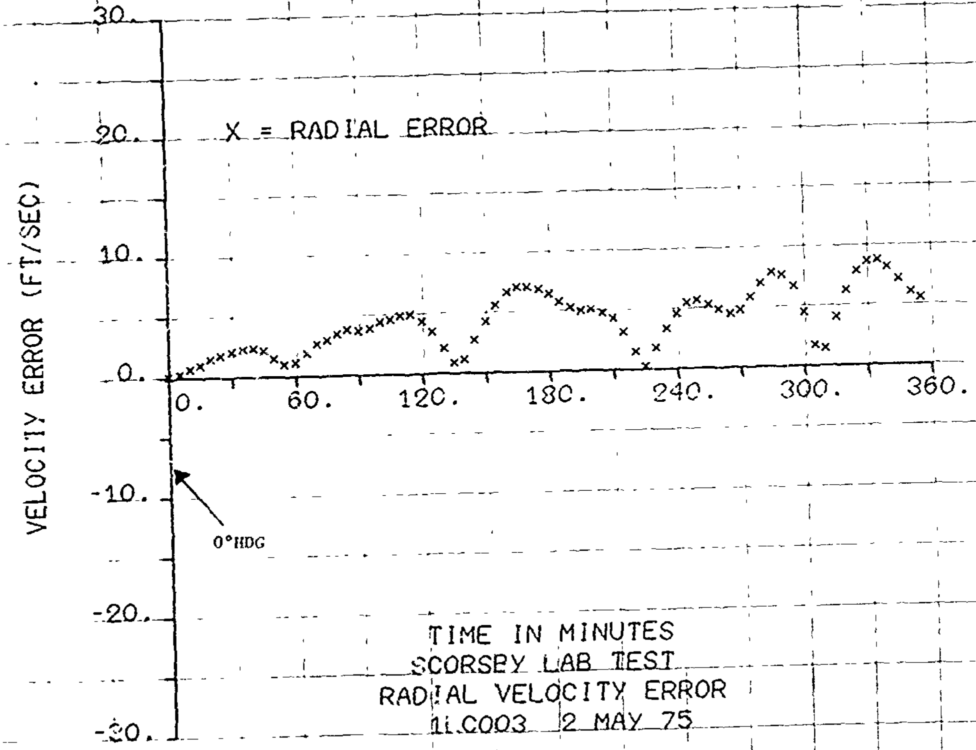
TIME IN MINUTES
SCORSBY LAB TEST
LATITUDE AND LONGITUDE
POSITION ERROR
1LC003 2 MAY 75

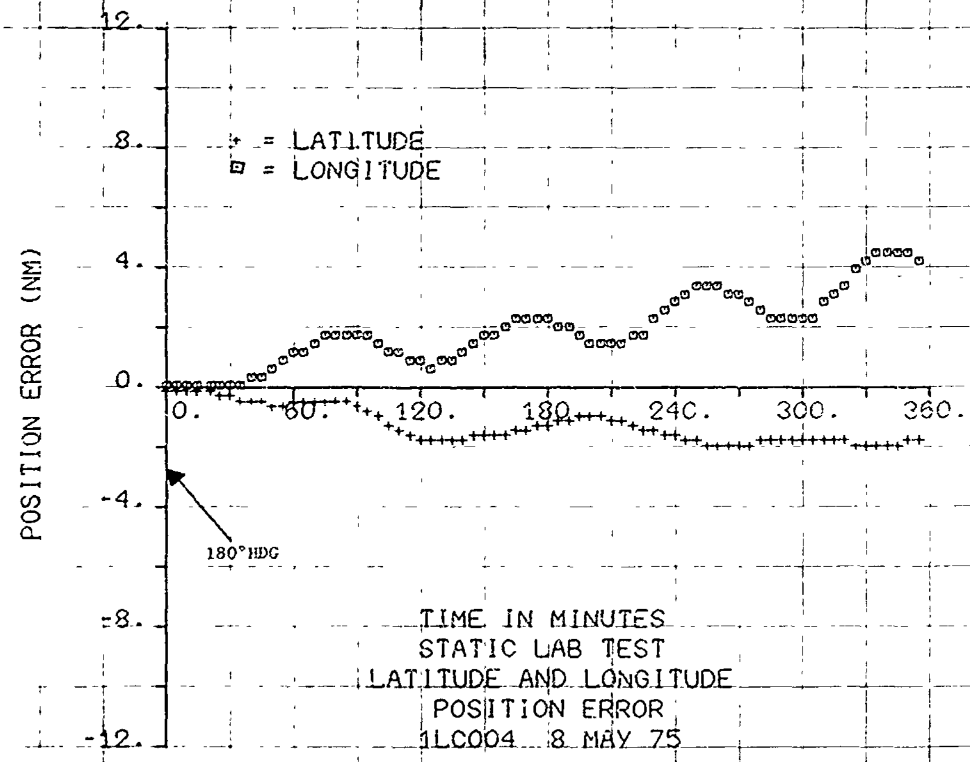


X = RADIAL ERROR
POSITION ERROR (NM)
12.
8.
4.
0.
-4.
-8.
-12.
0.
60.
120.
180.
240.
300.
360.
0° HDG
TIME IN MINUTES
SCORSBY LAB TEST
RADIAL POSITION ERROR
1LC003 2 MAY 75

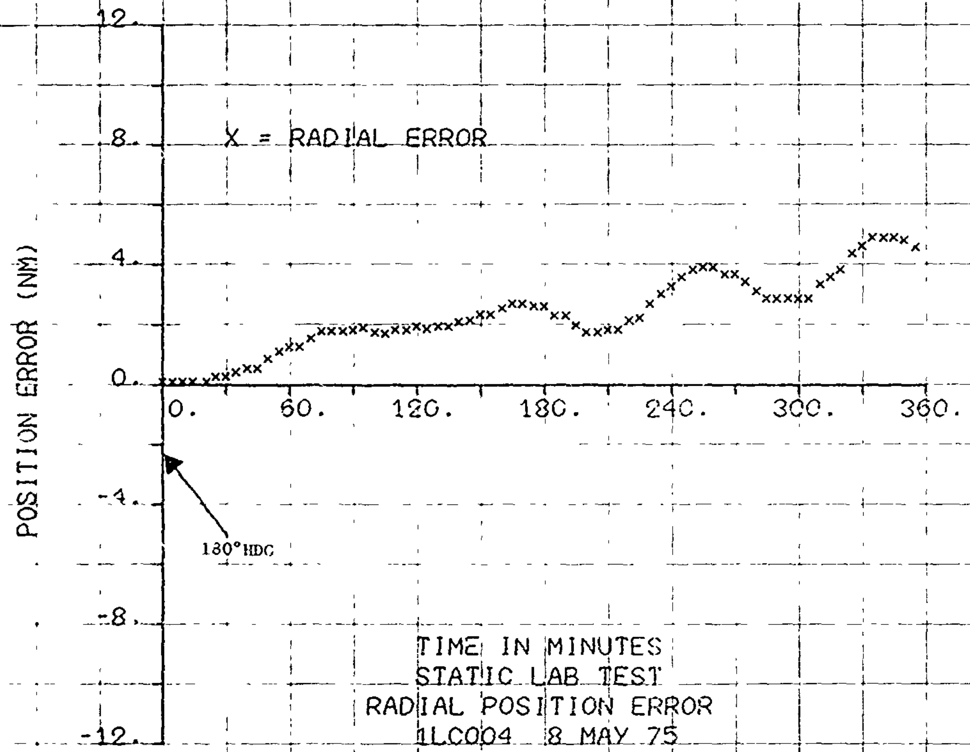


TIME IN MINUTES
SCORSBY LAB TEST
VELOCITY NORTH AND EAST ERROR
1LC003 2 MAY 75

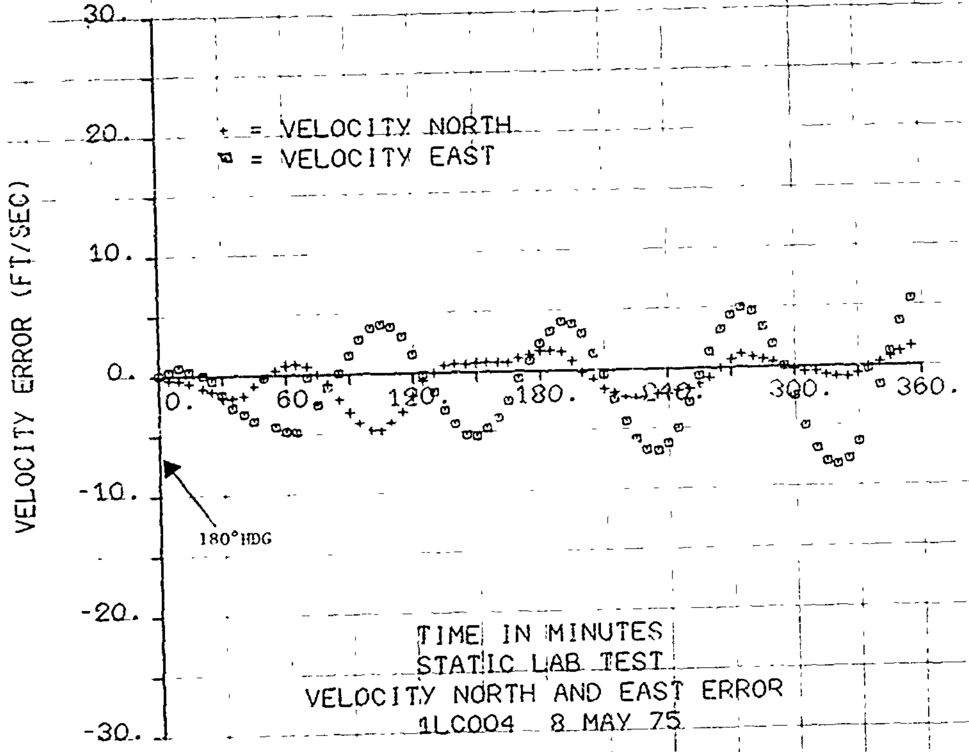

30.
20.
10.
0.
-10.
-20.
-30.
VELOCITY ERROR (FT/SEC)
X = RADIAL ERROR
0.
60.
120.
180.
240.
300.
360.
0°HDG
TIME IN MINUTES
SCORSBY LAB TEST
RADIAL VELOCITY ERROR
11.C003 2 MAY 75



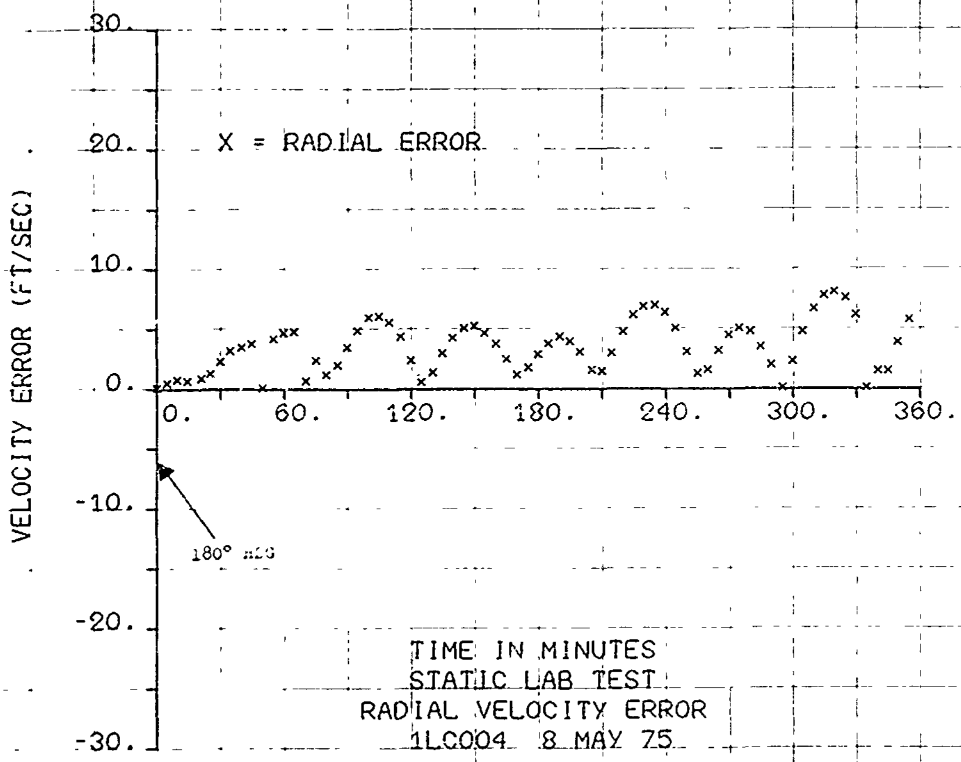
12.
8.
4.
0.
-4.
-8.
-12.
POSITION ERROR (NM)
0.
60.
120.
180.
240.
300.
360.
+ = LATITUDE
□ = LONGITUDE
180° HDG
TIME IN MINUTES
STATIC LAB TEST
LATITUDE AND LONGITUDE
POSITION ERROR
1LC004 8 MAY 75



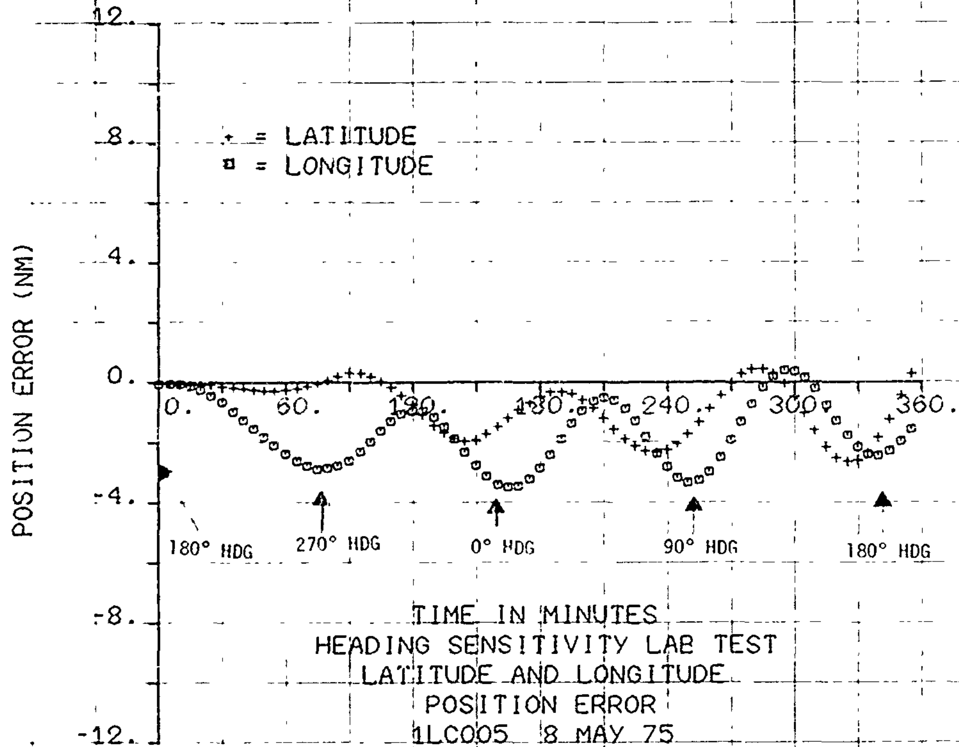
TIME IN MINUTES
STATIC LAB TEST
RADIAL POSITION ERROR
1LC004 8 MAY 75

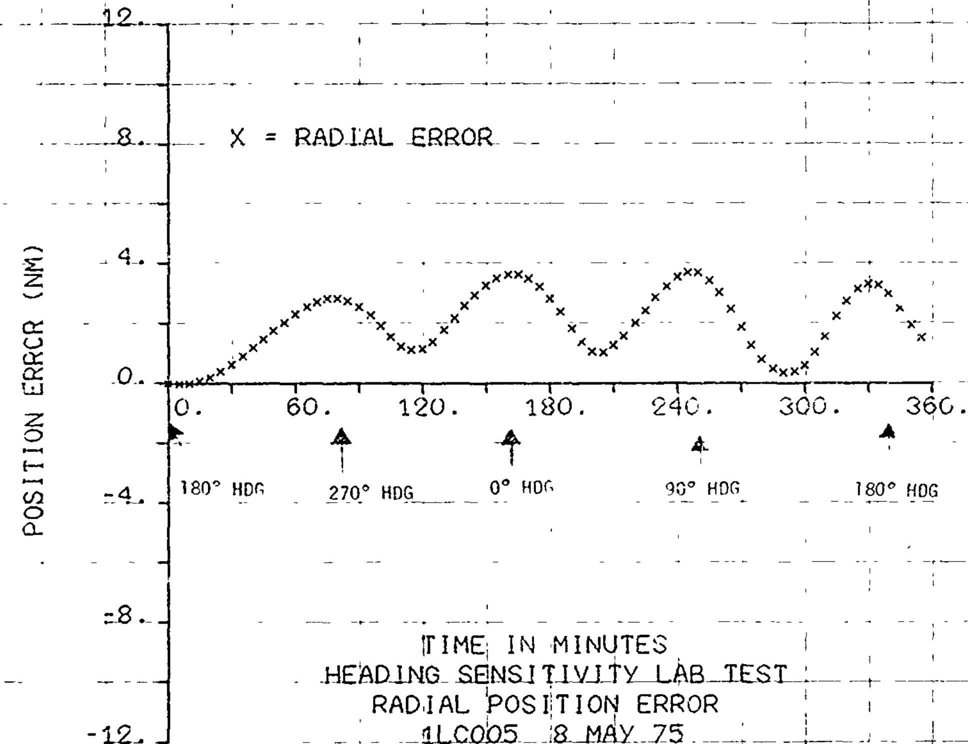


+ = VELOCITY NORTH
¤ = VELOCITY EAST
VELOCITY ERROR (FT/SEC)
30.
20.
10.
0.
-10.
-20.
-30.
0.
60.
120.
180.
240.
300.
360.
180° HDG
TIME IN MINUTES
STATIC LAB TEST
VELOCITY NORTH AND EAST ERROR
1LC004 8 MAY 75

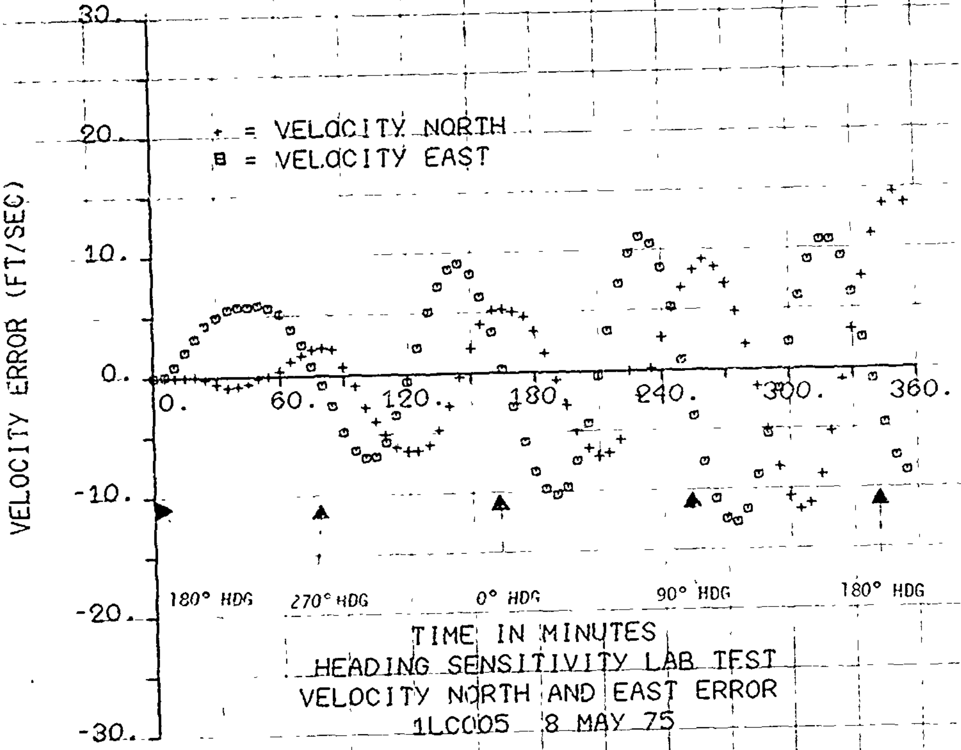


VELOCITY ERROR (FT/SEC)
30.
20.
10.
0.
-10.
-20.
-30.
X = RADIAL ERROR
0.
60.
120.
180.
240.
300.
360.
180°
TIME IN MINUTES
STATIC LAB TEST
RADIAL VELOCITY ERROR
1LC004 8 MAY 75

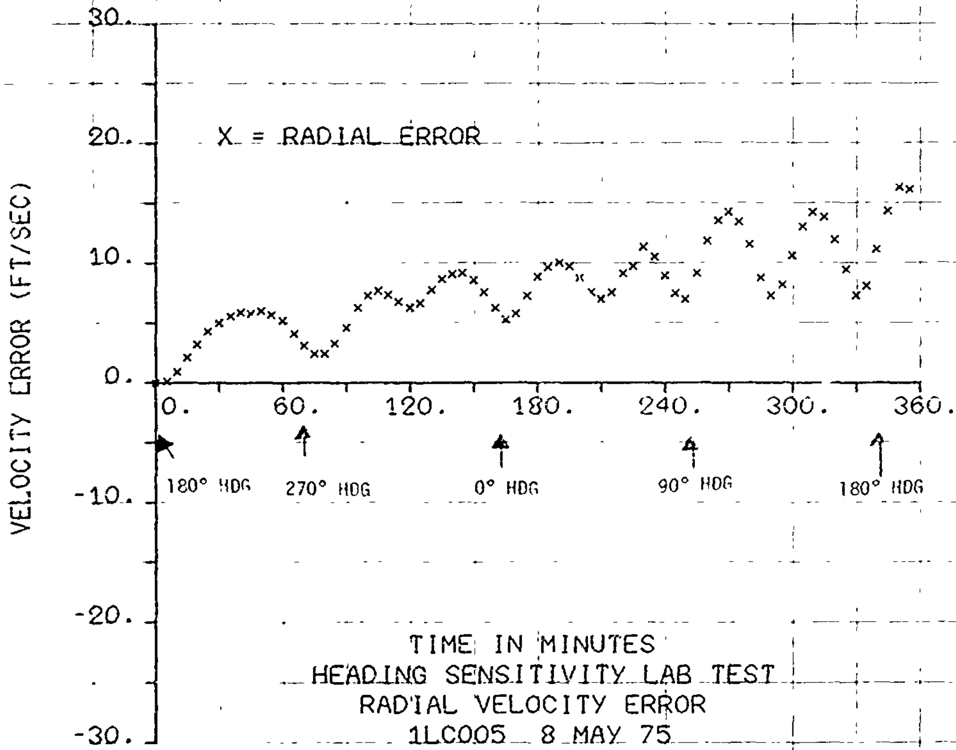

POSITION ERROR (NM)
12.
8.
4.
0.
-4.
-8.
-12.
+ = LATITUDE
¤ = LONGITUDE
0.
60.
120.
180.
240.
300.
360.
180° HDG
270° HDG
0° HDG
90° HDG
180° HDG
TIME IN MINUTES
HEADING SENSITIVITY LAB TEST
LATITUDE AND LONGITUDE
POSITION ERROR
1LC005 8 MAY 75

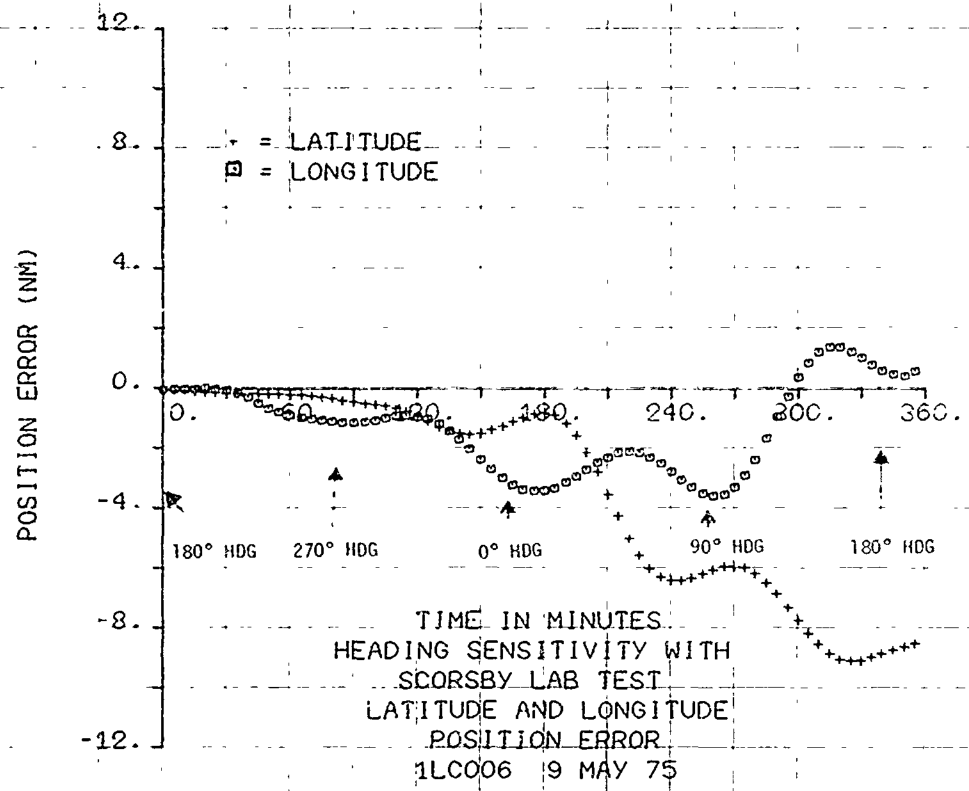


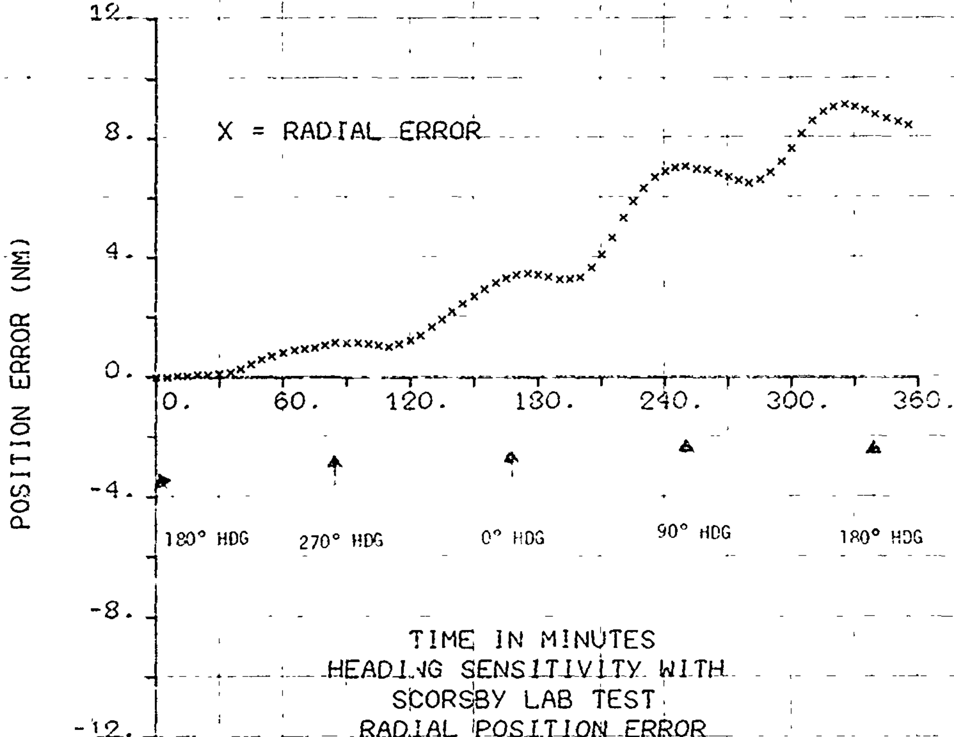
TIME IN MINUTES
HEADING SENSITIVITY LAB TEST
RADIAL POSITION ERROR
1LC005 8 MAY 75



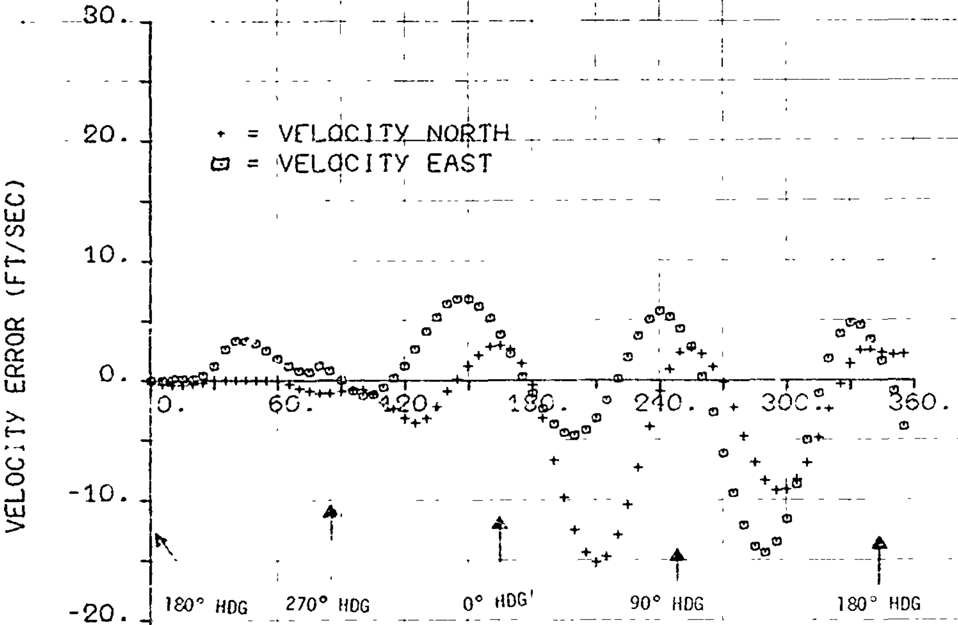
HEADING SENSITIVITY LAB TEST
VELOCITY NORTH AND EAST ERROR
1LC005 8 MAY 75


X = RADIAL ERROR
VELOCITY ERROR (FT/SEC)
30.
20.
10.
0.
-10.
-20.
-30.
0.
60.
120.
180.
240.
300.
360.
180° HDG
270° HDG
0° HDG
90° HDG
180° HDG
TIME IN MINUTES
HEADING SENSITIVITY LAB TEST
RADIAL VELOCITY ERROR
1LC005 8 MAY 75

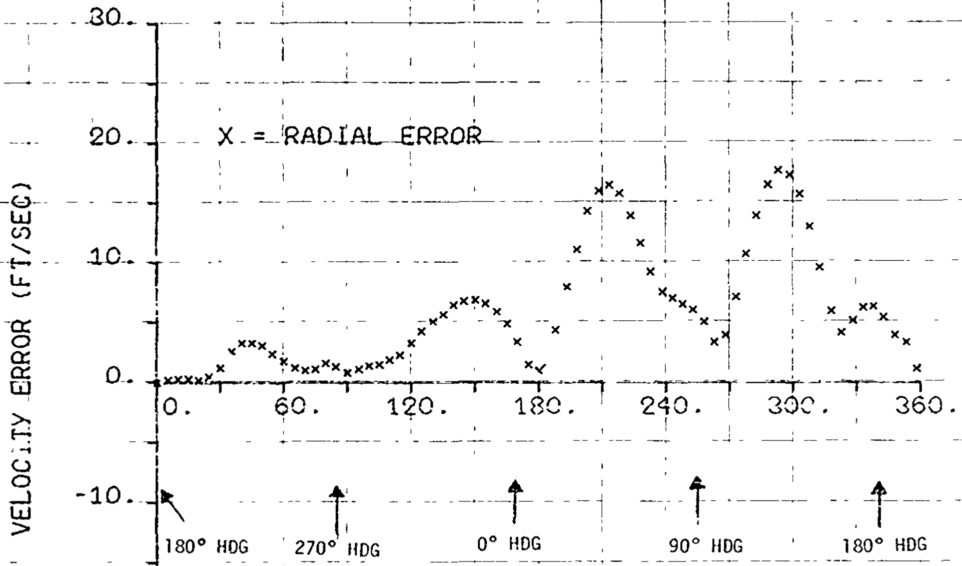

POSITION ERROR (NM)
12.
8.
4.
0.
-4.
-8.
-12.
+ = LATITUDE
□ = LONGITUDE
0.
60.
120.
180.
240.
300.
360.
180° HDG
270° HDG
0° HDG
90° HDG
180° HDG
TIME IN MINUTES
HEADING SENSITIVITY WITH
SCORSBY LAB TEST
LATITUDE AND LONGITUDE
POSITION ERROR
1LC006 9 MAY 75



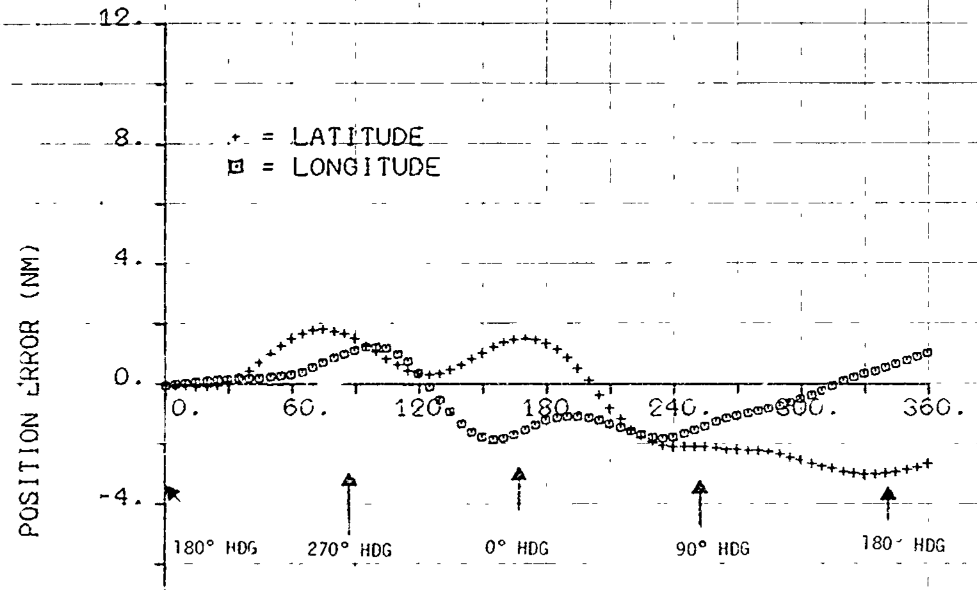
TIME IN MINUTES
HEADING SENSITIVITY WITH
SCORSBY LAB TEST
RADIAL POSITION ERROR
1LC006 9 MAY 75



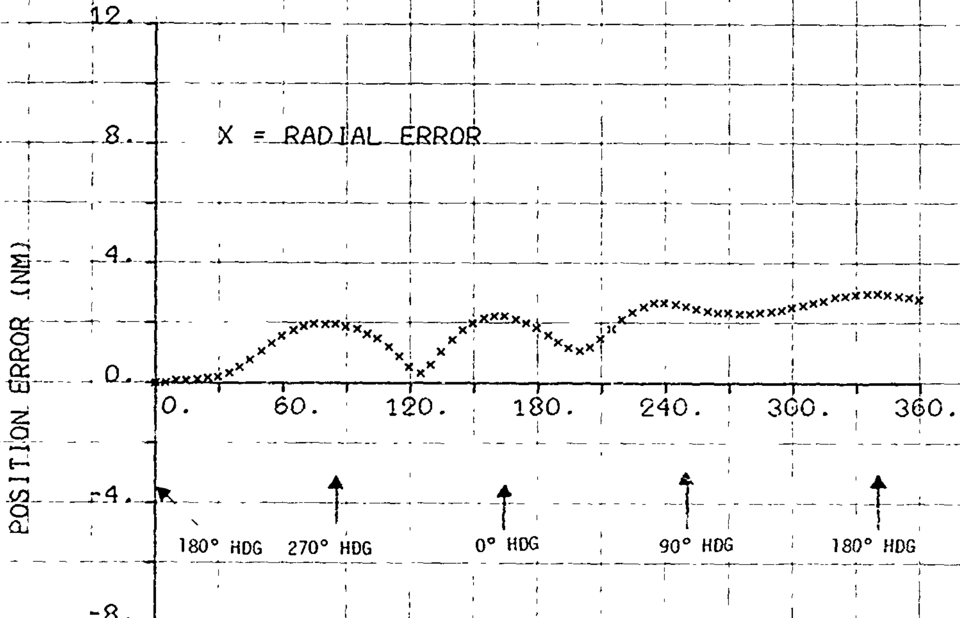
TIME IN MINUTES
HEADING SENSITIVITY WITH
SCORSBY LAB TEST
VELOCITY NORTH AND EAST ERROR
1LC006 9 MAY 75



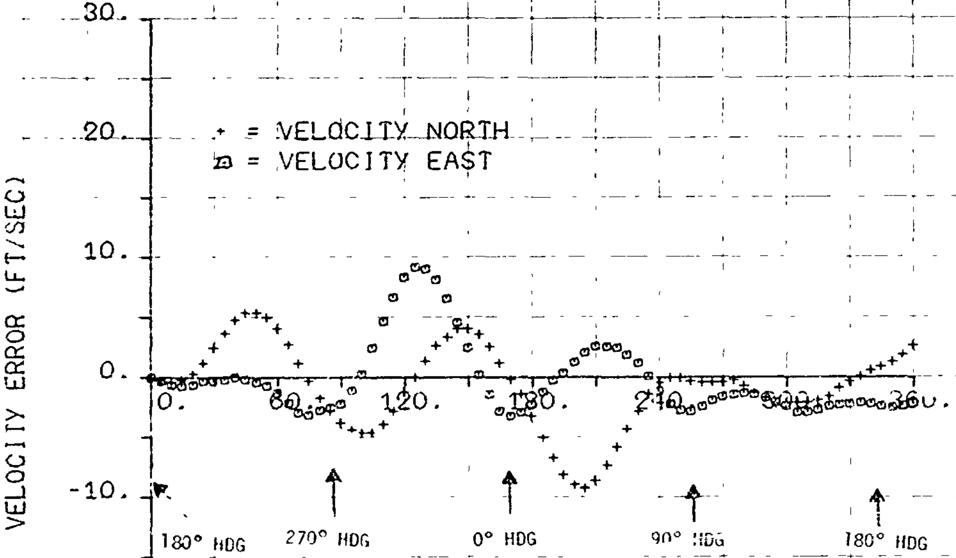
TIME IN MINUTES
HEADING SENSITIVITY WITH
SCORSBY LAB TEST
RADIAL VELOCITY ERROR
1LC006 9 MAY 75



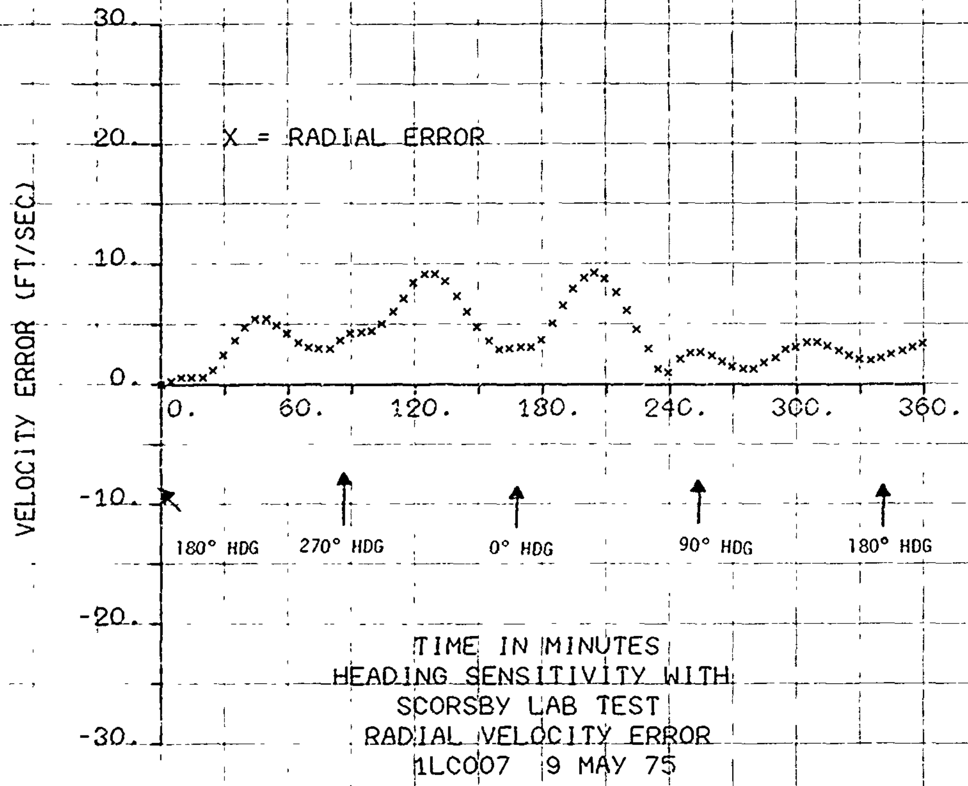
TIME IN MINUTES
HEADING SENSITIVITY WITH
SCORSBY LAB TEST
LATITUDE AND LONGITUDE
POSITION ERROR
1LC007 9 MAY 75

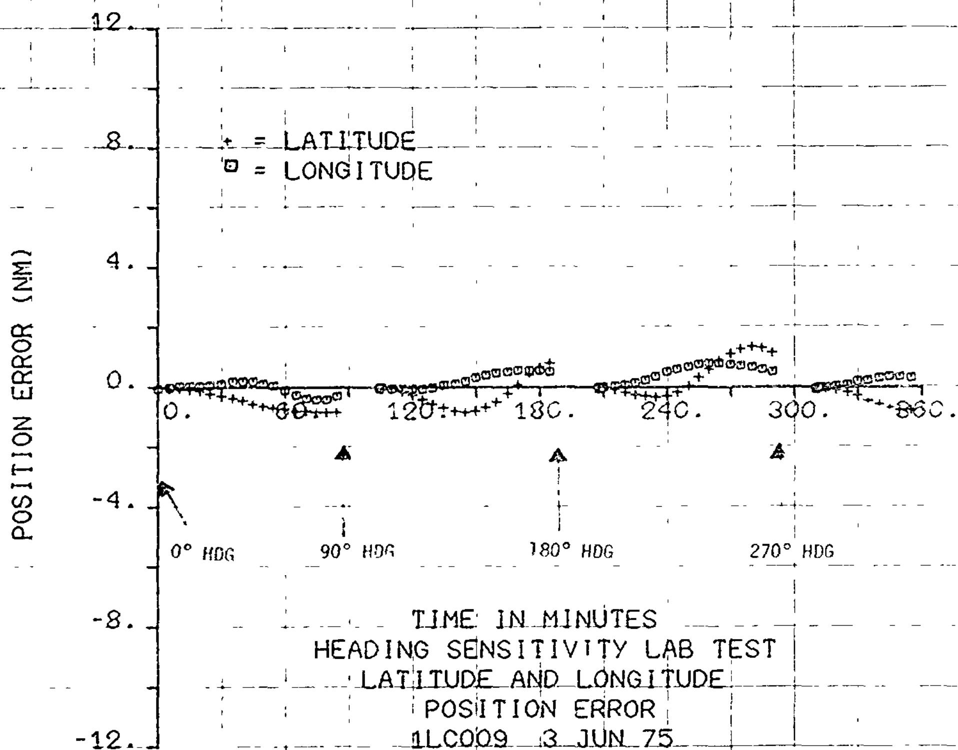


TIME IN MINUTES
HEADING SENSITIVITY WITH
SCORSBY LAB TEST
RADIAL POSITION ERROR
1LC007 9 MAY 75

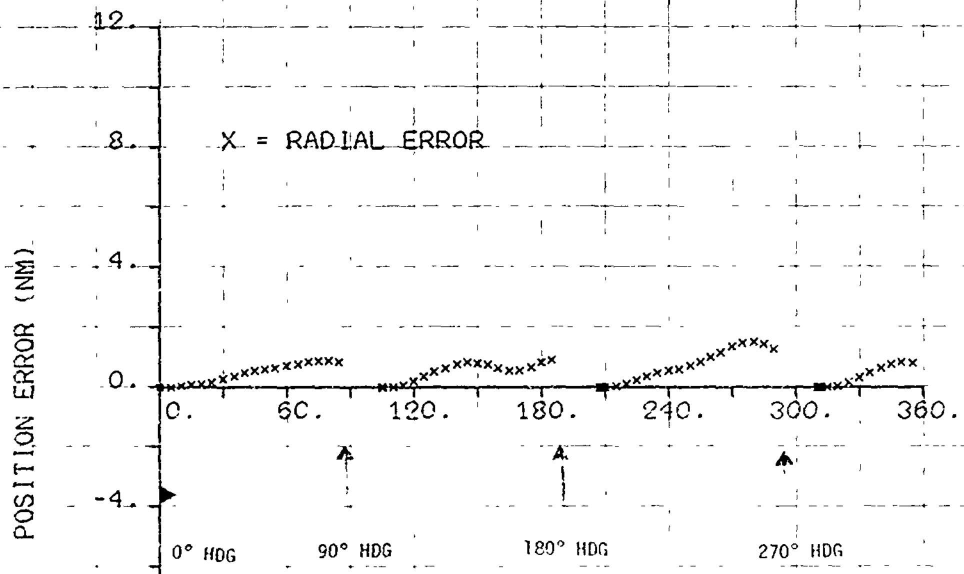


TIME IN MINUTES
HEADING SENSITIVITY WITH
SCORSBY LAB TEST
VELOCITY NORTH AND EAST ERROR
1LC007 9 MAY 75

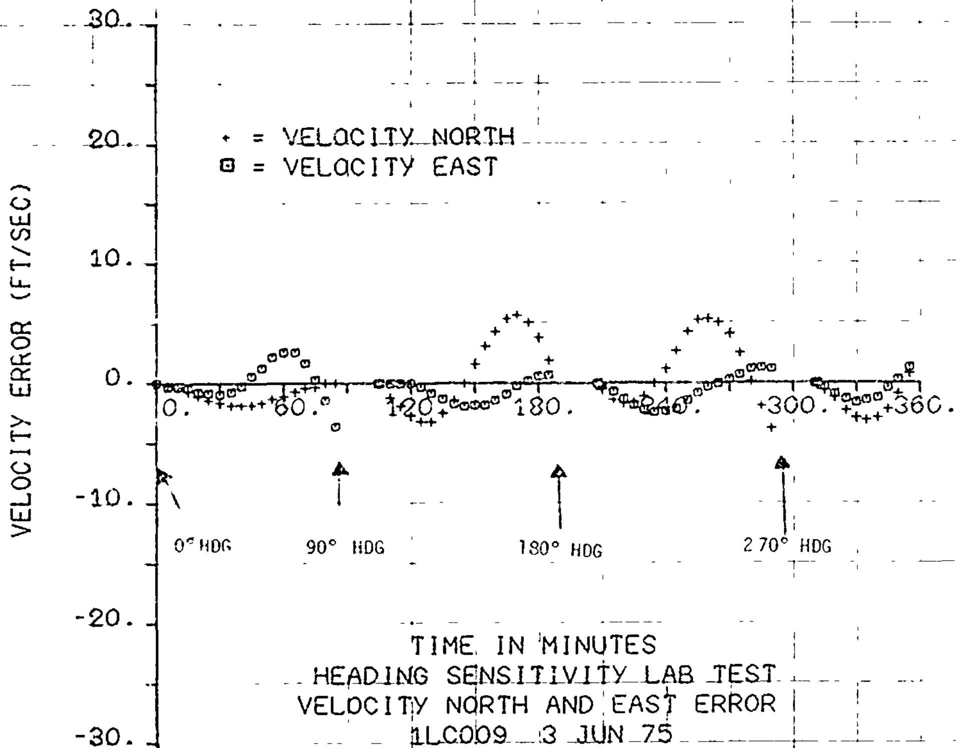

VELOCITY ERROR (FT/SEC)
30.
20.
10.
0.
-10.
-20.
-30.
X = RADIAL ERROR
0.
60.
120.
180.
240.
300.
360.
180° HDG
270° HDG
0° HDG
90° HDG
180° HDG
TIME IN MINUTES
HEADING SENSITIVITY WITH
SCORSBY LAB TEST
RADIAL VELOCITY ERROR
1LC007 9 MAY 75

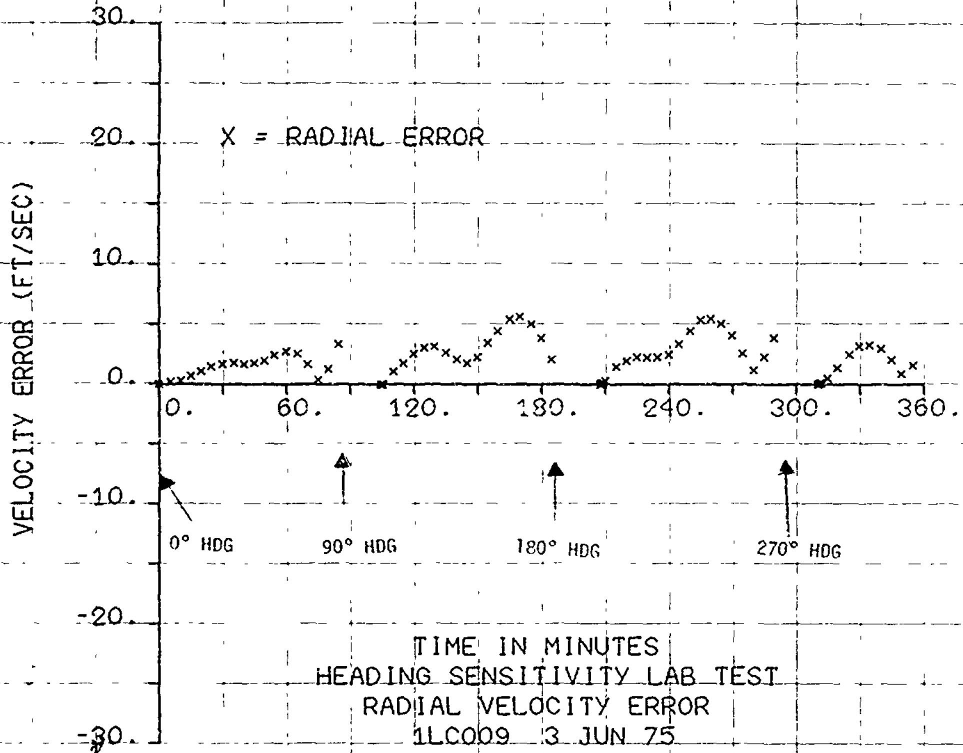


+ = LATITUDE
□ = LONGITUDE
POSITION ERROR (NM)
12.
8.
4.
0.
-4.
-8.
-12.
0.
60.
120.
180.
240.
300.
360.
0° HDG
90° HDG
180° HDG
270° HDG
TIME IN MINUTES
HEADING SENSITIVITY LAB TEST
LATITUDE AND LONGITUDE
POSITION ERROR
1LC009 3 JUN 75

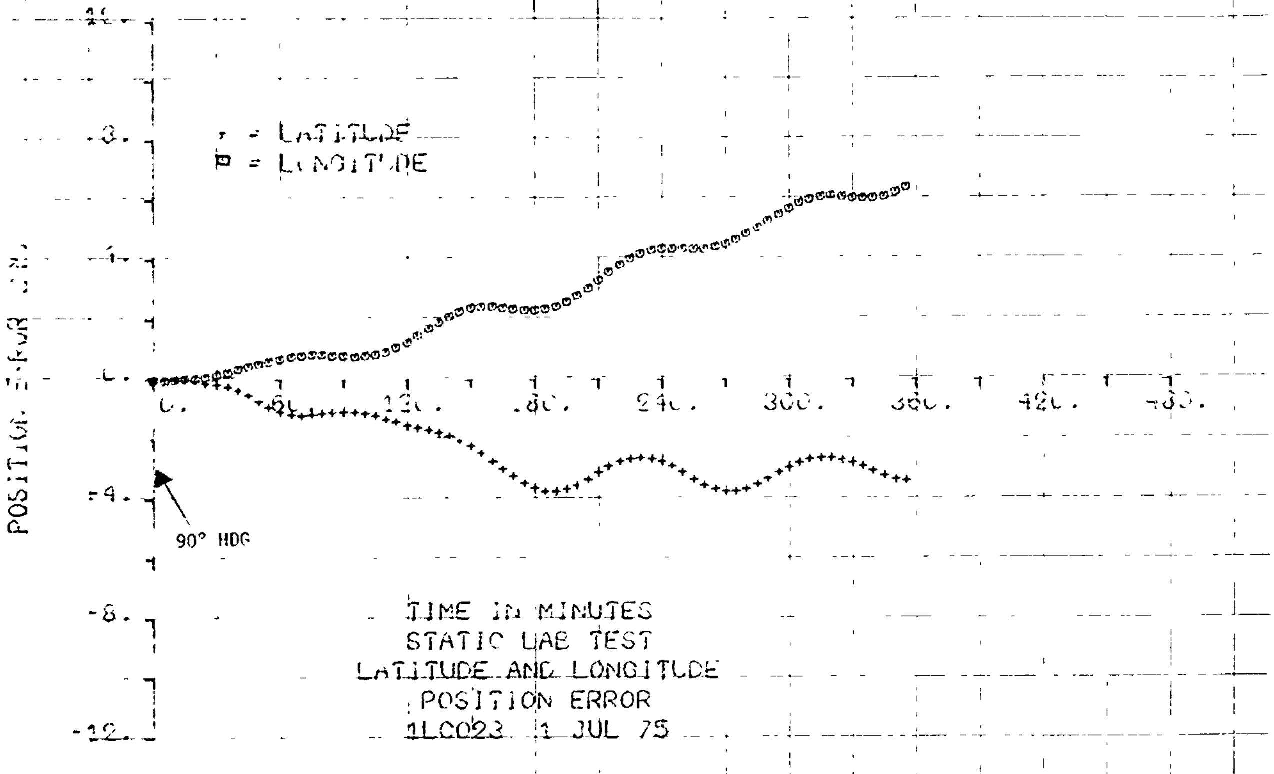


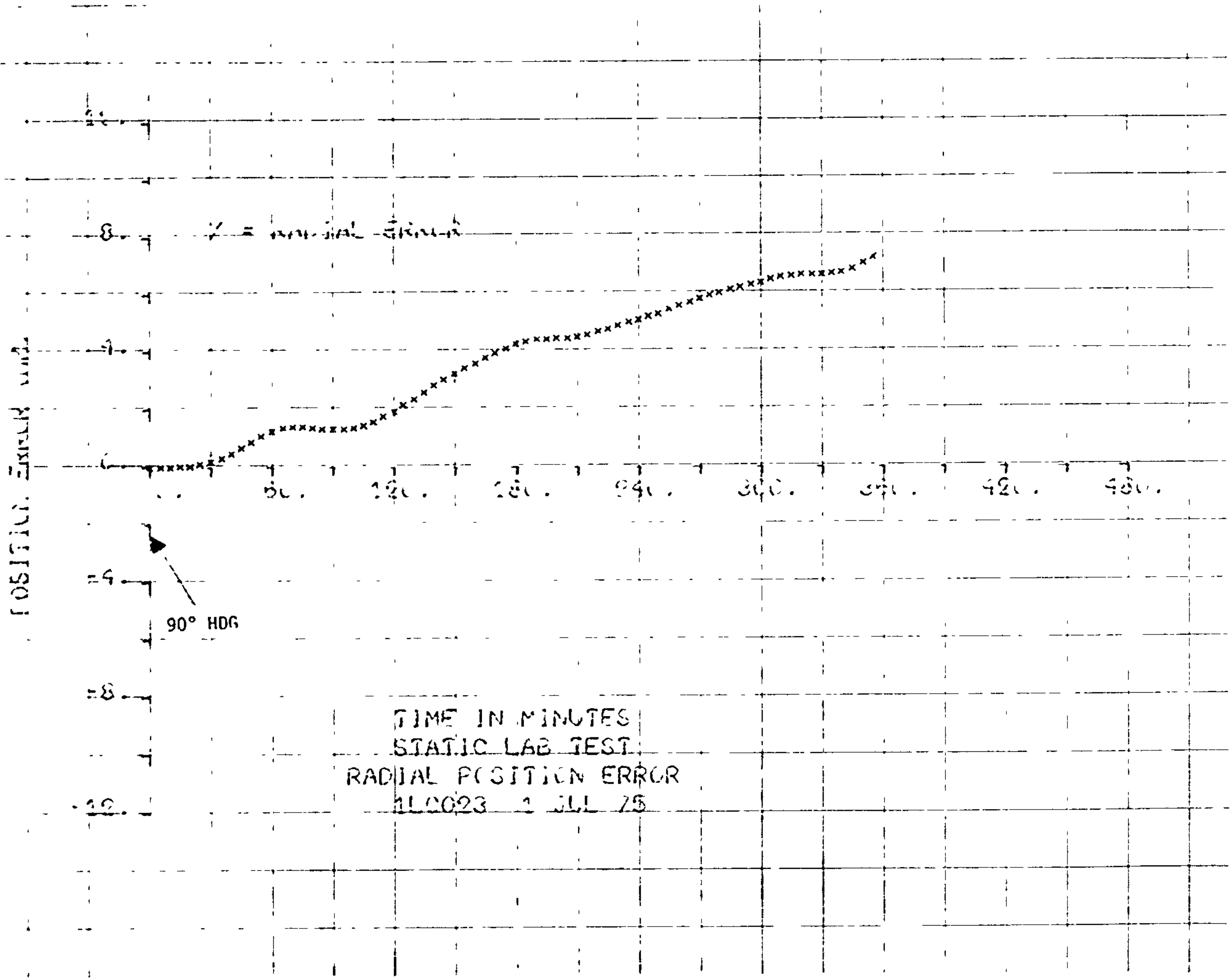
TIME IN MINUTES
HEADING SENSITIVITY LAB TEST
RADIAL POSITION ERROR
1LC009 3 JUN 75

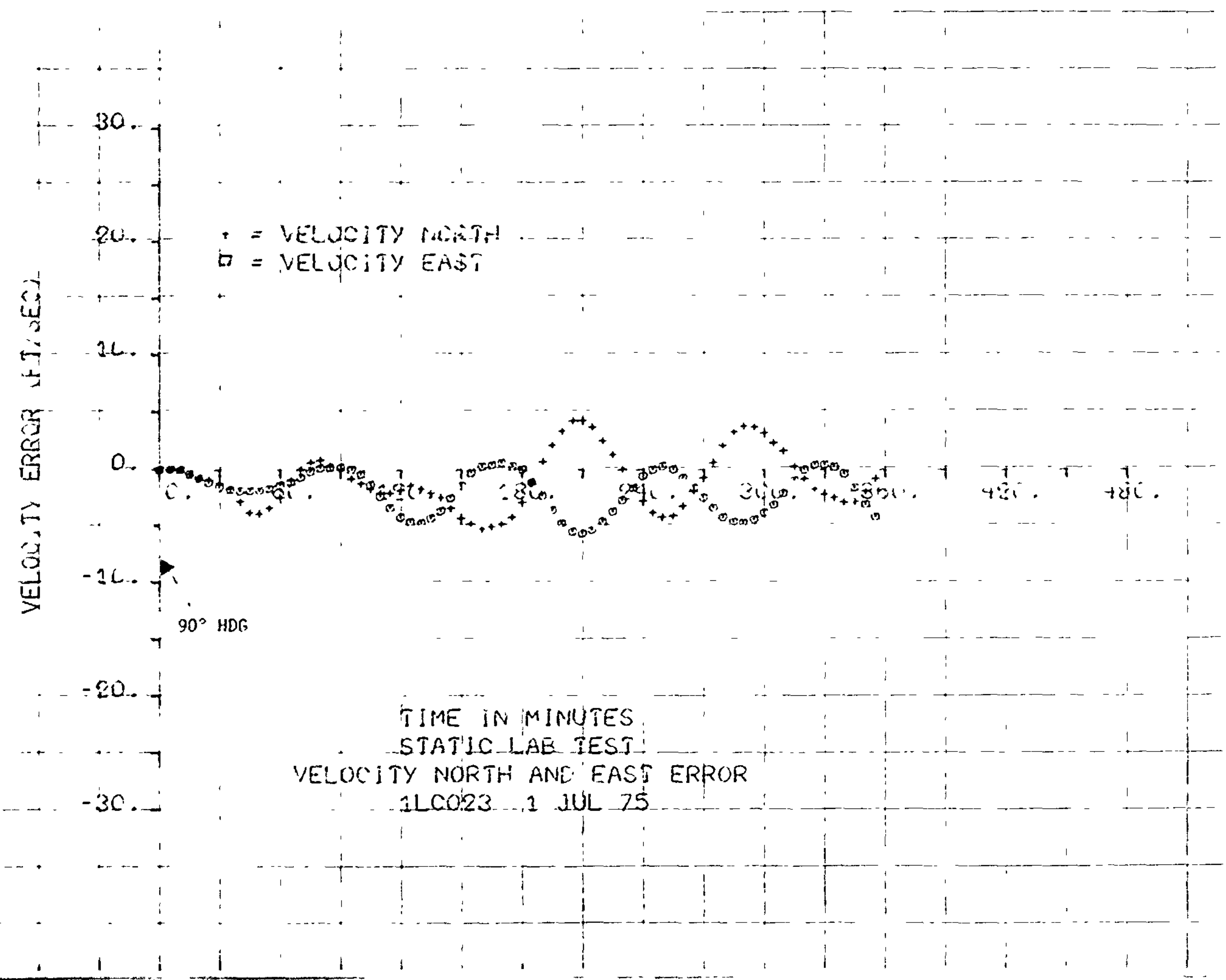

+ = VELOCITY NORTH
□ = VELOCITY EAST
VELOCITY ERROR (FT/SEC)
30.
20.
10.
0.
-10.
-20.
-30.
0.
60.
120.
180.
240.
300.
360.
0° HDG
90° HDG
180° HDG
270° HDG
TIME IN MINUTES
HEADING SENSITIVITY LAB TEST
VELOCITY NORTH AND EAST ERROR
1LC009 3 JUN 75

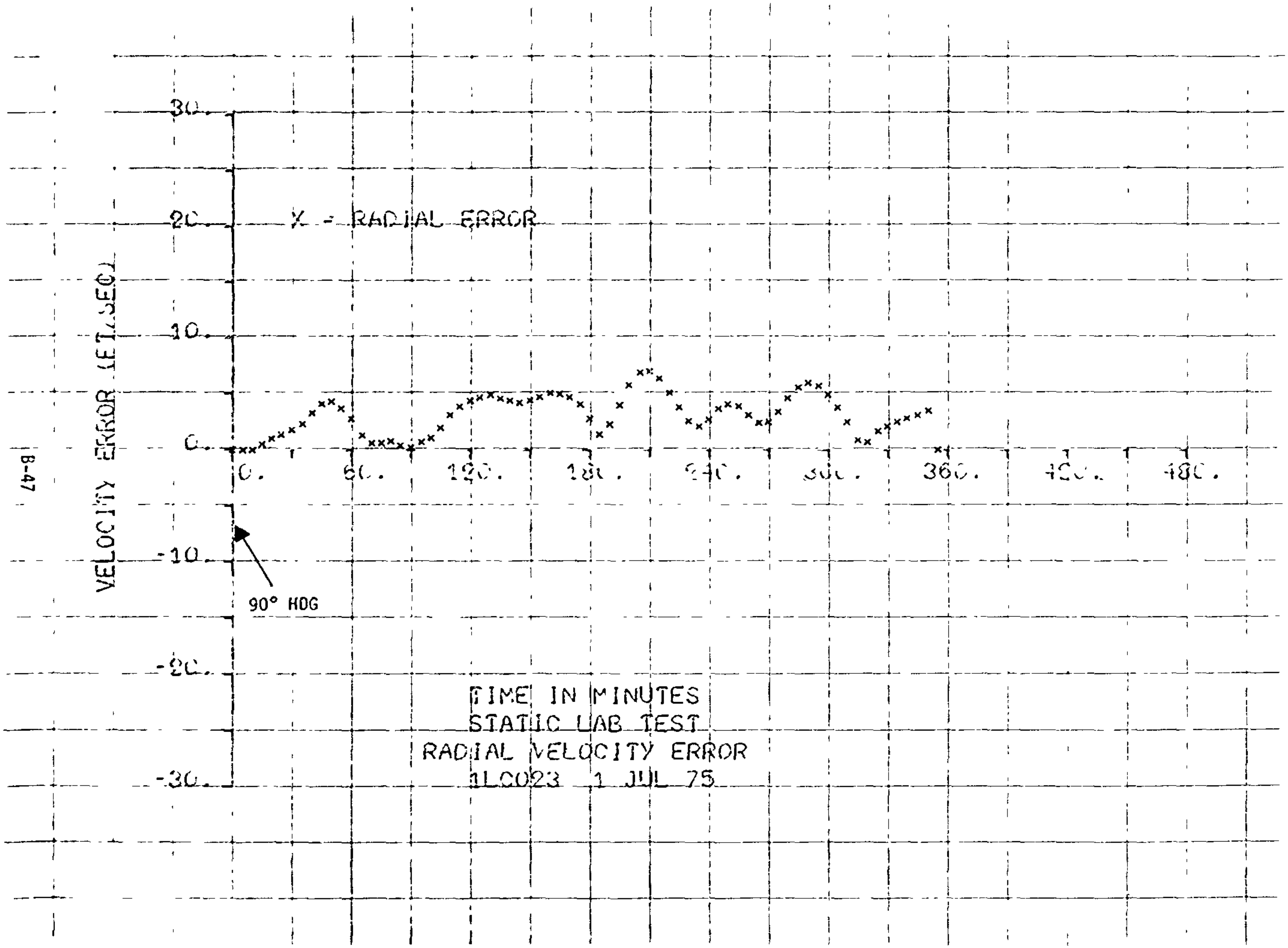


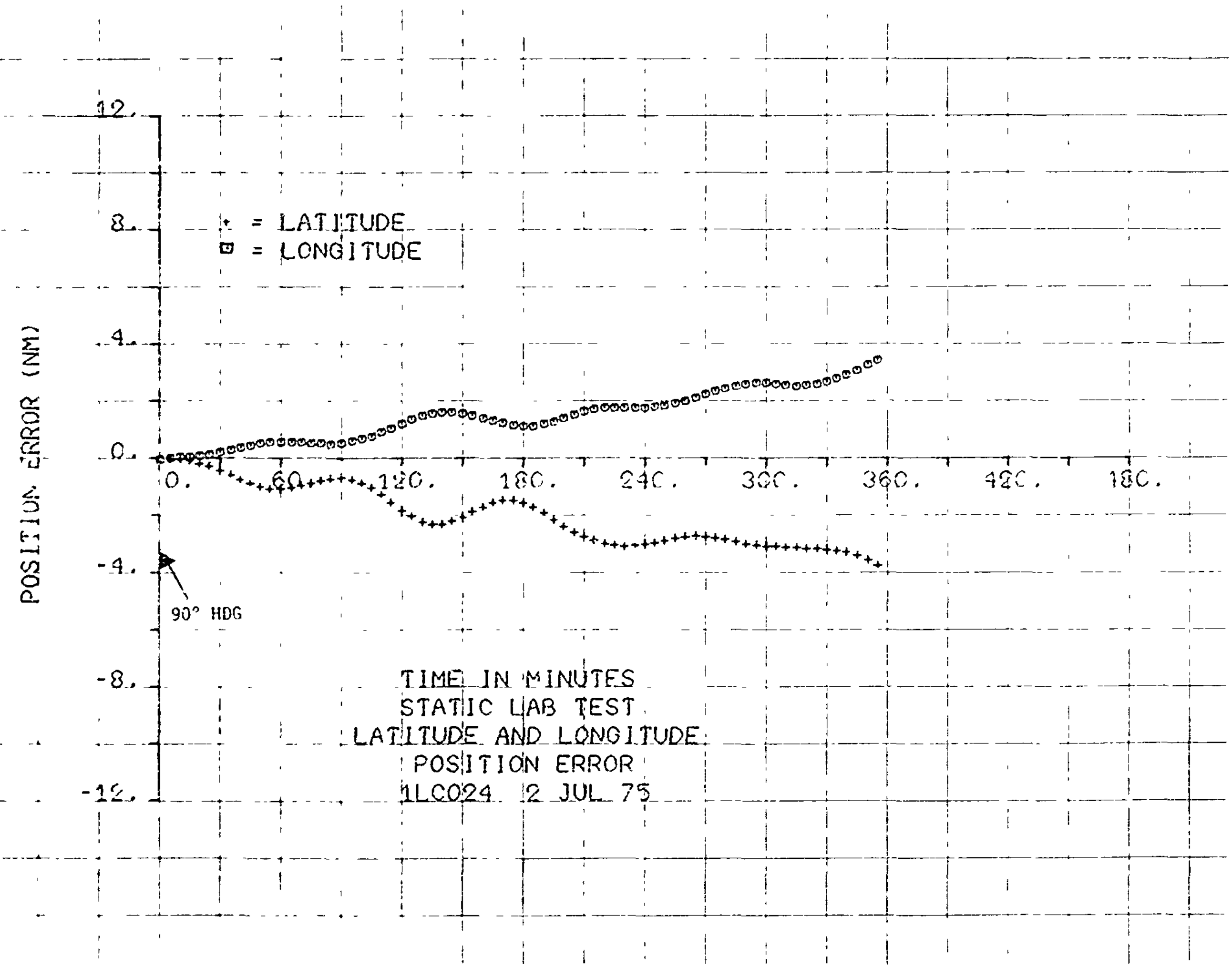
VELOCITY ERROR (FT/SEC)
30.
20.
10.
0.
-10.
-20.
-30.
X = RADIAL ERROR
0.
60.
120.
180.
240.
300.
360.
0° HDG
90° HDG
180° HDG
270° HDG
TIME IN MINUTES
HEADING SENSITIVITY LAB TEST
RADIAL VELOCITY ERROR
1LC009 3 JUN 75

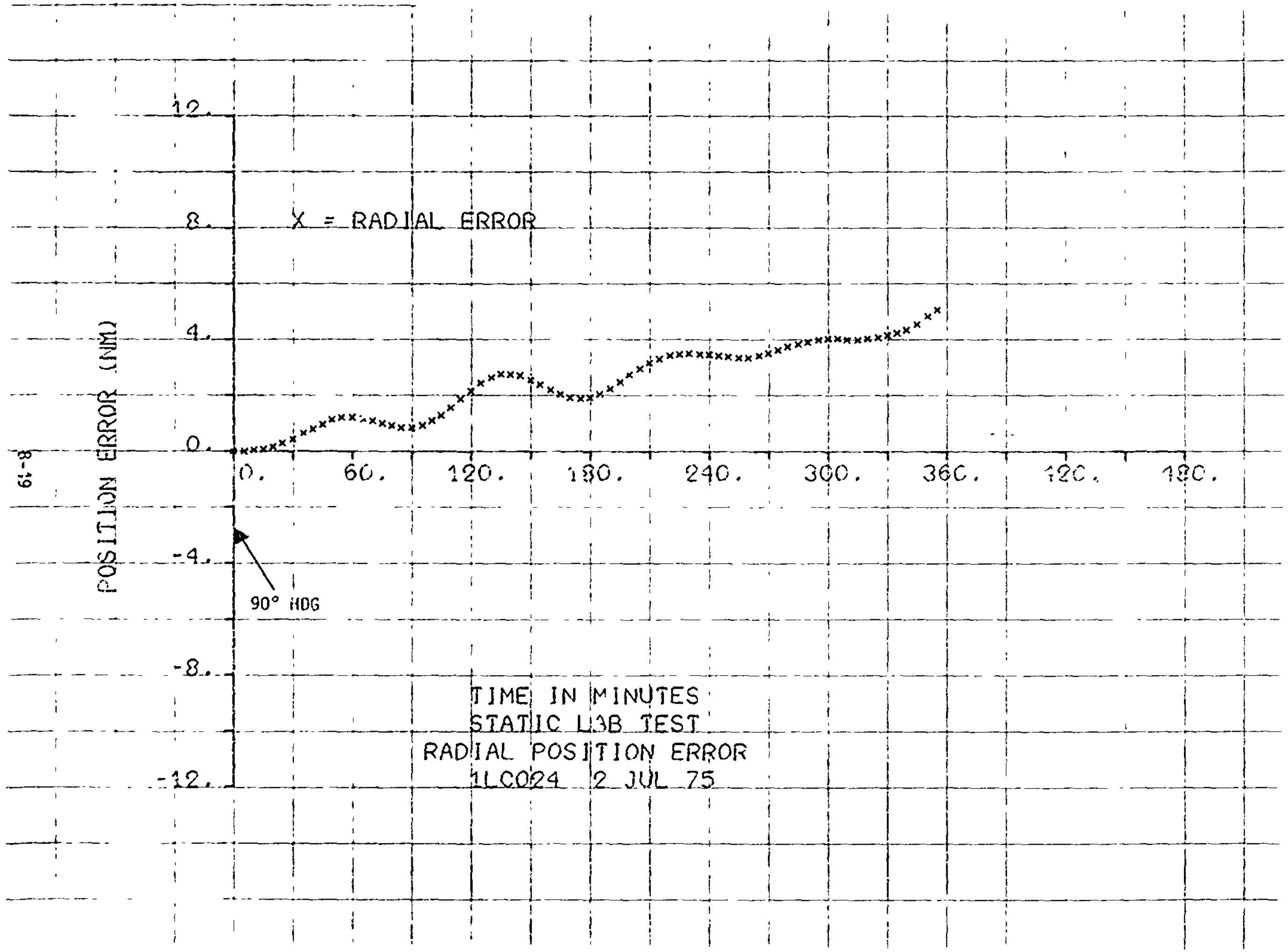

+ = LATITUDE
▫ = LONGITUDE
POSITION ERROR (NM)
90° HDG
TIME IN MINUTES
STATIC LAB TEST
LATITUDE AND LONGITUDE
POSITION ERROR
1LC023 1 JUL 75

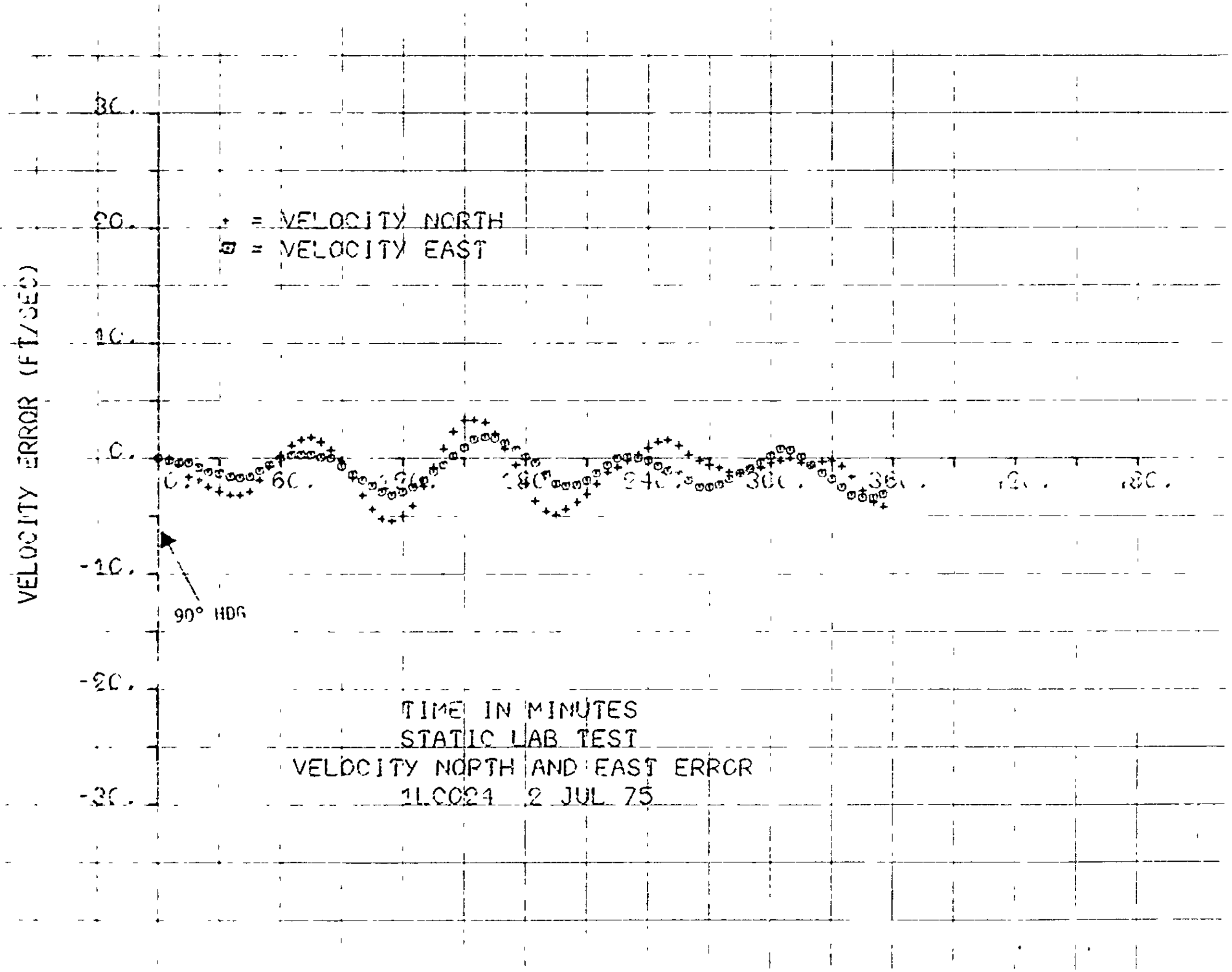

90° HDG
8
4
-4
-8
60.
120.
180.
240.
300.
360.
420.
480.
TIME IN MINUTES
STATIC LAB TEST
RADIAL POSITION ERROR


+ = VELOCITY NORTH
▫ = VELOCITY EAST
30.
20.
10.
0.
-10.
-20.
-30.
90° HDG
TIME IN MINUTES
STATIC LAB TEST
VELOCITY NORTH AND EAST ERROR
1LC023 1 JUL 75

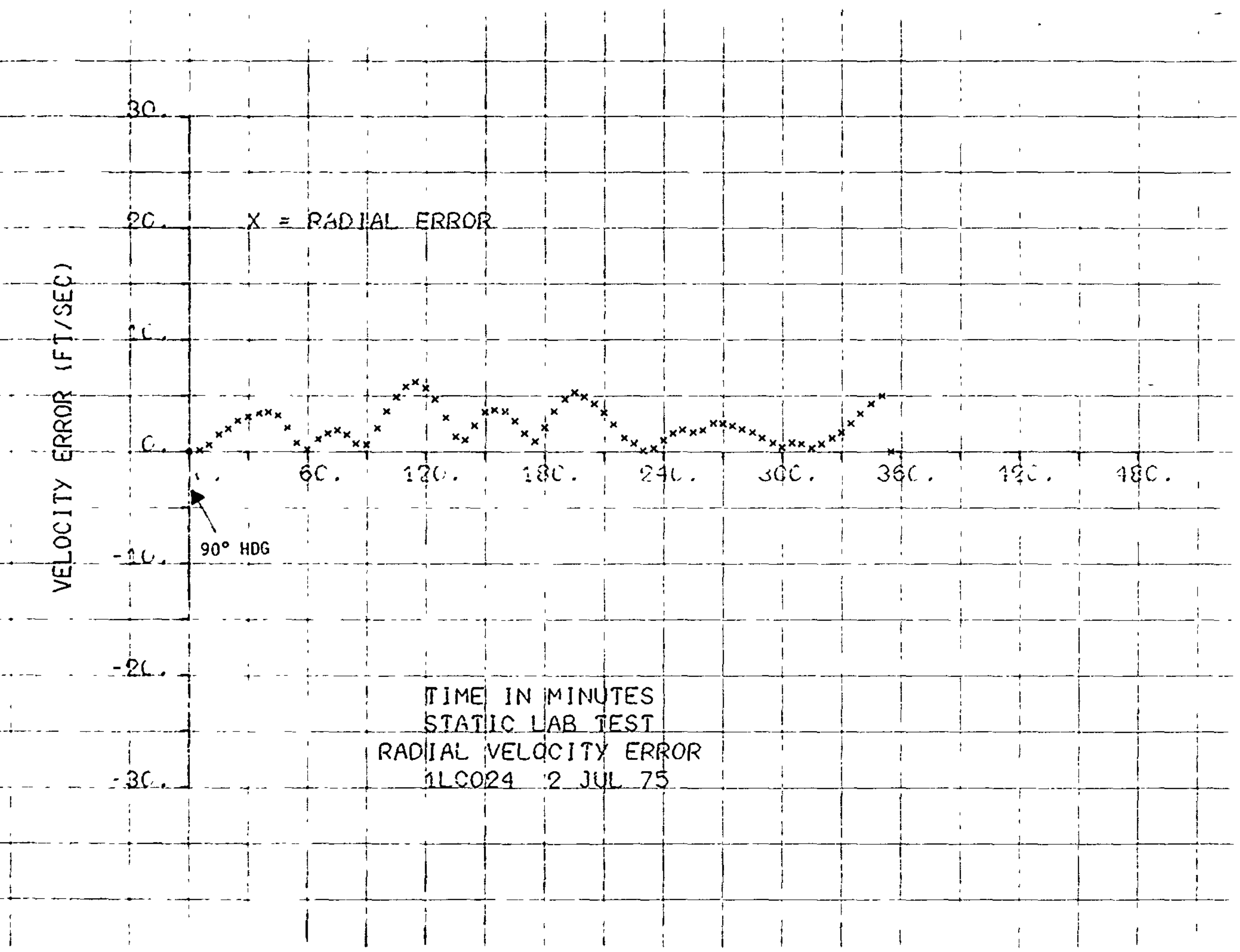

X - RADIAL ERROR
VELOCITY ERROR (FT/SEC)
30.
20.
10.
0.
-10.
-20.
-30.
0.
60.
120.
180.
240.
300.
360.
420.
480.
90° HDG
TIME IN MINUTES
STATIC LAB TEST
RADIAL VELOCITY ERROR
1LC023 1 JUL 75

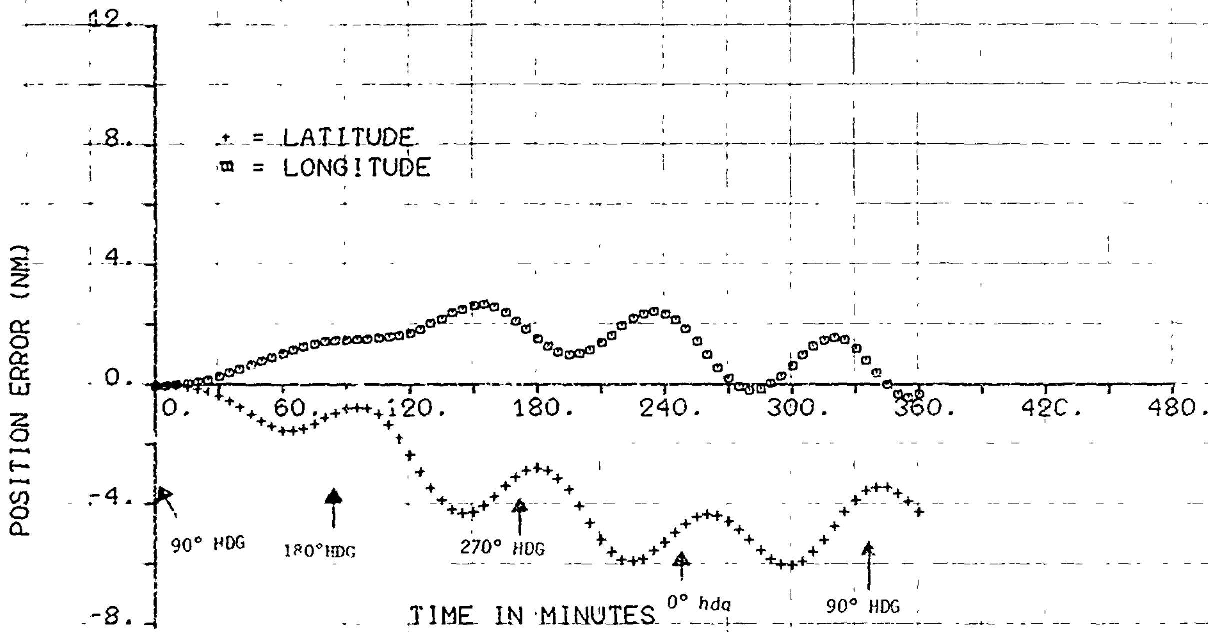

+ = LATITUDE
□ = LONGITUDE
POSITION ERROR (NM)
12.
8.
4.
0.
-4.
-8.
-12.
0.
60.
120.
180.
240.
300.
360.
420.
480.
90° HDG
TIME IN MINUTES
STATIC LAB TEST
LATITUDE AND LONGITUDE
POSITION ERROR
1LC024 2 JUL 75


X = RADIAL ERROR
POSITION ERROR (NM)
12.
8.
4.
0.
-4.
-8.
-12.
0.
60.
120.
180.
240.
300.
360.
90° HDG
TIME IN MINUTES
STATIC LAB TEST
RADIAL POSITION ERROR
1LC024 2 JUL 75

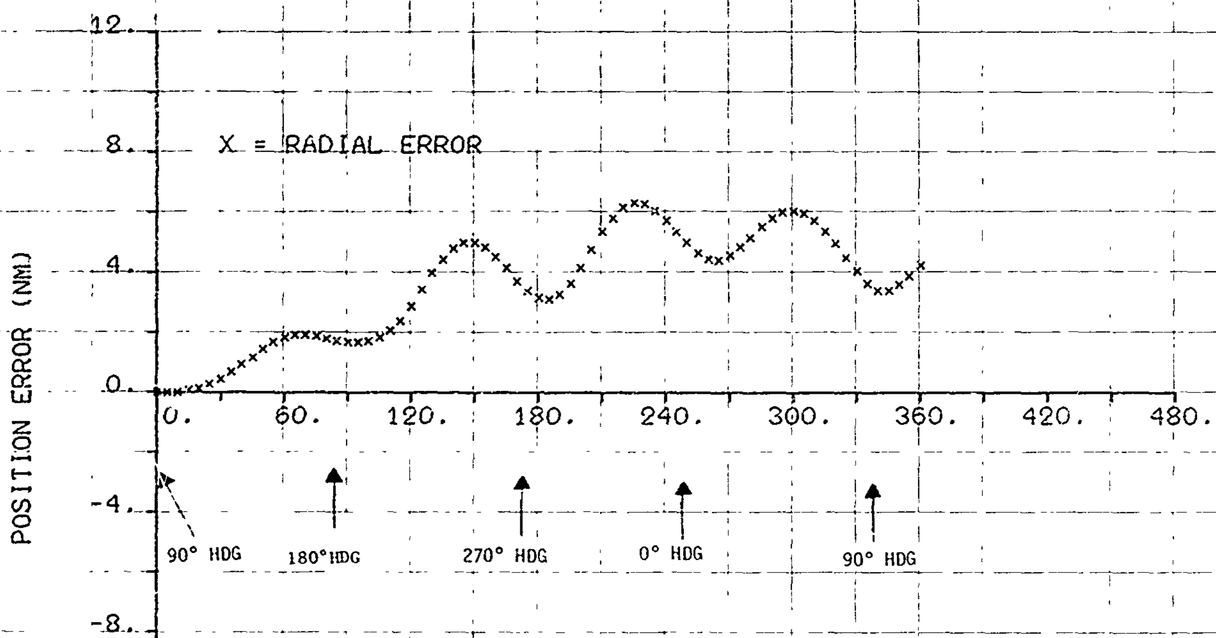


TIME IN MINUTES
STATIC LAB TEST
VELOCITY NORTH AND EAST ERROR
1LC024 2 JUL 75

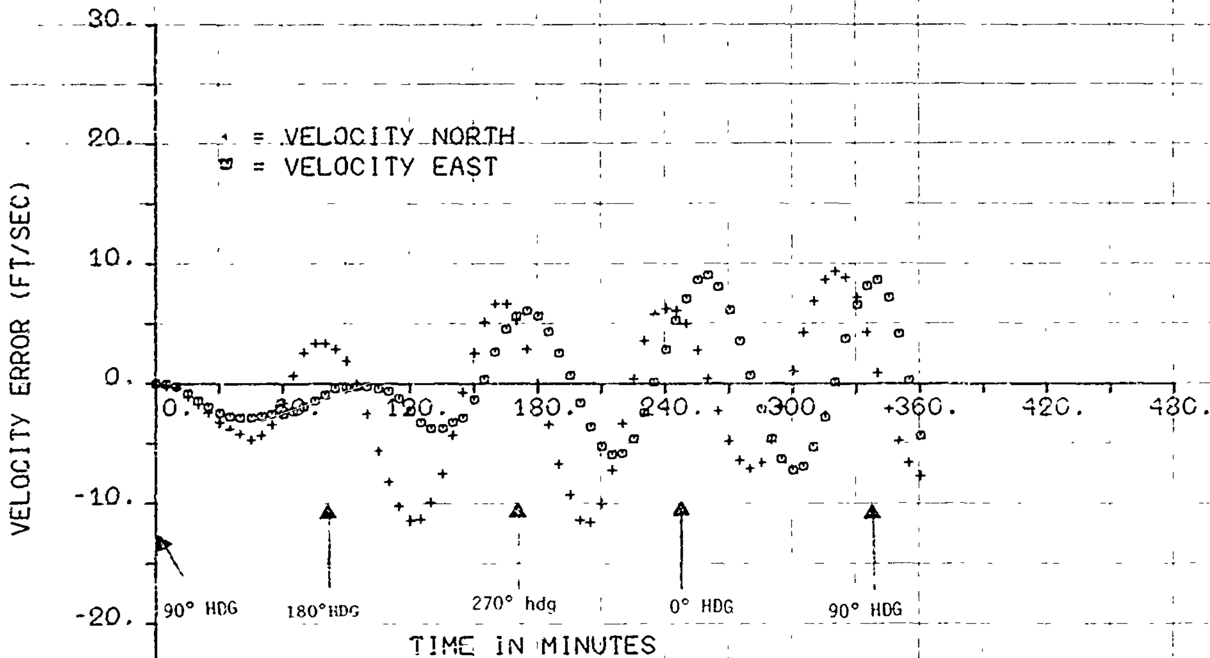

VELOCITY ERROR (FT/SEC)
30.
20.
10.
0.
-10.
-20.
-30.
X = RADIAL ERROR
90° HDG
60.
120.
180.
240.
300.
360.
420.
480.
TIME IN MINUTES
STATIC LAB TEST
RADIAL VELOCITY ERROR
1LC024 2 JUL 75



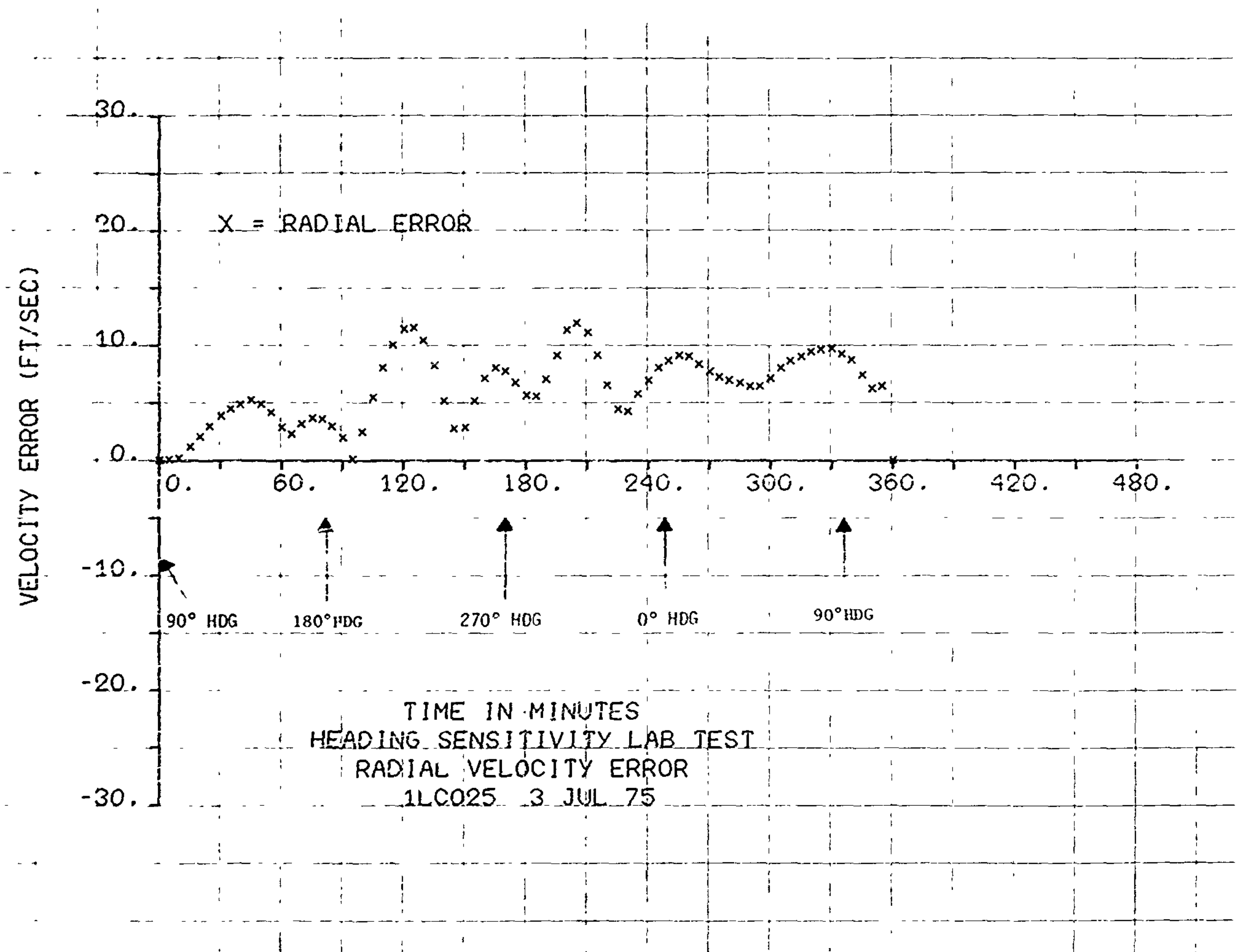
HEADING SENSITIVITY LAB TEST
LATITUDE AND LONGITUDE
POSITION ERROR
1LC025 3 JUL 75

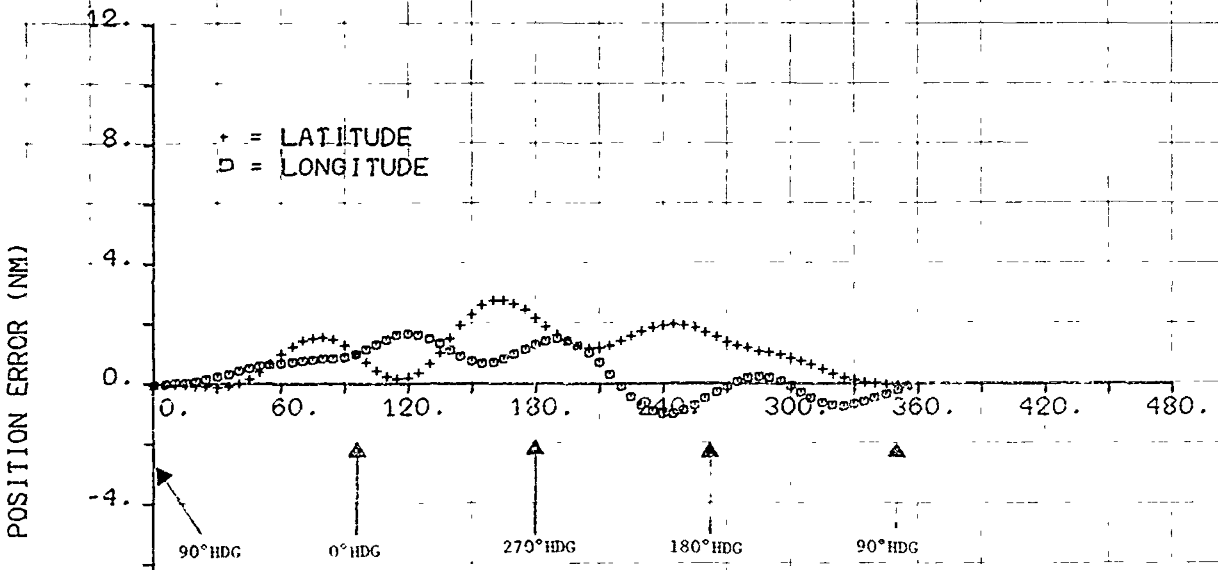


TIME IN MINUTES
HEADING SENSITIVITY LAB TEST
RADIAL POSITION ERROR
1LC025 3 JUL 75

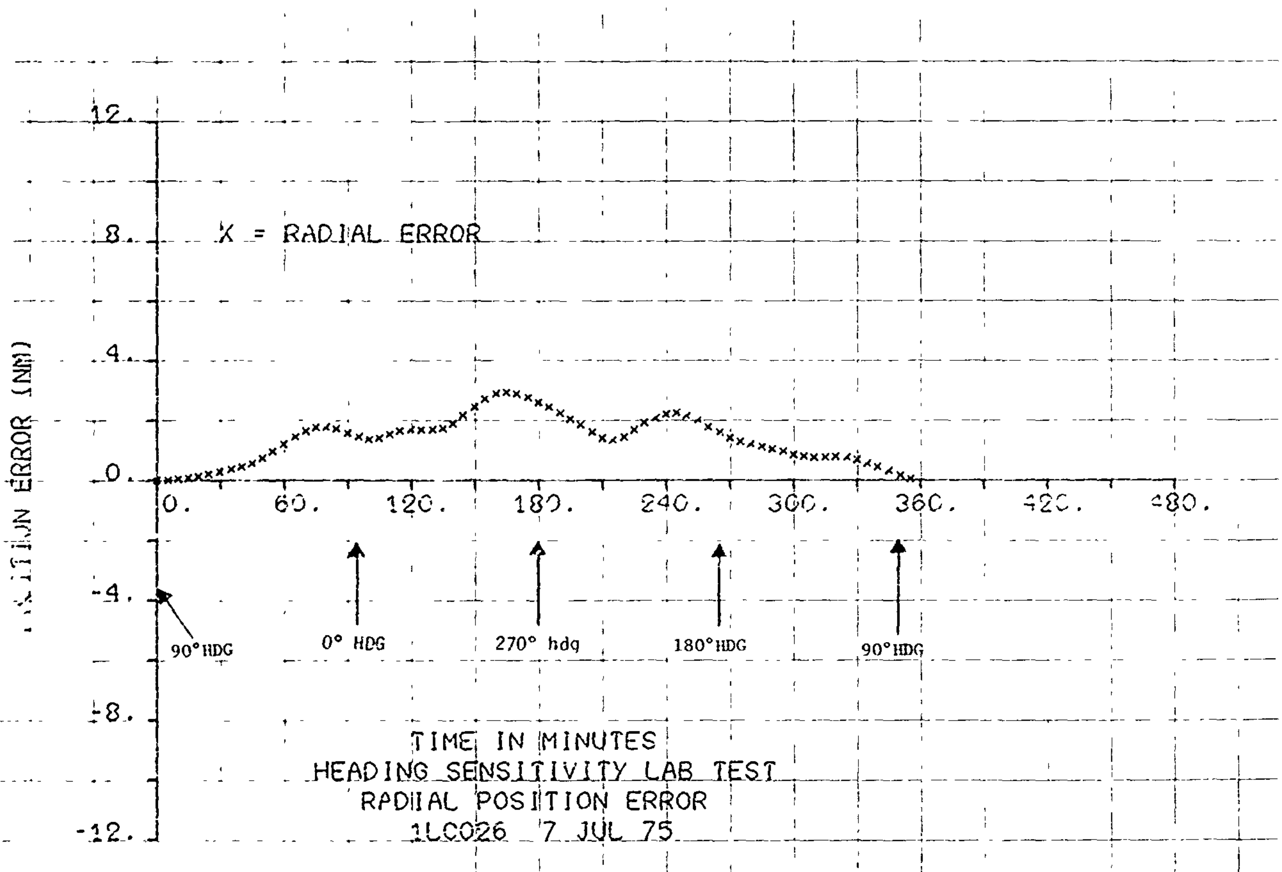


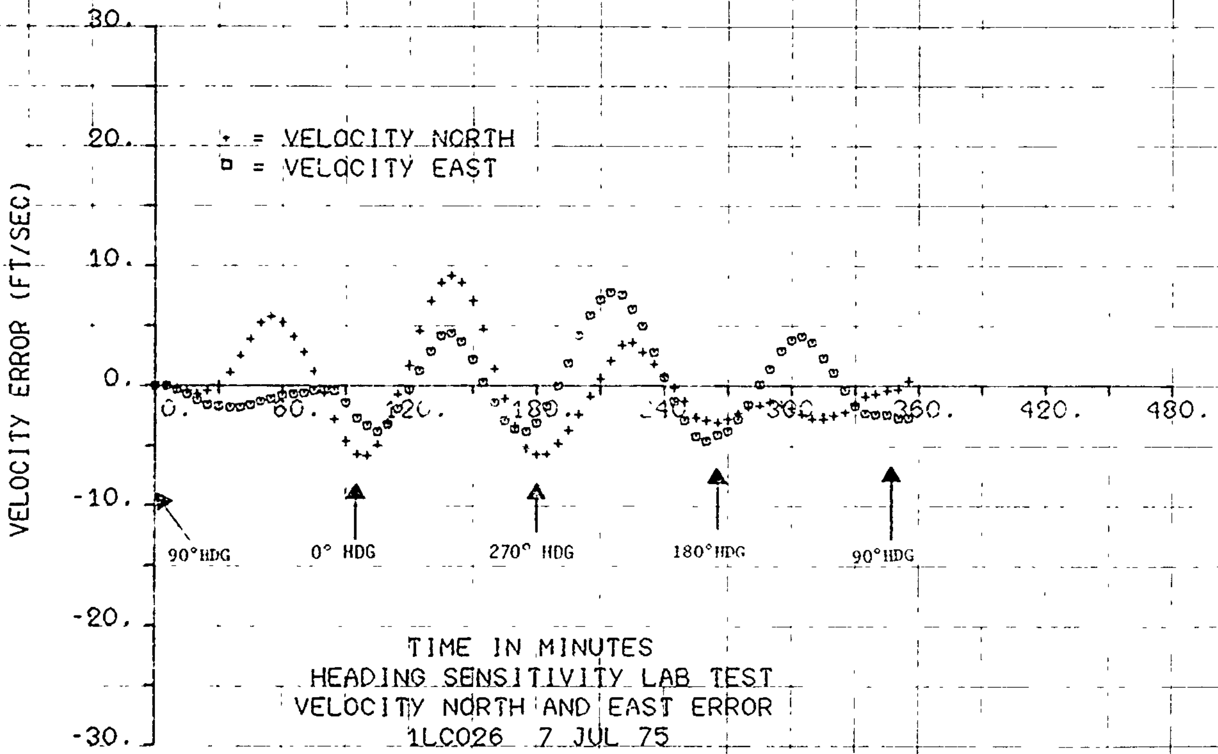
HEADING SENSITIVITY LAB TEST
VELOCITY NORTH AND EAST ERROR
1LC025 3 JUL 75

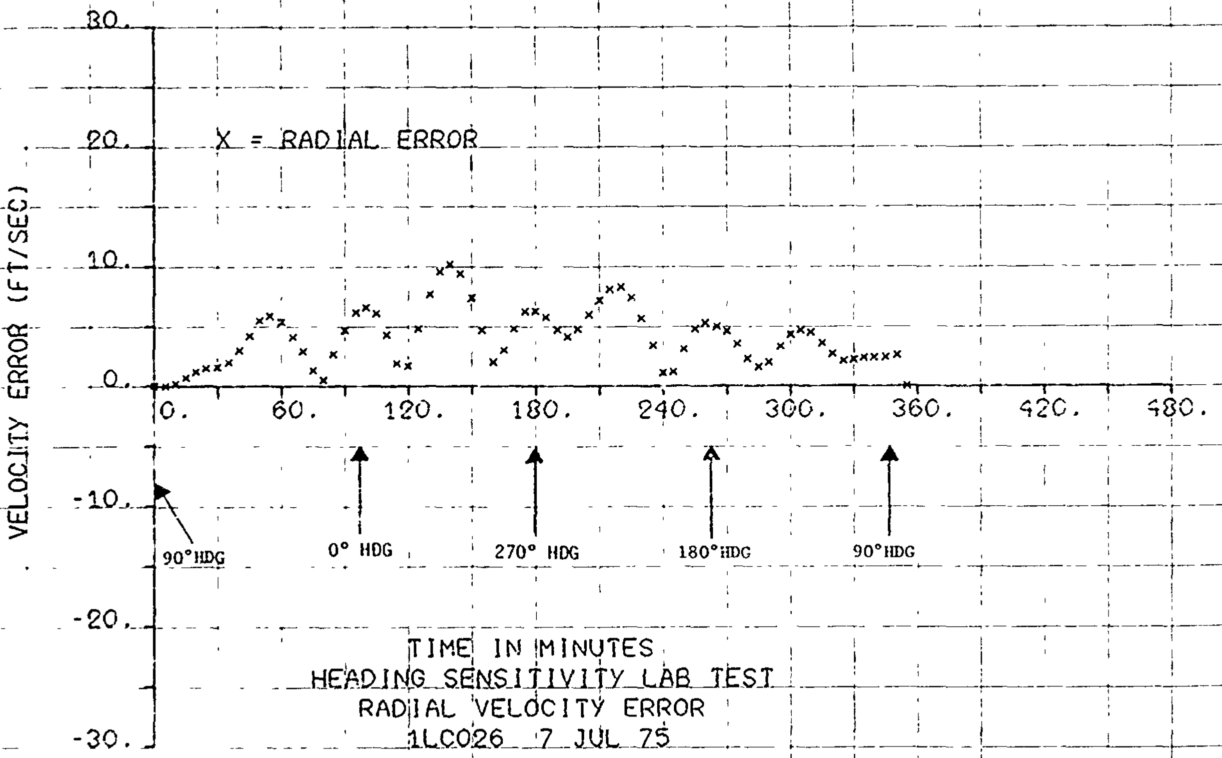

X = RADIAL ERROR
VELOCITY ERROR (FT/SEC)
30.
20.
10.
0.
-10.
-20.
-30.
0.
60.
120.
180.
240.
300.
360.
420.
480.
90° HDG
180° HDG
270° HDG
0° HDG
90° HDG
TIME IN MINUTES
HEADING SENSITIVITY LAB TEST
RADIAL VELOCITY ERROR
1LC025 3 JUL 75



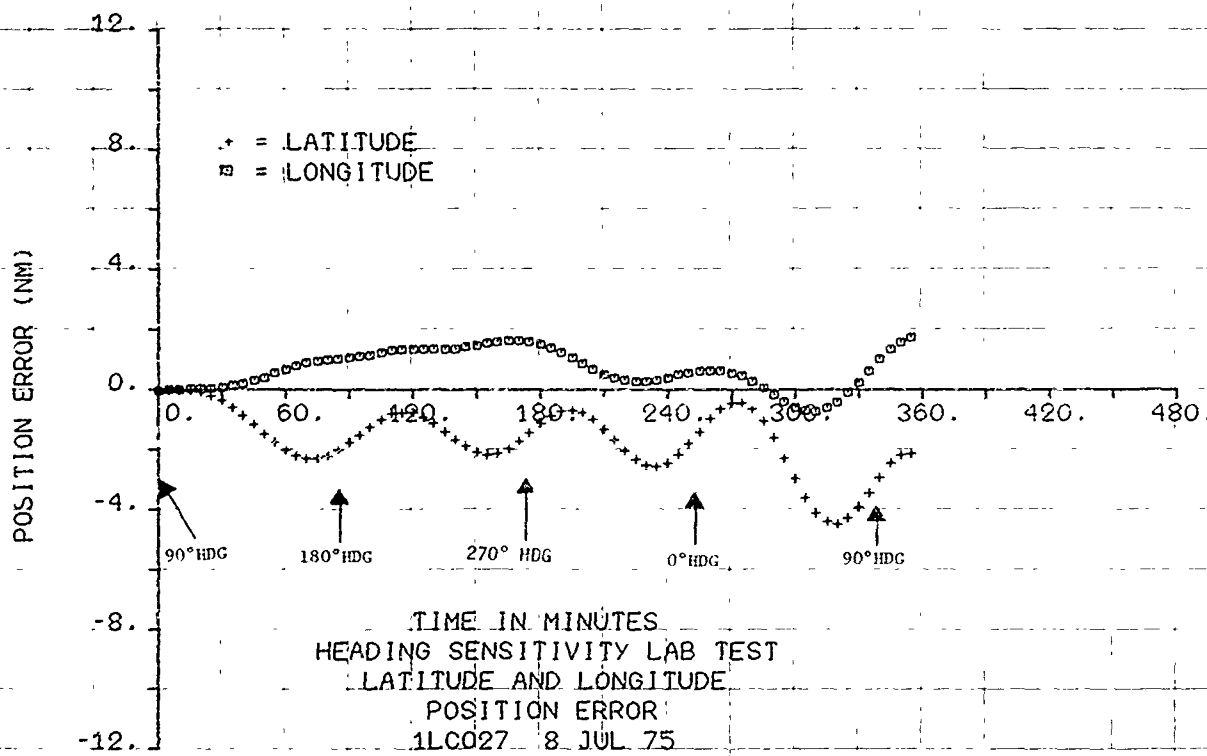
TIME IN MINUTES
HEADING SENSITIVITY LAB TEST
LATITUDE AND LONGITUDE
POSITION ERROR
1LC026 7 JUL 75

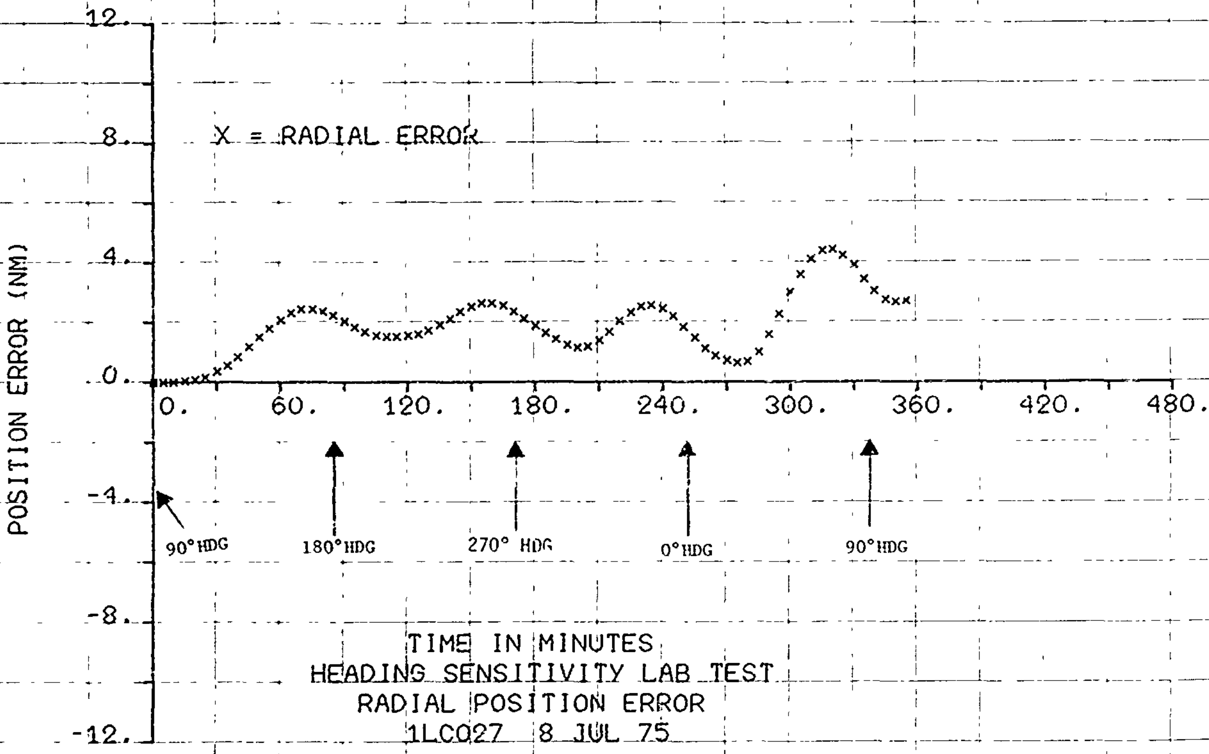

X = RADIAL ERROR
POSITION ERROR (NM)
12.
8.
4.
0.
-4.
-8.
-12.
0.
60.
120.
180.
240.
300.
360.
420.
480.
90° HDG
0° HDG
270° hdg
180° HDG
90° HDG
TIME IN MINUTES
HEADING SENSITIVITY LAB TEST
RADIAL POSITION ERROR
1LC026 7 JUL 75


+ = VELOCITY NORTH
□ = VELOCITY EAST
VELOCITY ERROR (FT/SEC)
30.
20.
10.
0.
-10.
-20.
-30.
0.
60.
120.
180.
240.
300.
360.
420.
480.
90°HDG
0° HDG
270° HDG
180°HDG
90°HDG
TIME IN MINUTES
HEADING SENSITIVITY LAB TEST
VELOCITY NORTH AND EAST ERROR
1LC026 7 JUL 75

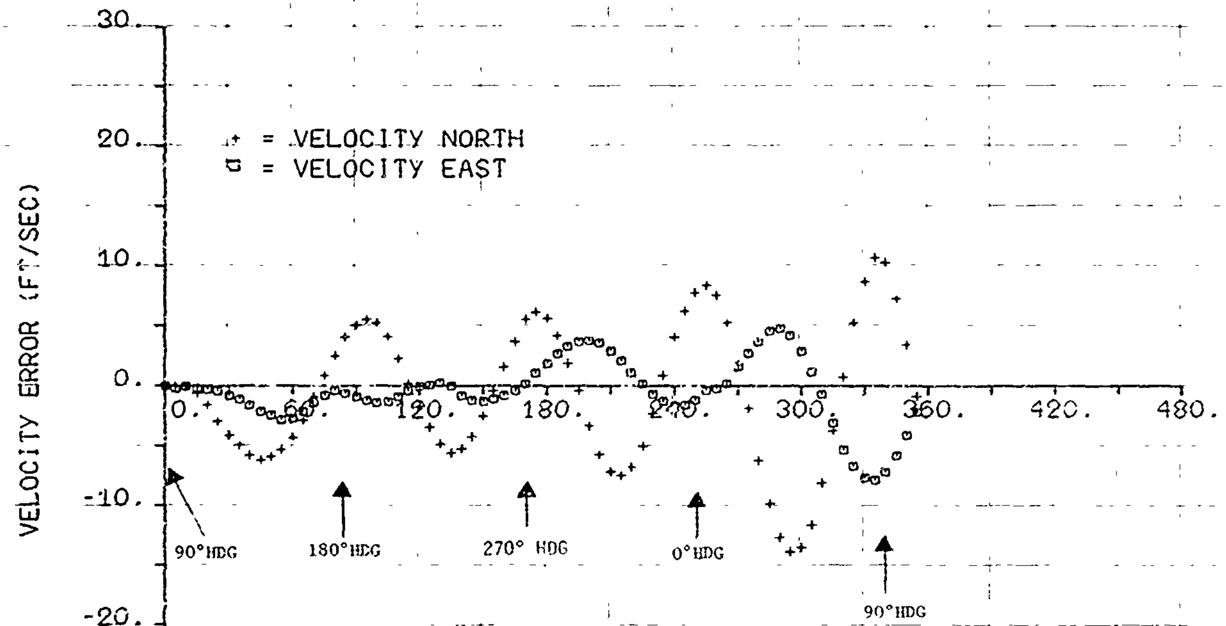


HEADING SENSITIVITY LAB TEST
RADIAL VELOCITY ERROR
1LC026 7 JUL 75

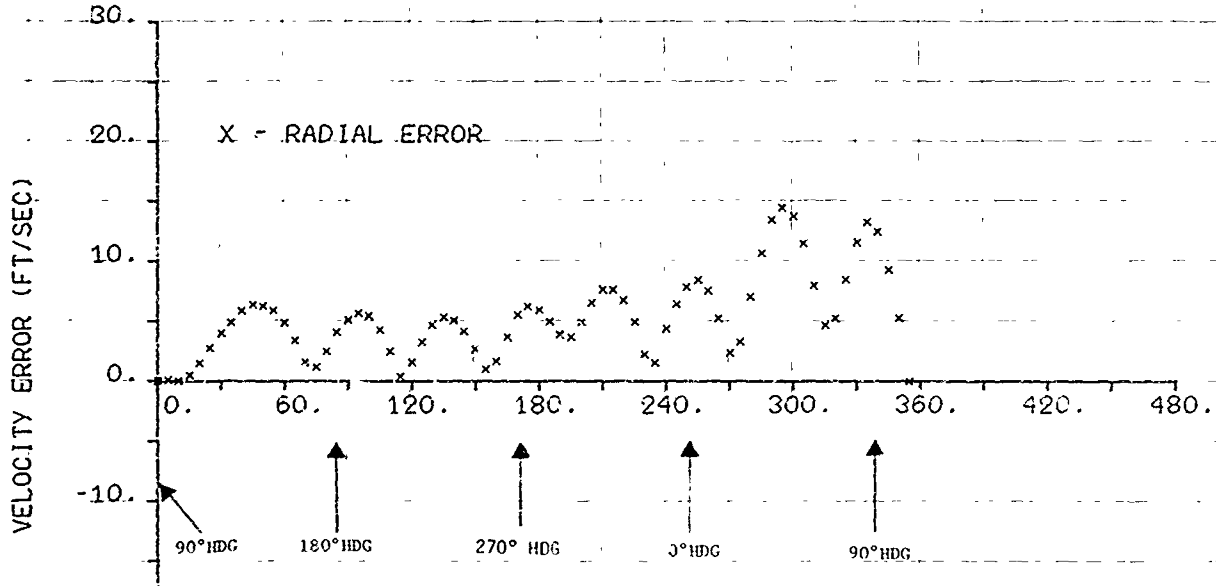

POSITION ERROR (NM)
12.
8.
4.
0.
-4.
-8.
-12.
0.
60.
120.
180.
240.
300.
360.
420.
480.
+ = LATITUDE
□ = LONGITUDE
90° HDG
180° HDG
270° HDG
0° HDG
90° HDG
TIME IN MINUTES
HEADING SENSITIVITY LAB TEST
LATITUDE AND LONGITUDE
POSITION ERROR
1LC027 8 JUL 75



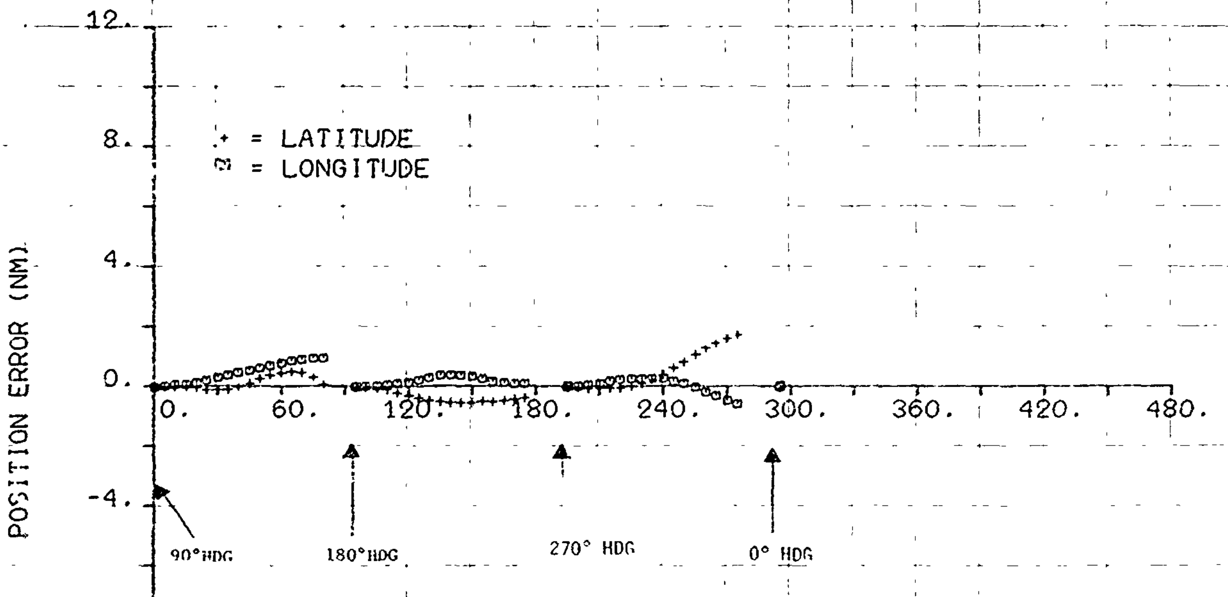
X = RADIAL ERROR
POSITION ERROR (NM)
12.
8.
4.
0.
-4.
-8.
-12.
0.
60.
120.
180.
240.
300.
360.
420.
480.
90°HDG
180°HDG
270° HDG
0°HDG
90°HDG
TIME IN MINUTES
HEADING SENSITIVITY LAB TEST
RADIAL POSITION ERROR
1LC027 8 JUL 75



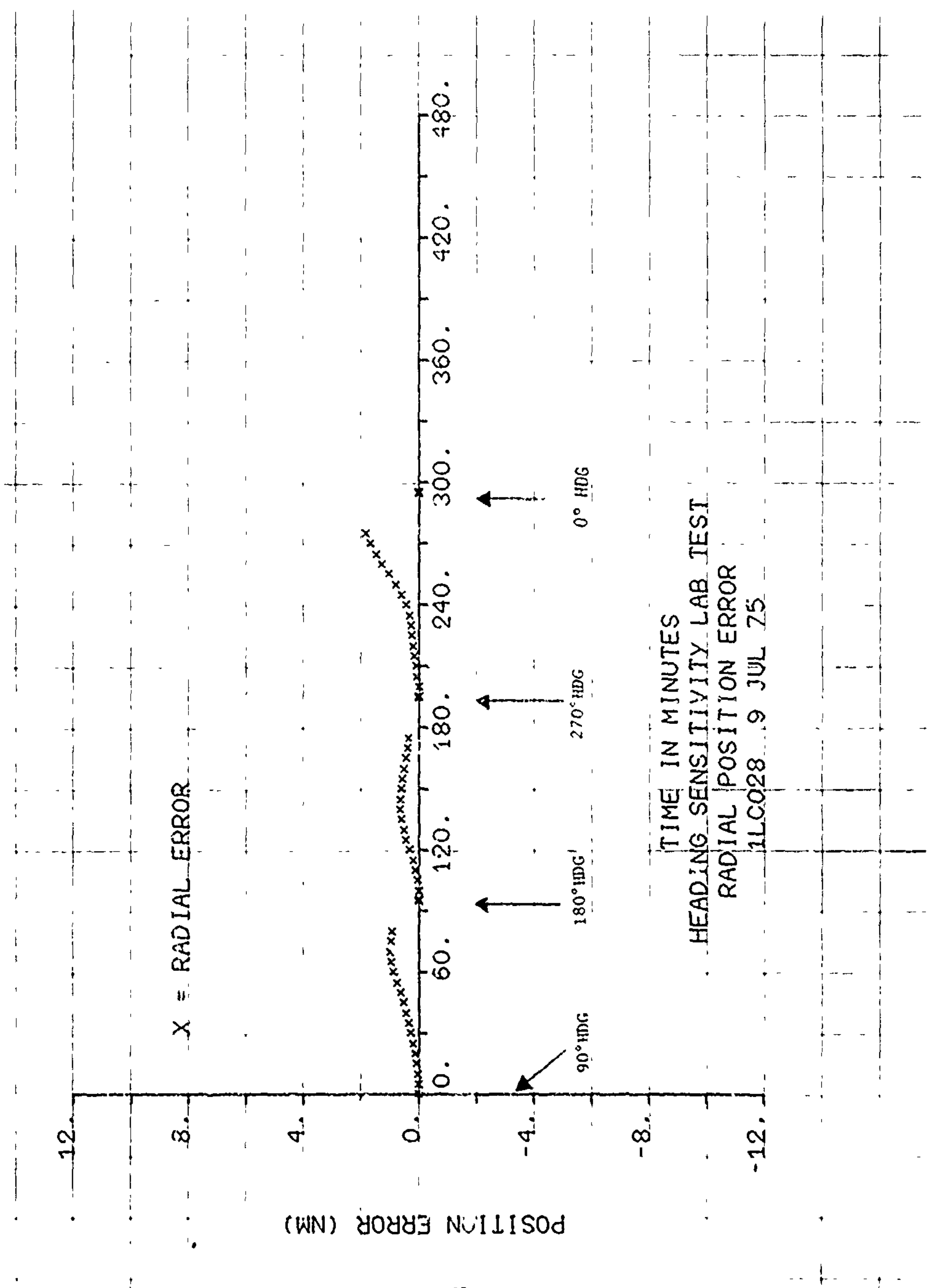
TIME IN MINUTES
HEADING SENSITIVITY LAB TEST
VELOCITY NORTH AND EAST ERROR
1LC027 8 JUL 75

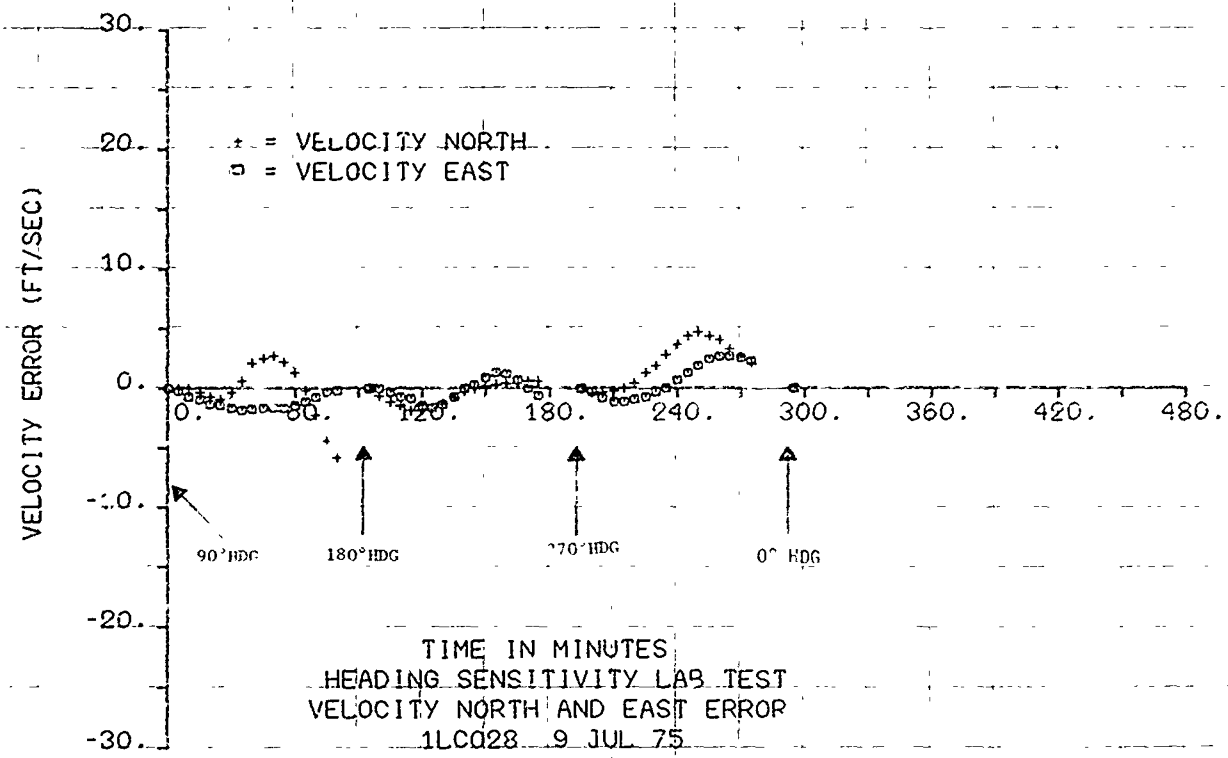


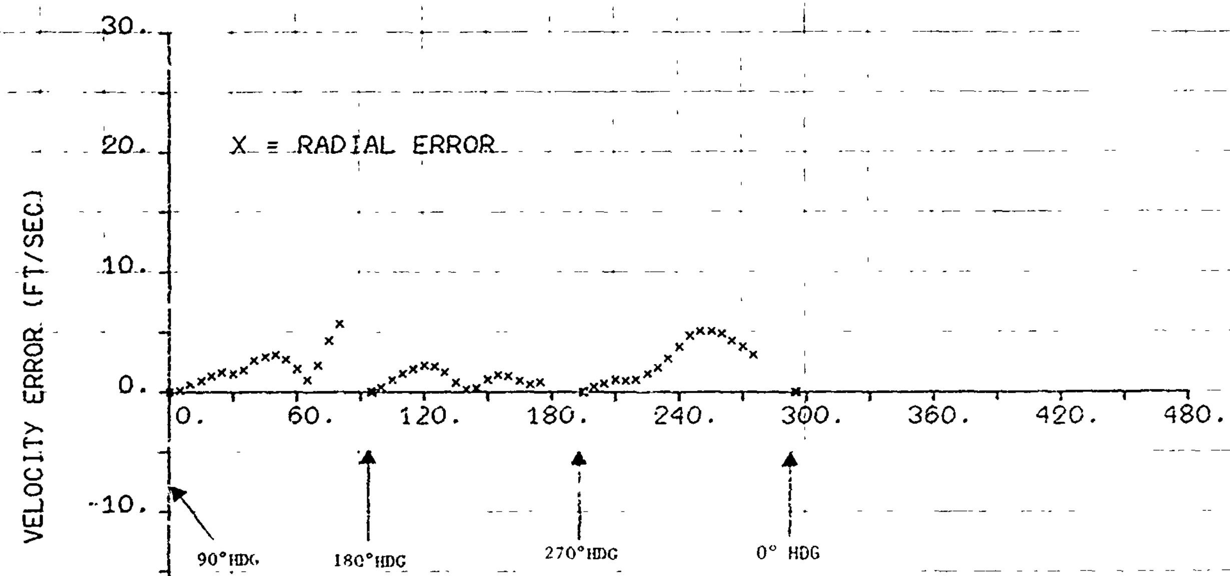
HEADING SENSITIVITY LAB TEST
RADIAL VELOCITY ERROR
1LC027 8 JUL 75



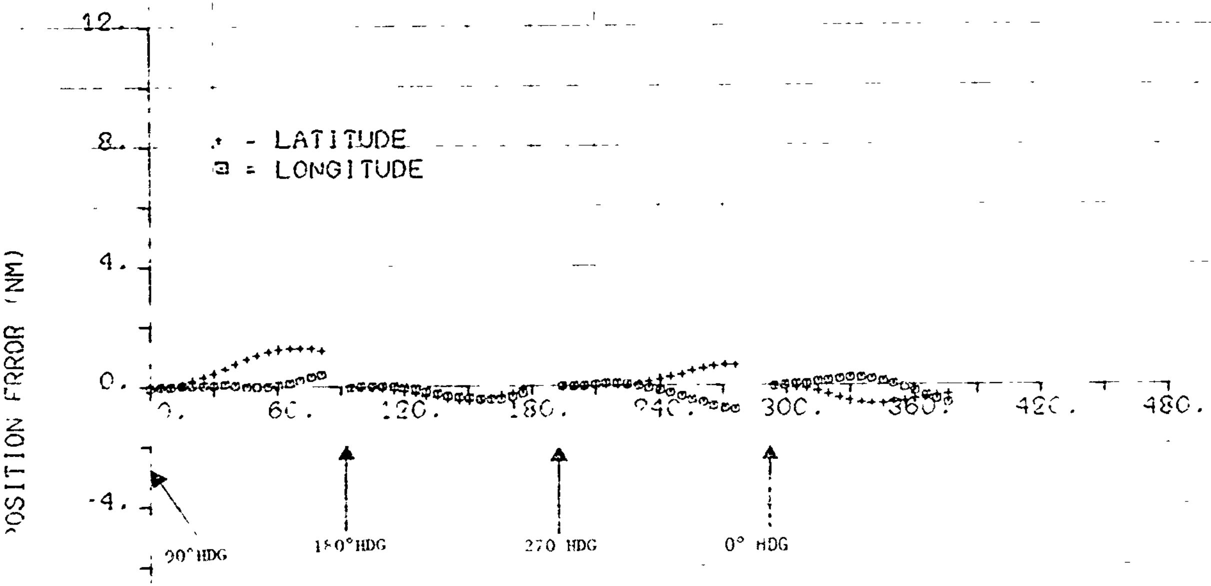
TIME IN MINUTES
HEADING SENSITIVITY LAB TEST
LATITUDE AND LONGITUDE
POSITION ERROR
1LC028 9 JUL 75


X = RADIAL ERROR
90°HDG
180°HDG
270°HDG
0° HDG
POSITION ERROR (NM)
12.
8.
4.
0.
-4.
-8.
-12.
0.
60.
120.
180.
240.
300.
360.
420.
480.
TIME IN MINUTES
HEADING SENSITIVITY LAB TEST
RADIAL POSITION ERROR
1LC028 9 JUL 75

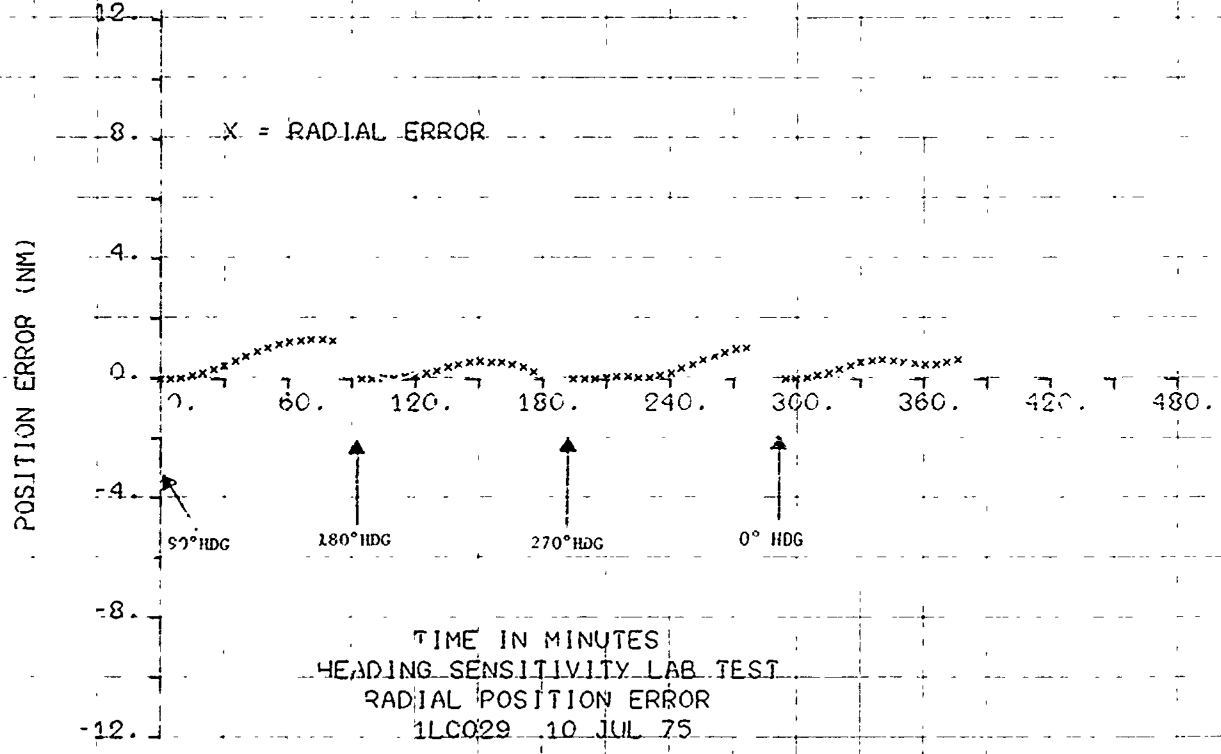

VELOCITY ERROR (FT/SEC)
30.
20.
10.
0.
-10.
-20.
-30.
+ = VELOCITY NORTH
□ = VELOCITY EAST
0.
60.
120.
180.
240.
300.
360.
420.
480.
90° HDG
180° HDG
270° HDG
0° HDG
TIME IN MINUTES
HEADING SENSITIVITY LAB TEST
VELOCITY NORTH AND EAST ERROR
1LC028 9 JUL 75



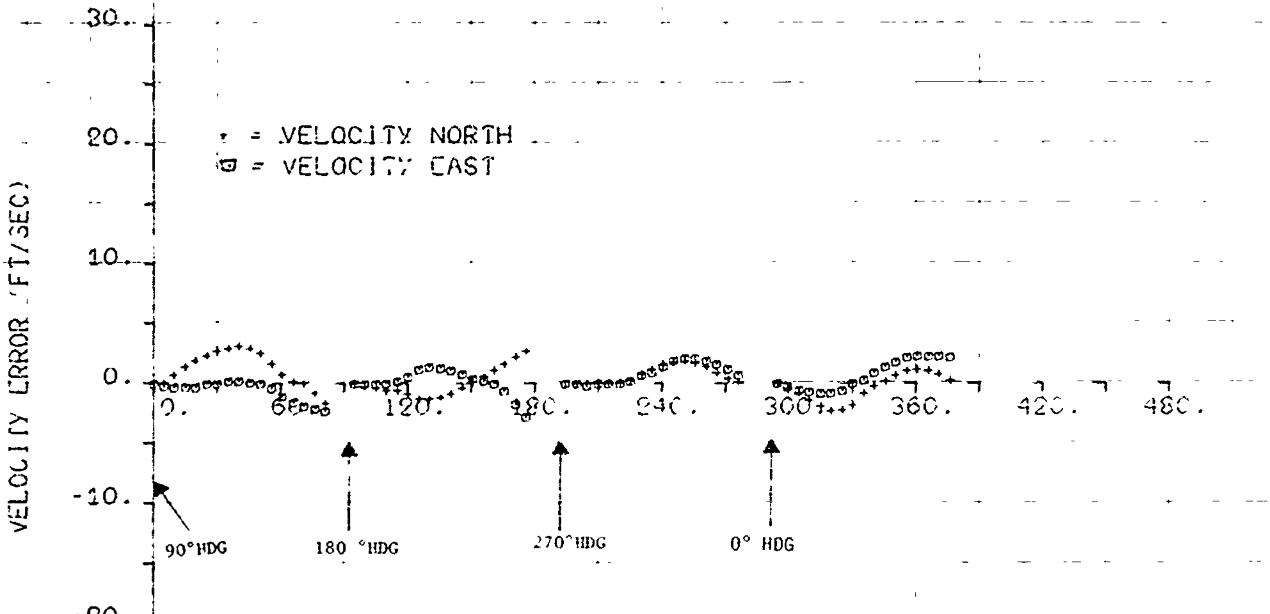
TIME IN MINUTES
HEADING SENSITIVITY LAB TEST
RADIAL VELOCITY ERROR
1LC028 9 JUL 75



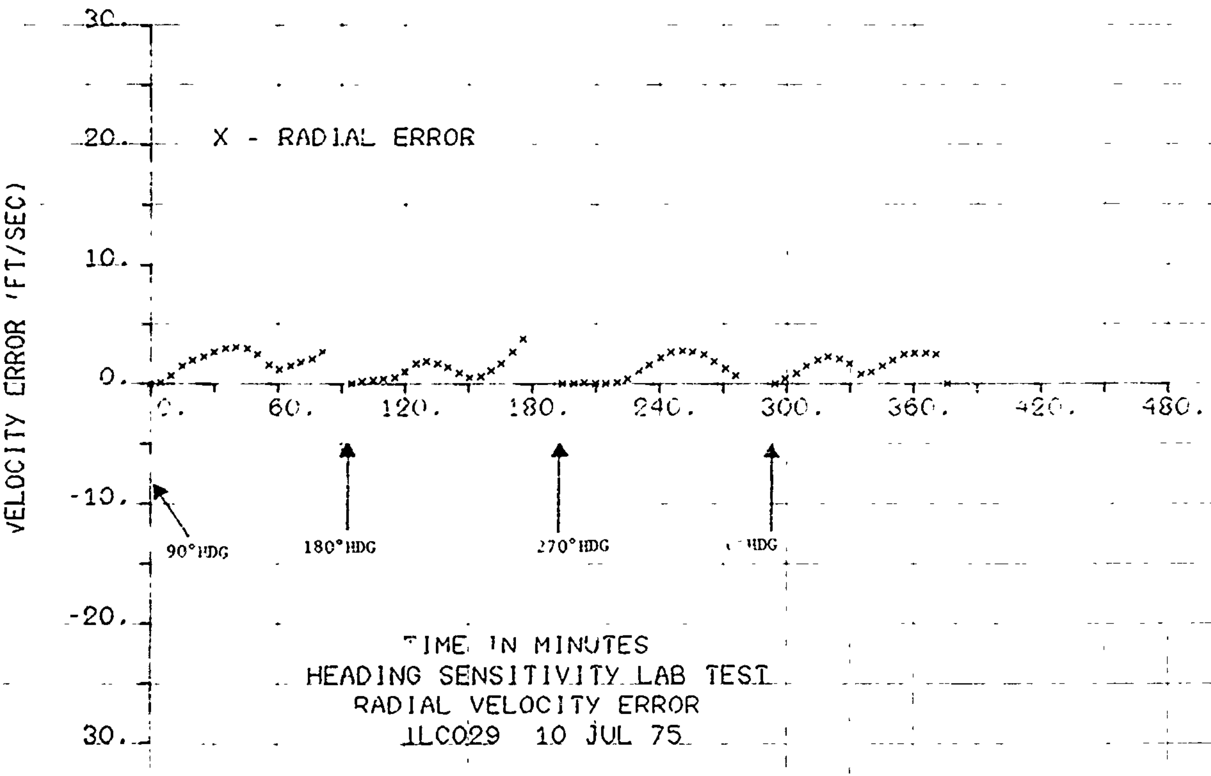
HEADING SENSITIVITY LAB TEST
LATITUDE AND LONGITUDE
POSITION ERROR
1LC029 10 JUL 75



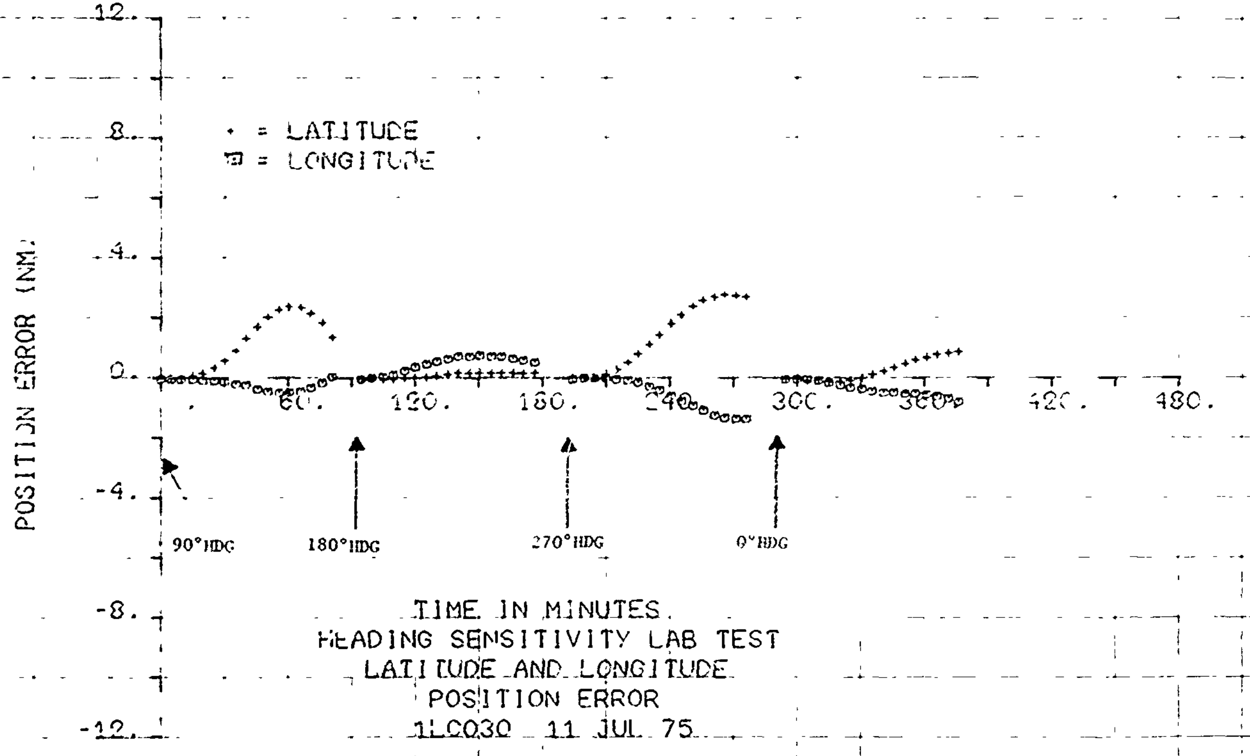
HEADING SENSITIVITY LAB TEST
RADIAL POSITION ERROR
1LC029 10 JUL 75



TIME IN MINUTES
HEADING SENSITIVITY LAB TEST
VELOCITY NORTH AND EAST ERROR
1LC029 10 JUL 75



HEADING SENSITIVITY LAB TEST
RADIAL VELOCITY ERROR
1LC029 10 JUL 75



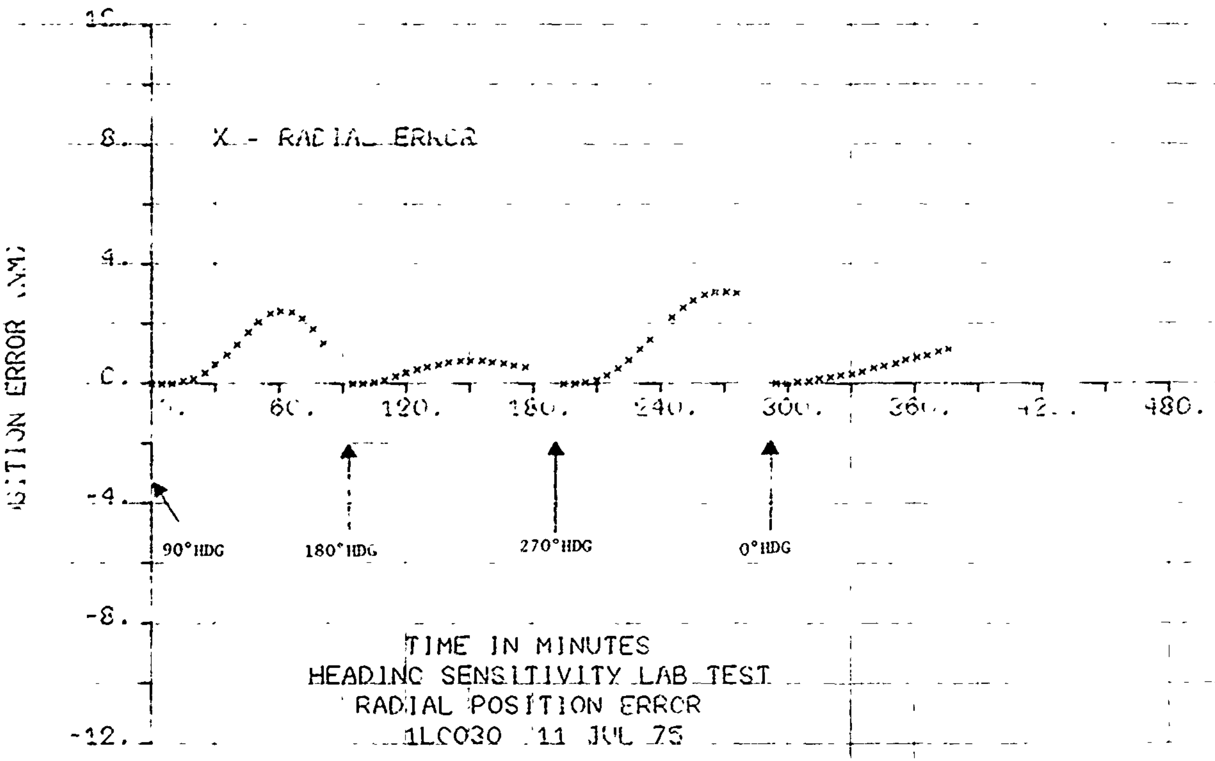
TIME IN MINUTES

HEADING SENSITIVITY LAB TEST

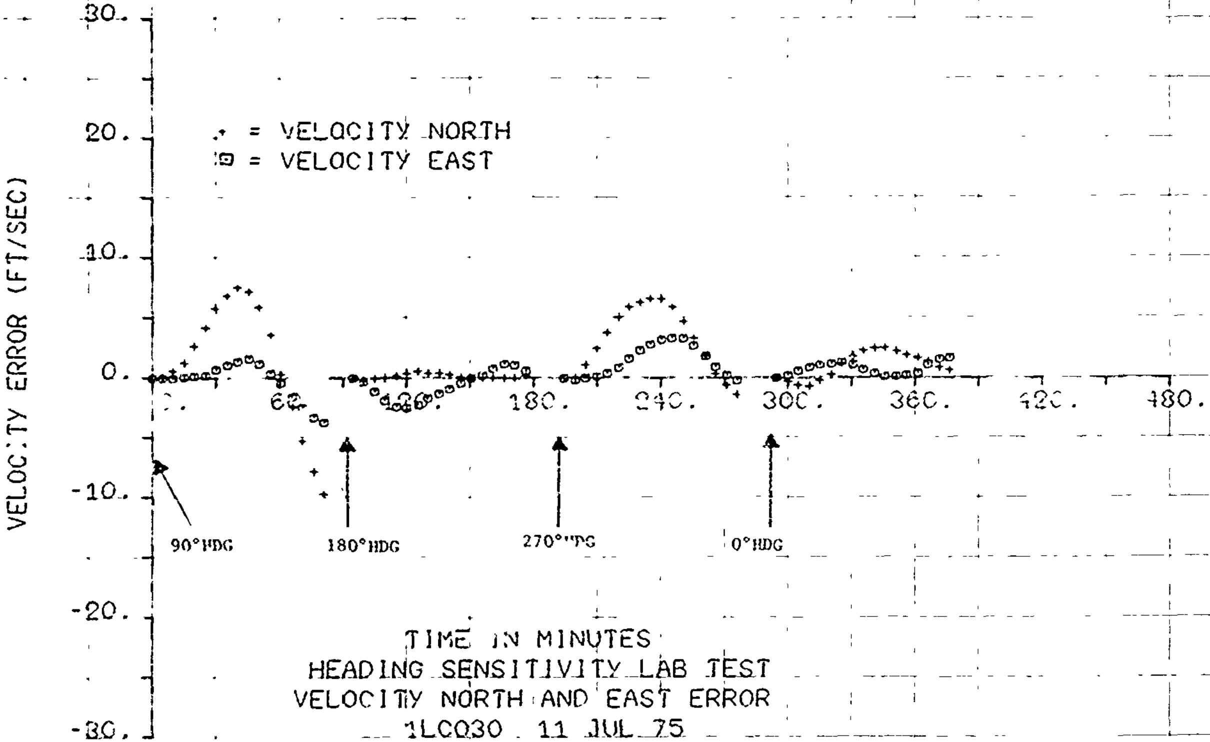
LATITUDE AND LONGITUDE

POSITION ERROR

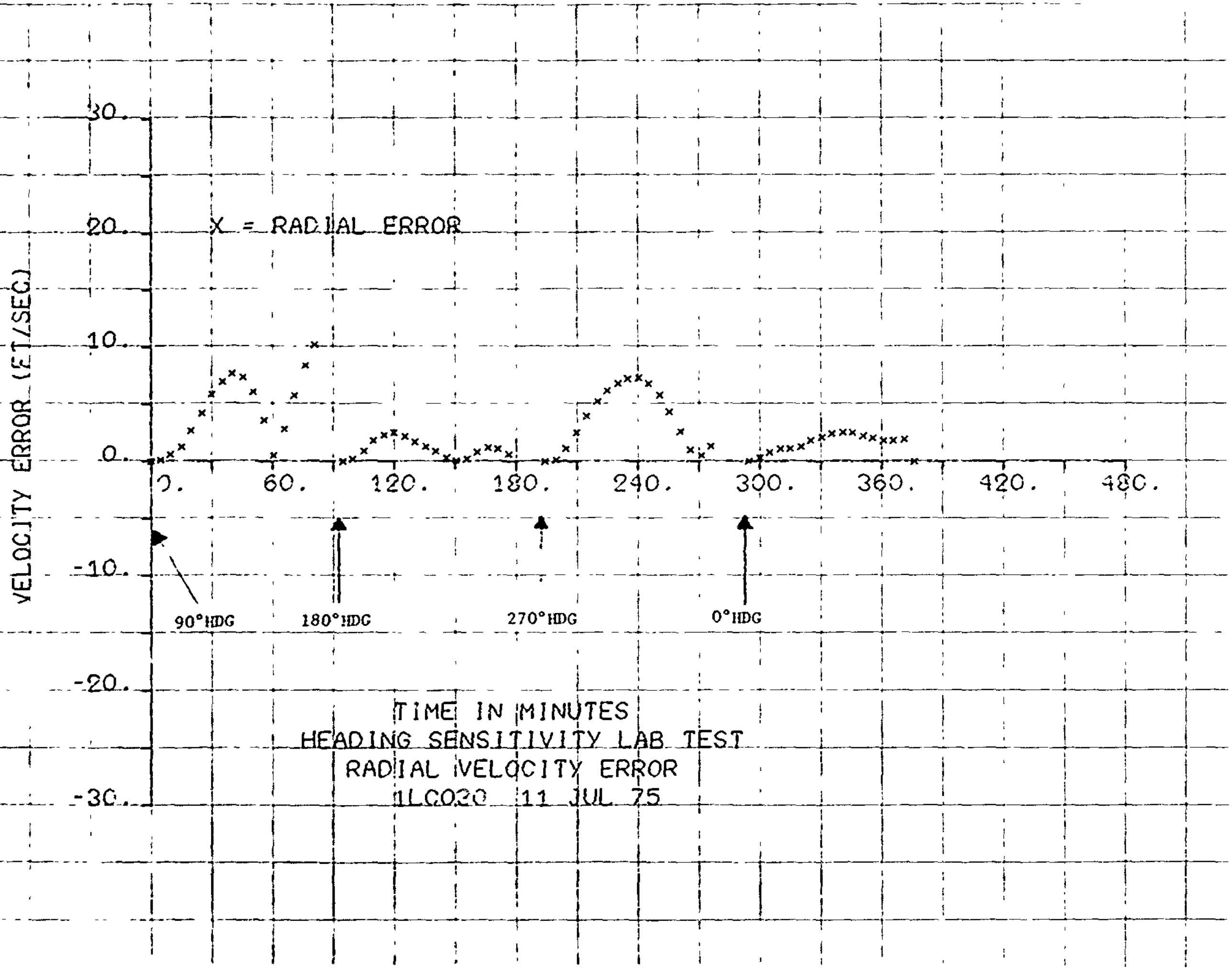
1LC030 11 JUL 75



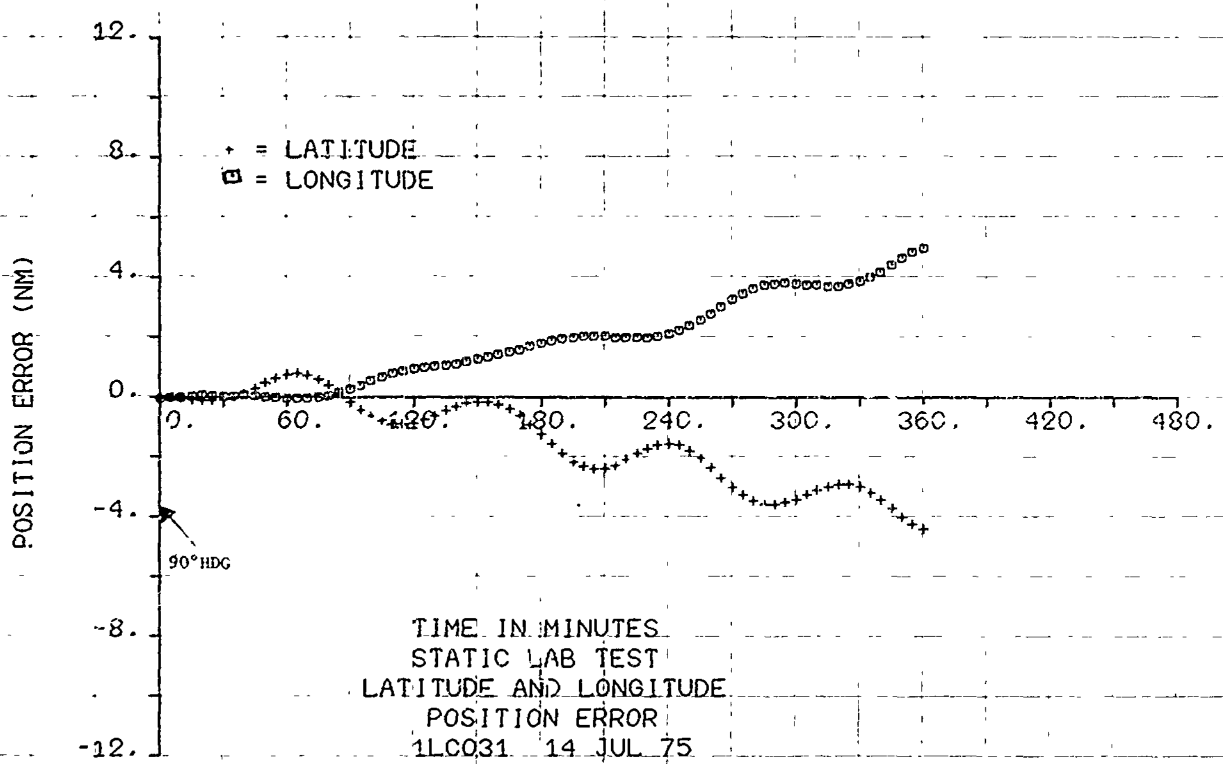
TIME IN MINUTES
HEADING SENSITIVITY LAB TEST
RADIAL POSITION ERROR
1LC030 11 JUL 75



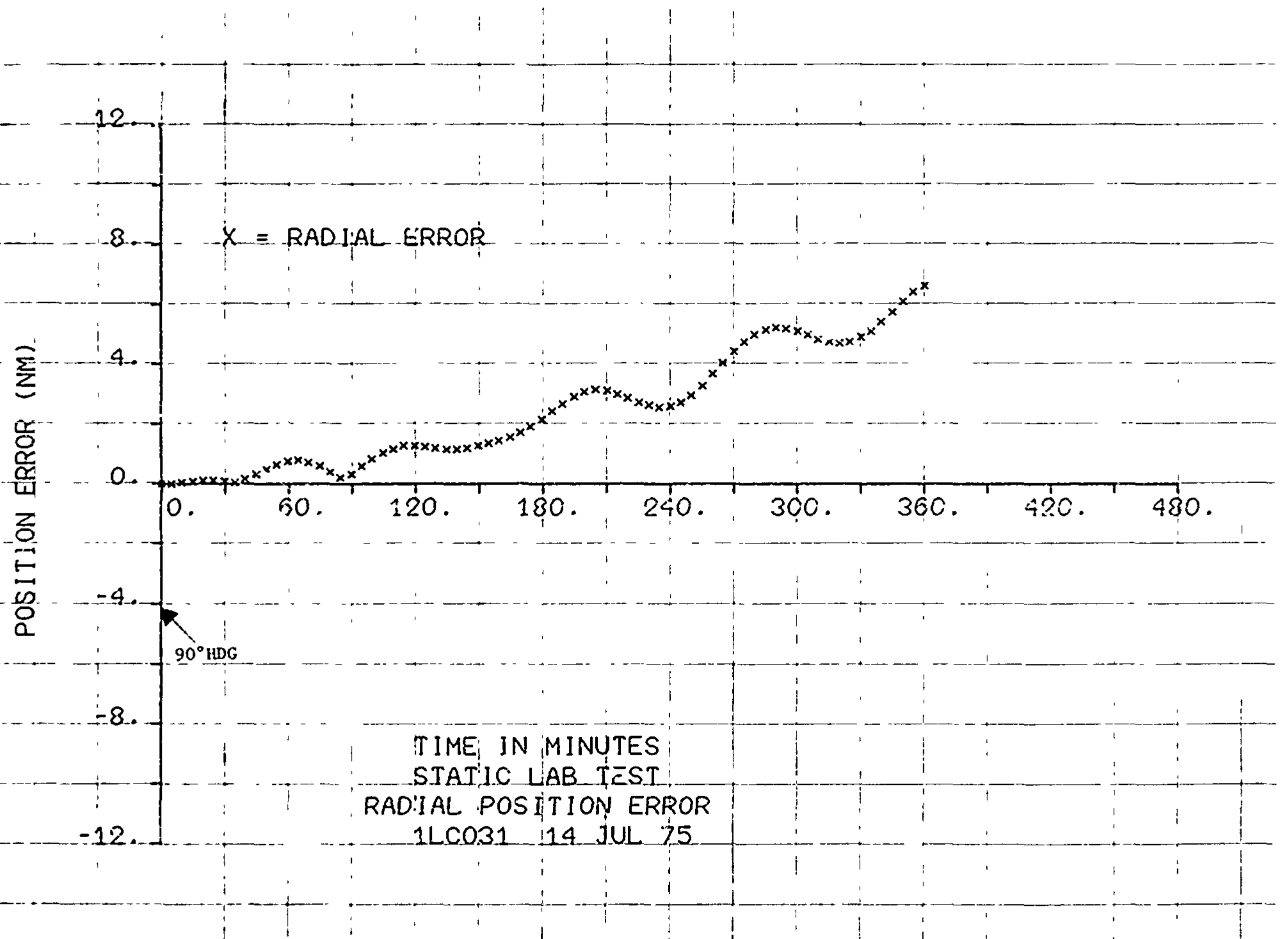
TIME IN MINUTES
HEADING SENSITIVITY LAB TEST
VELOCITY NORTH AND EAST ERROR
1LC030 11 JUL 75

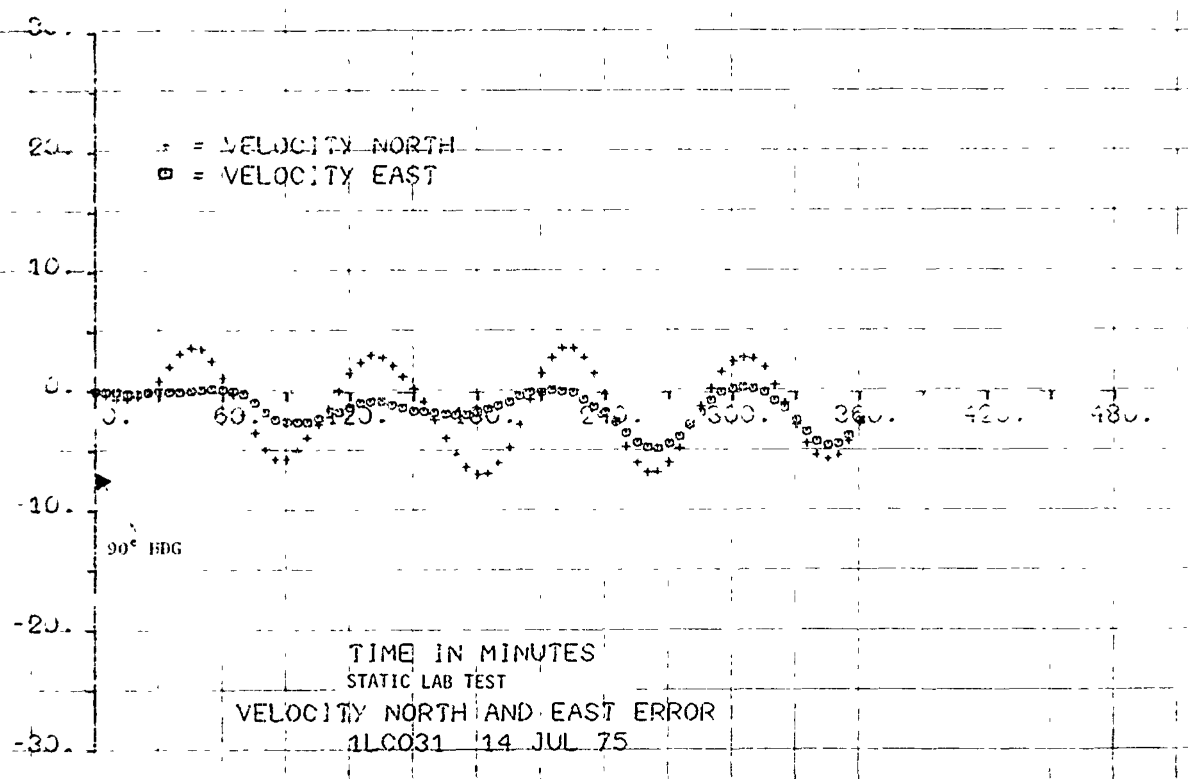


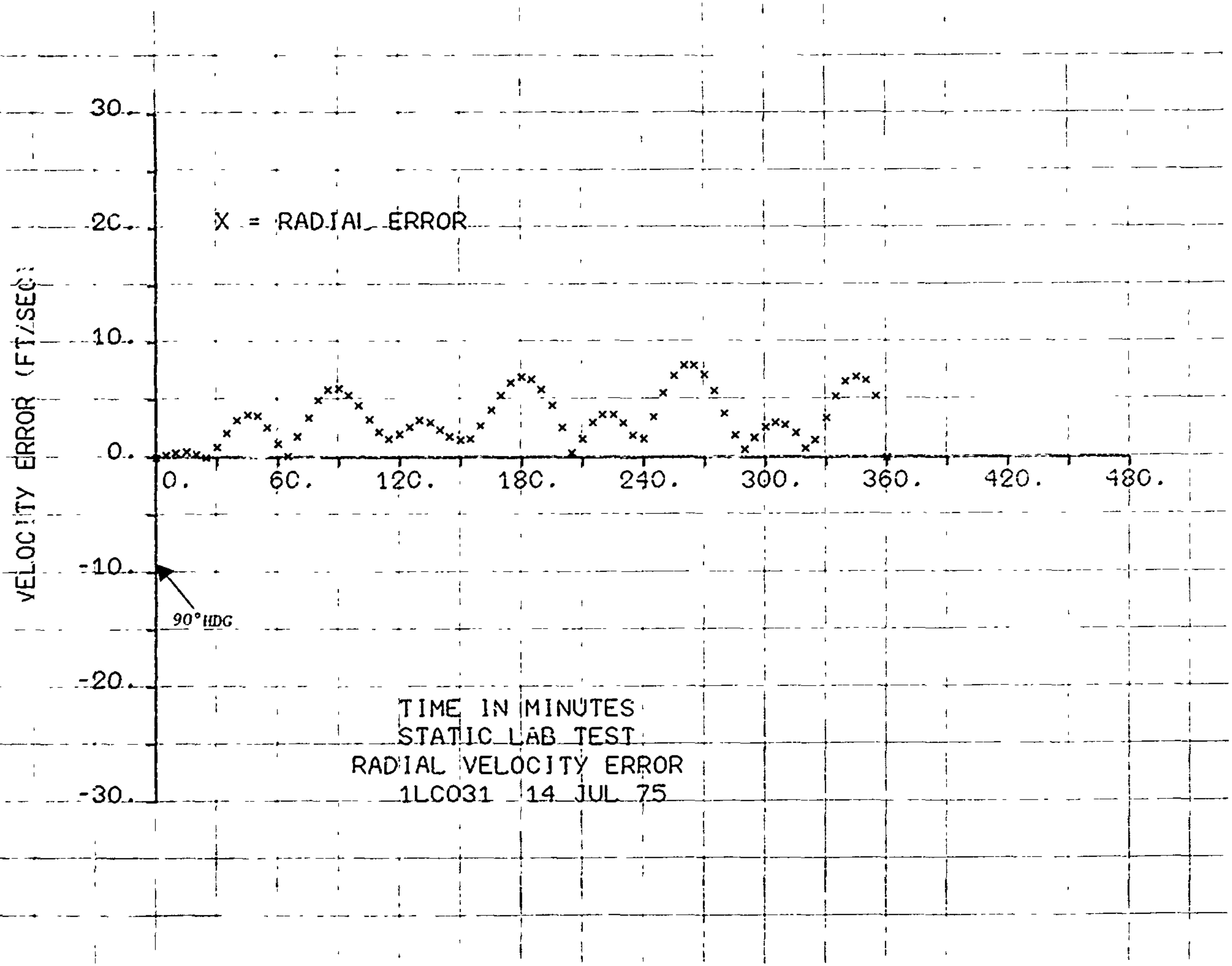
HEADING SENSITIVITY LAB TEST
RADIAL VELOCITY ERROR
1LC020 11 JUL 75

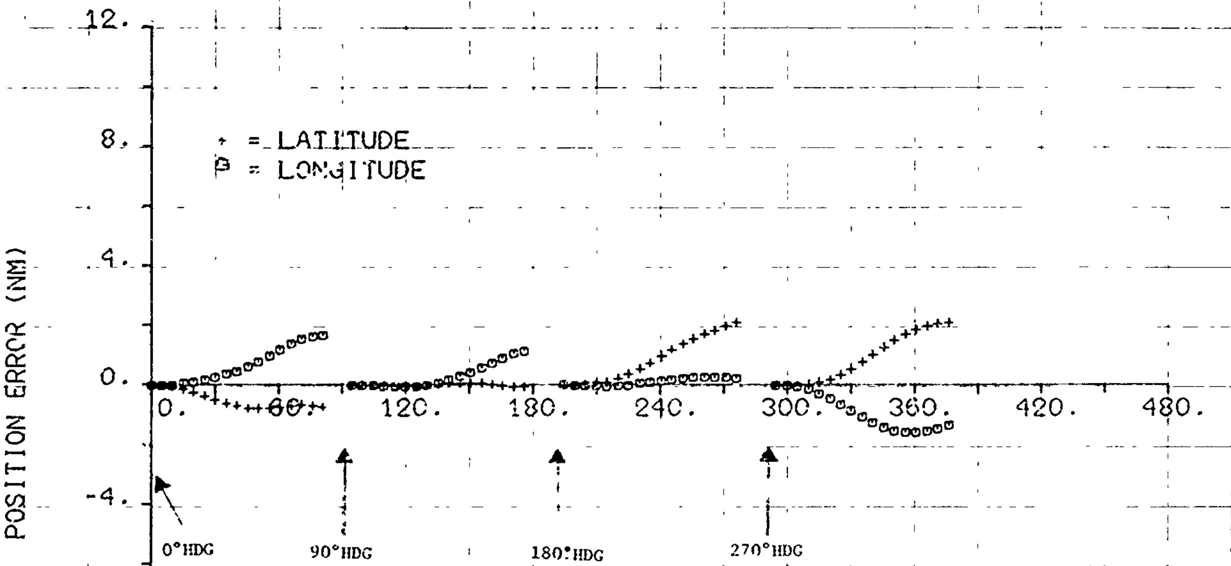


TIME IN MINUTES
STATIC LAB TEST
LATITUDE AND LONGITUDE
POSITION ERROR
1LC031 14 JUL 75

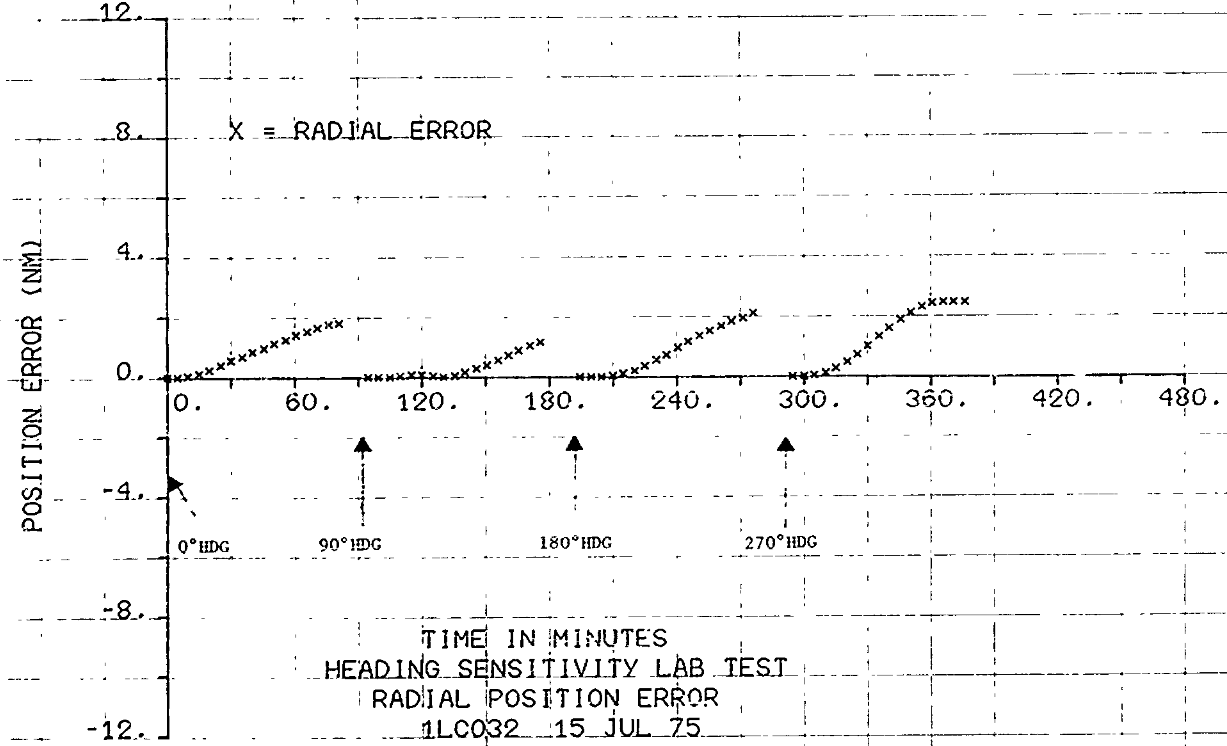

X = RADIAL ERROR
POSITION ERROR (NM)
12.
8.
4.
0.
-4.
-8.
-12.
0.
60.
120.
180.
240.
300.
360.
420.
480.
90°HDG
TIME IN MINUTES
STATIC LAB TEST
RADIAL POSITION ERROR
1LC031 14 JUL 75


+ = VELOCITY NORTH
□ = VELOCITY EAST
20.
10.
0.
-10.
-20.
-30.
0.
60.
120.
180.
240.
300.
360.
90° HDG
TIME IN MINUTES
STATIC LAB TEST
VELOCITY NORTH AND EAST ERROR
1LC031 14 JUL 75

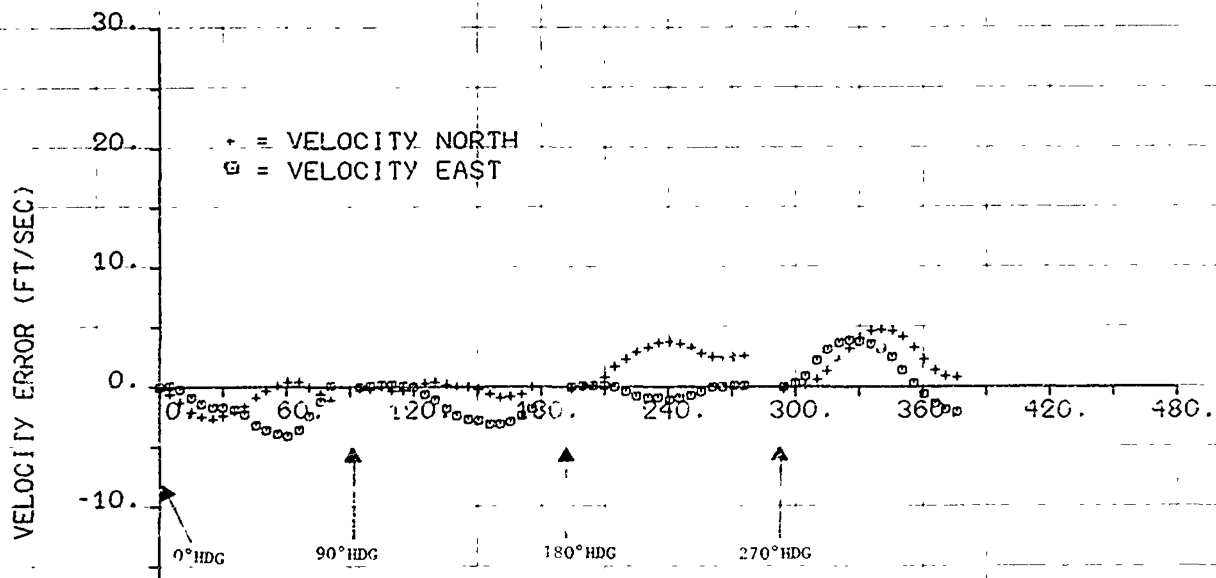

X = RADIAL ERROR
VELOCITY ERROR (FT/SEC)
30.
20.
10.
0.
-10.
-20.
-30.
0.
60.
120.
180.
240.
300.
360.
420.
480.
90° HDG
TIME IN MINUTES
STATIC LAB TEST
RADIAL VELOCITY ERROR
1LC031 14 JUL 75



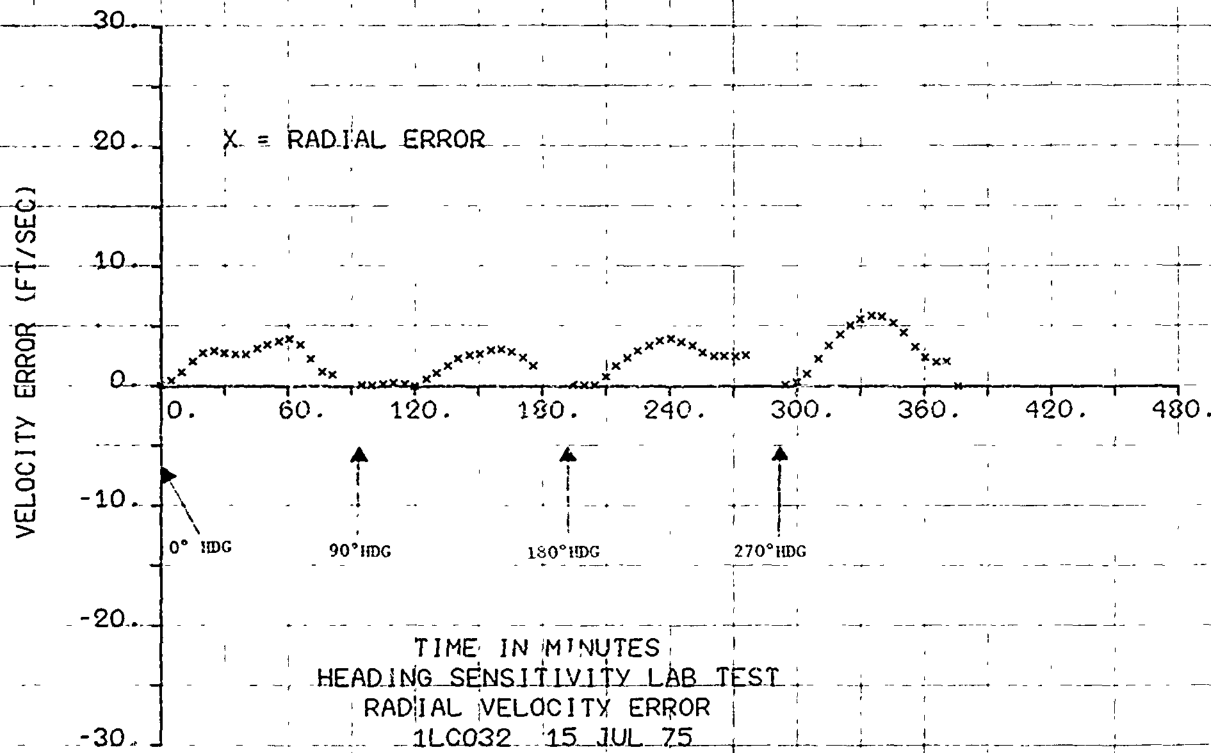
TIME IN MINUTES
HEADING SENSITIVITY LAB TEST
LATITUDE AND LONGITUDE
POSITION ERROR
1LC032 15 JUL 75

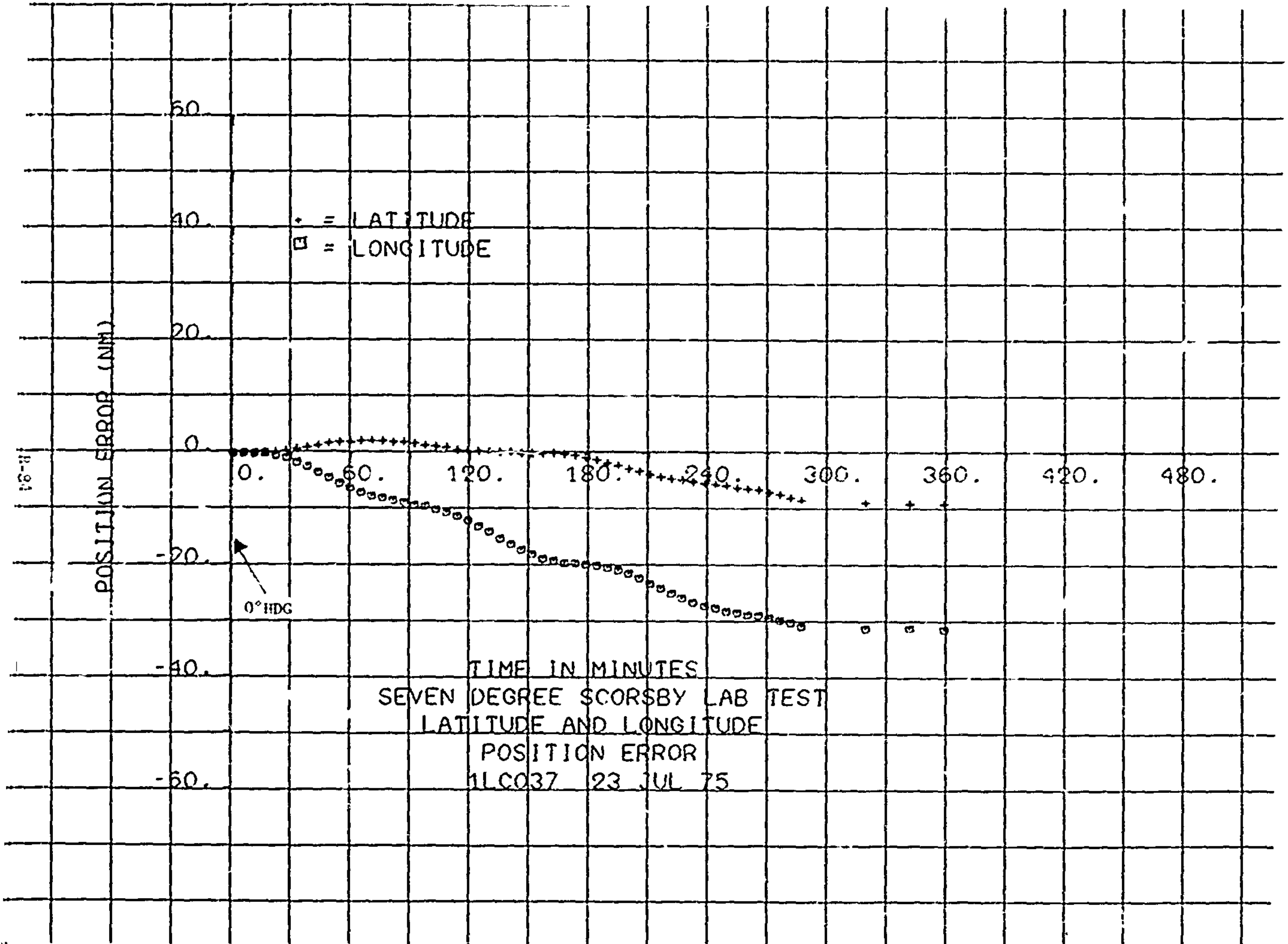


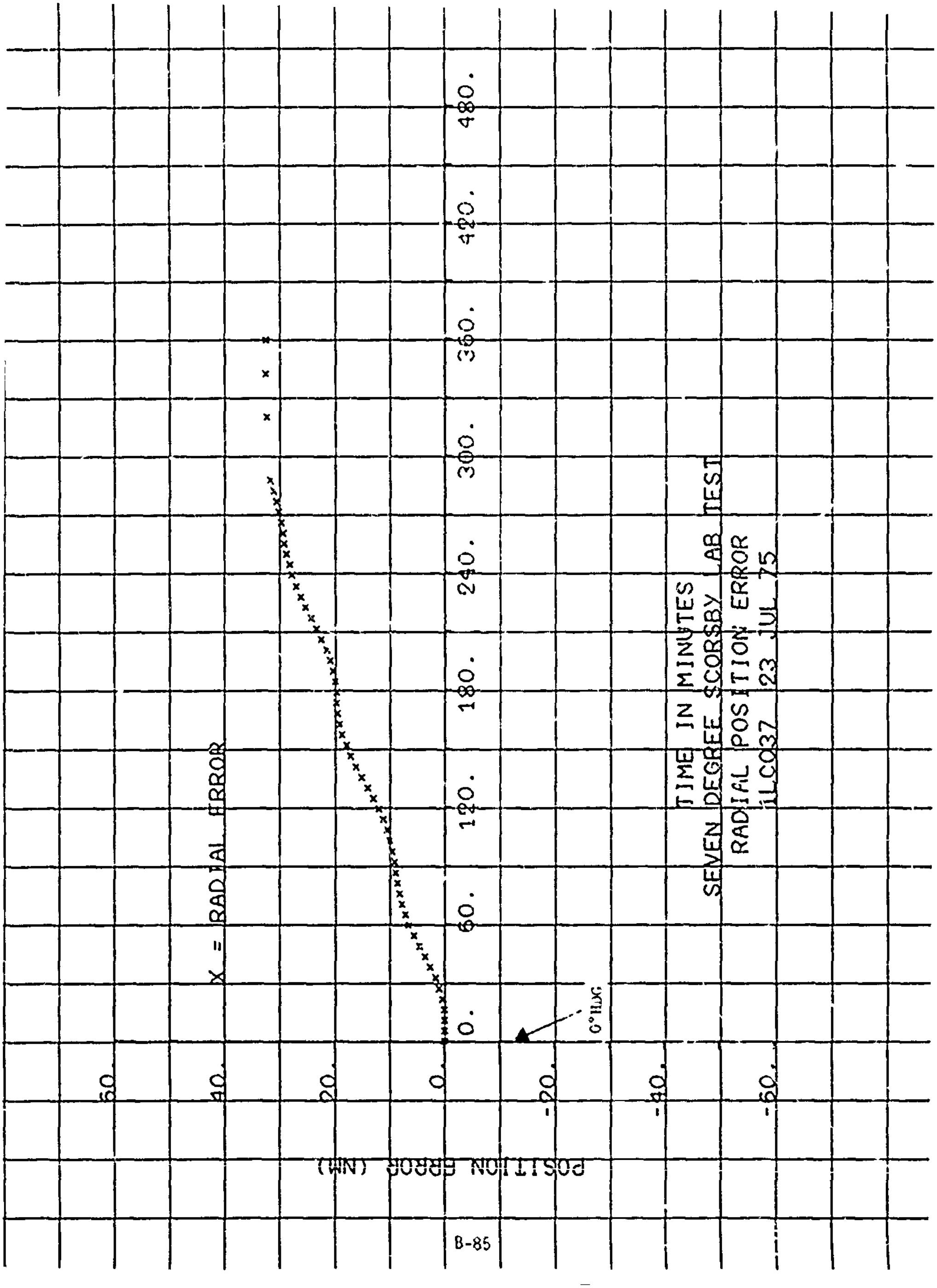
HEADING SENSITIVITY LAB TEST
RADIAL POSITION ERROR
1LC032 15 JUL 75



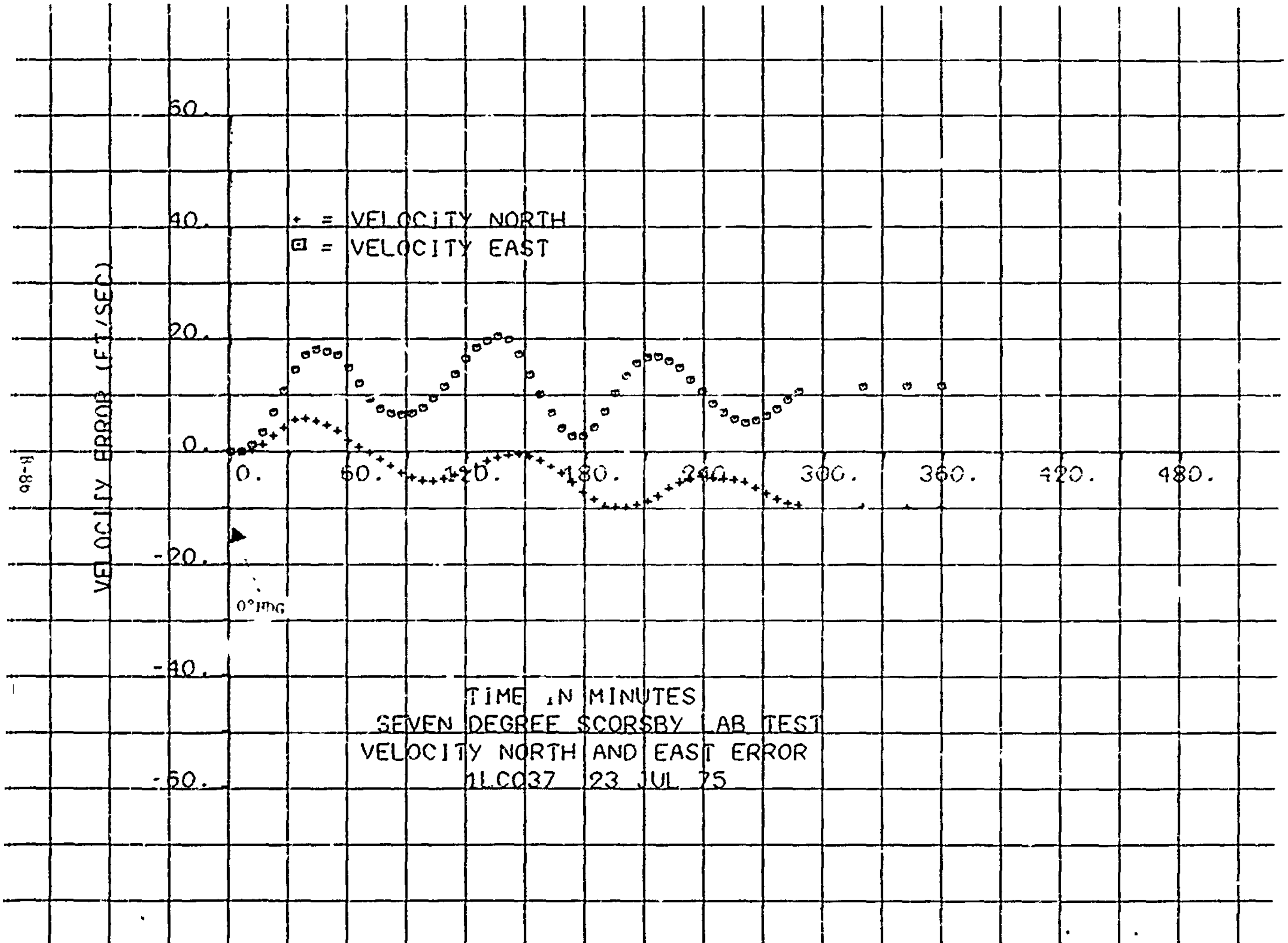
TIME IN MINUTES
HEADING SENSITIVITY LAB TEST
VELOCITY NORTH AND EAST ERROR
1LC032 15 JUL 75


VELOCITY ERROR (FT/SEC)
30.
20.
10.
0.
-10.
-20.
-30.
X = RADIAL ERROR
0.
60.
120.
180.
240.
300.
360.
420.
480.
0° HDG
90° HDG
180° HDG
270° HDG
TIME IN MINUTES
HEADING SENSITIVITY LAB TEST
RADIAL VELOCITY ERROR
1LC032 15 JUL 75

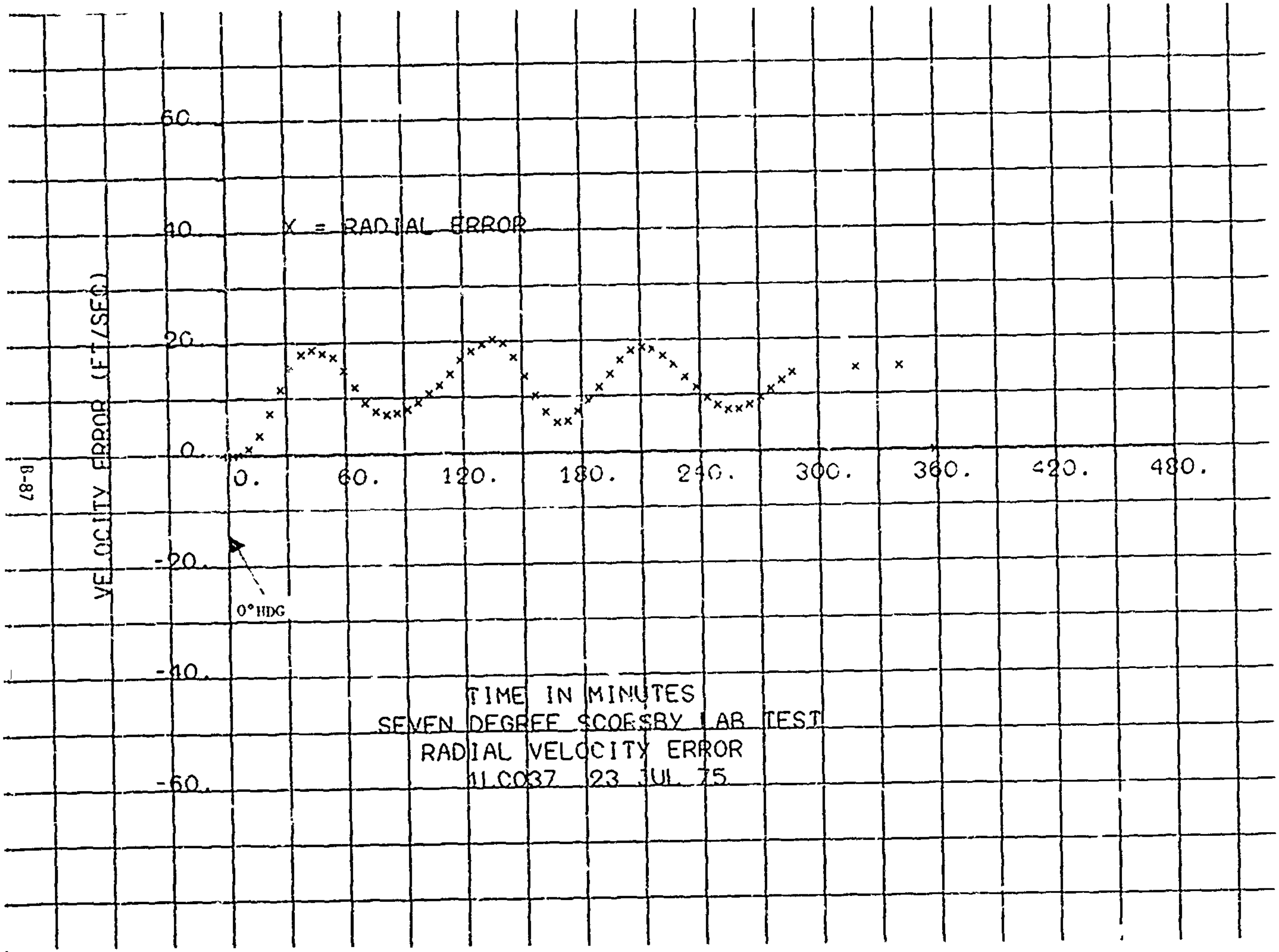

+ = LATITUDE
□ = LONGITUDE
POSITION ERROR (NM)
60.
40.
20.
0.
-20.
-40.
-60.
0.
60.
120.
180.
240.
300.
360.
420.
480.
0° HDG
TIME IN MINUTES
SEVEN DEGREE SCORSBY LAB TEST
LATITUDE AND LONGITUDE
POSITION ERROR
1LC037 23 JUL 75

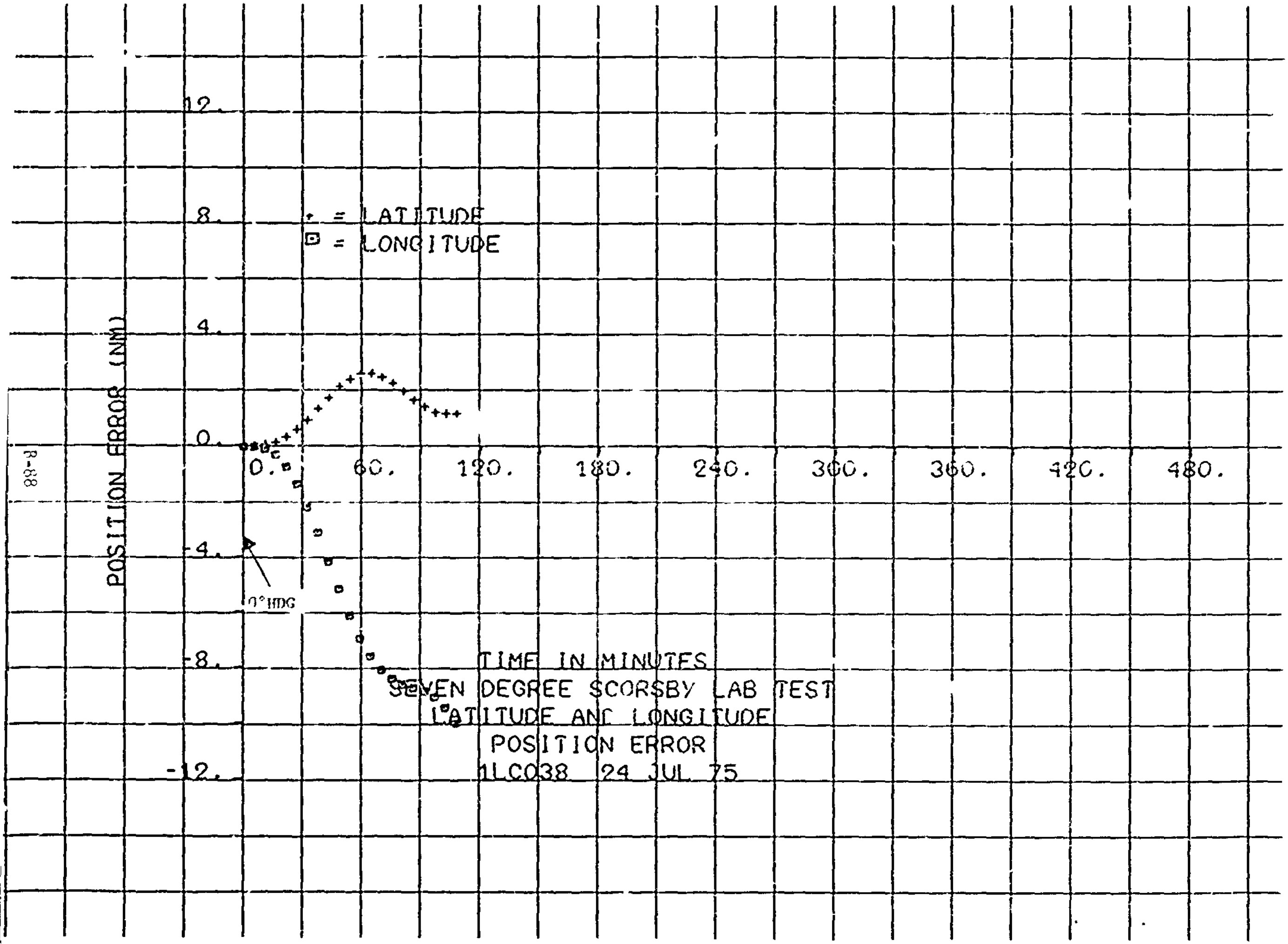


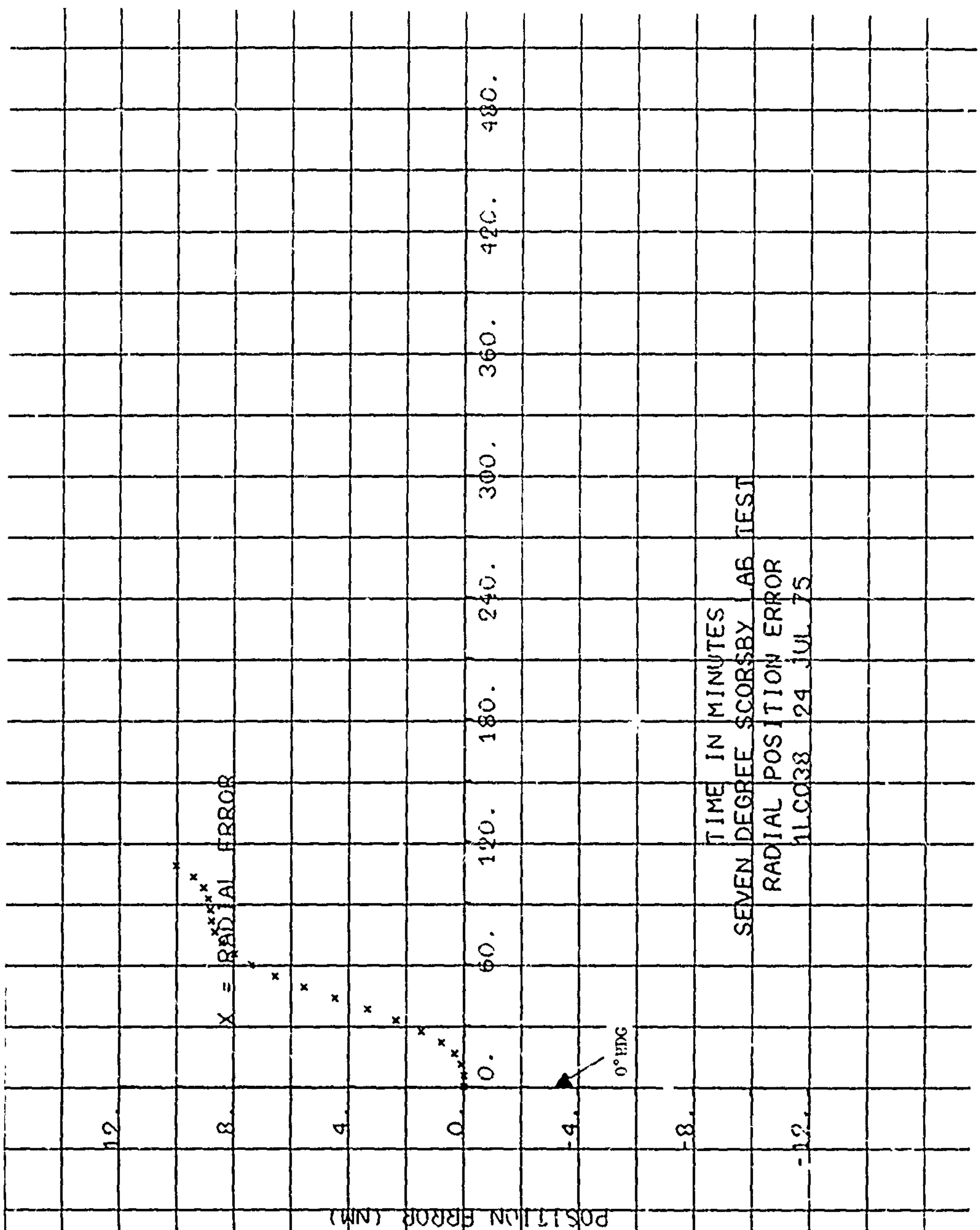
X = RADIAL ERROR
0.
60.
120.
180.
240.
300.
360.
420.
480.
60.
40.
20.
0.
-20.
-40.
-60.
POSITION ERROR (NM)
0°HDG
TIME IN MINUTES
SEVEN DEGREE SCORSBY LAB TEST
RADIAL POSITION ERROR
1LC037 23 JUL 75



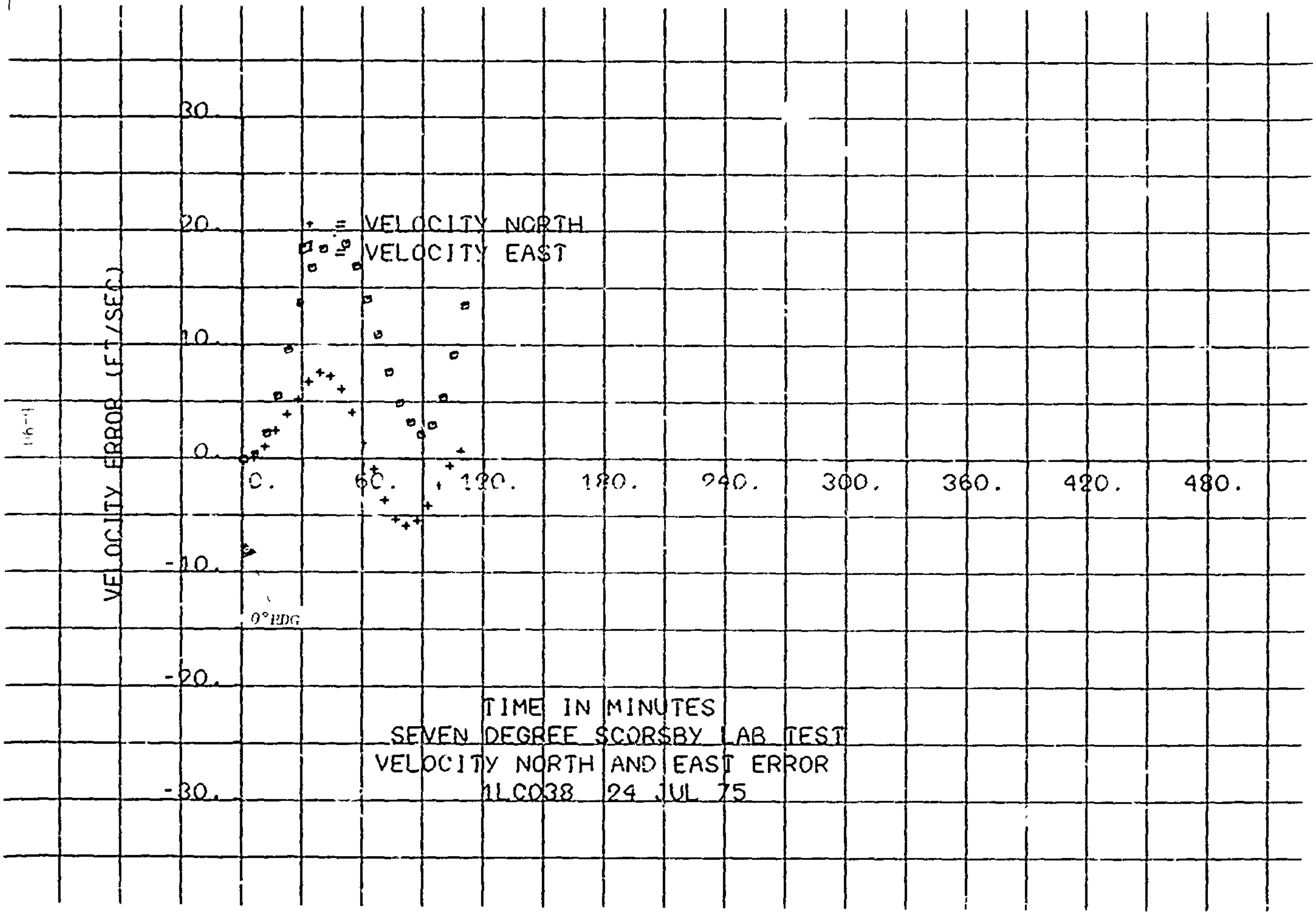
SEVEN DEGREE SCORSBY LAB TEST
VELOCITY NORTH AND EAST ERROR
1LC037 23 JUL 75

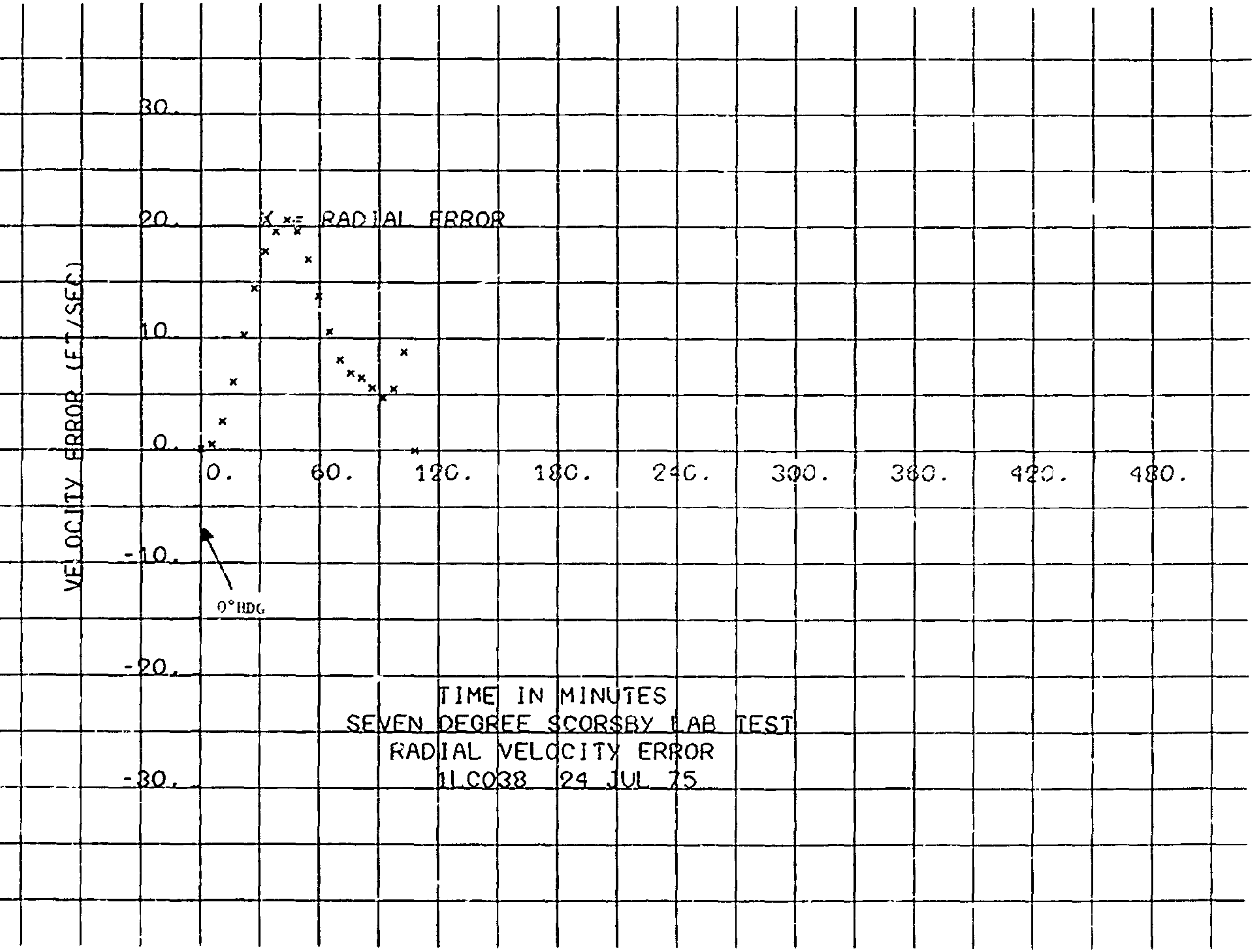

60.
40.
20.
0.
-20.
-40.
-60.
X = RADIAL ERROR
VELOCITY ERROR (FT/SEC)
0. 60. 120. 180. 240. 300. 360. 420. 480.
0° HDG
TIME IN MINUTES
SEVEN DEGREE SCORSBY LAB TEST
RADIAL VELOCITY ERROR
1LC037 23 JUL 75

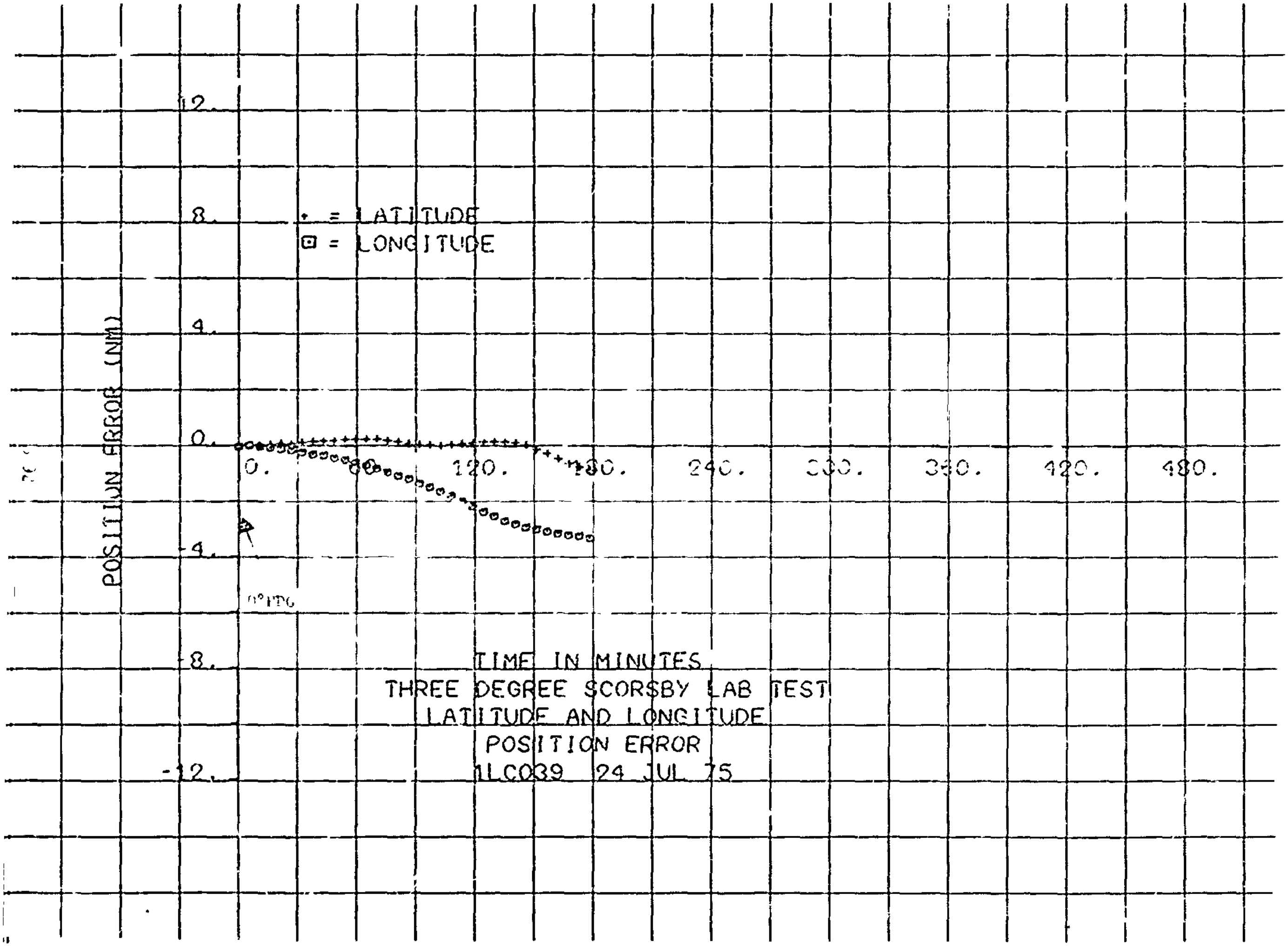

+ = LATITUDE
□ = LONGITUDE
12.
8.
4.
0.
-4.
-8.
-12.
POSITION ERROR (NM)
0.
60.
120.
180.
240.
300.
360.
420.
480.
0° HDG
TIME IN MINUTES
SEVEN DEGREE SCORSBY LAB TEST
LATITUDE AND LONGITUDE
POSITION ERROR
1LC038 24 JUL 75

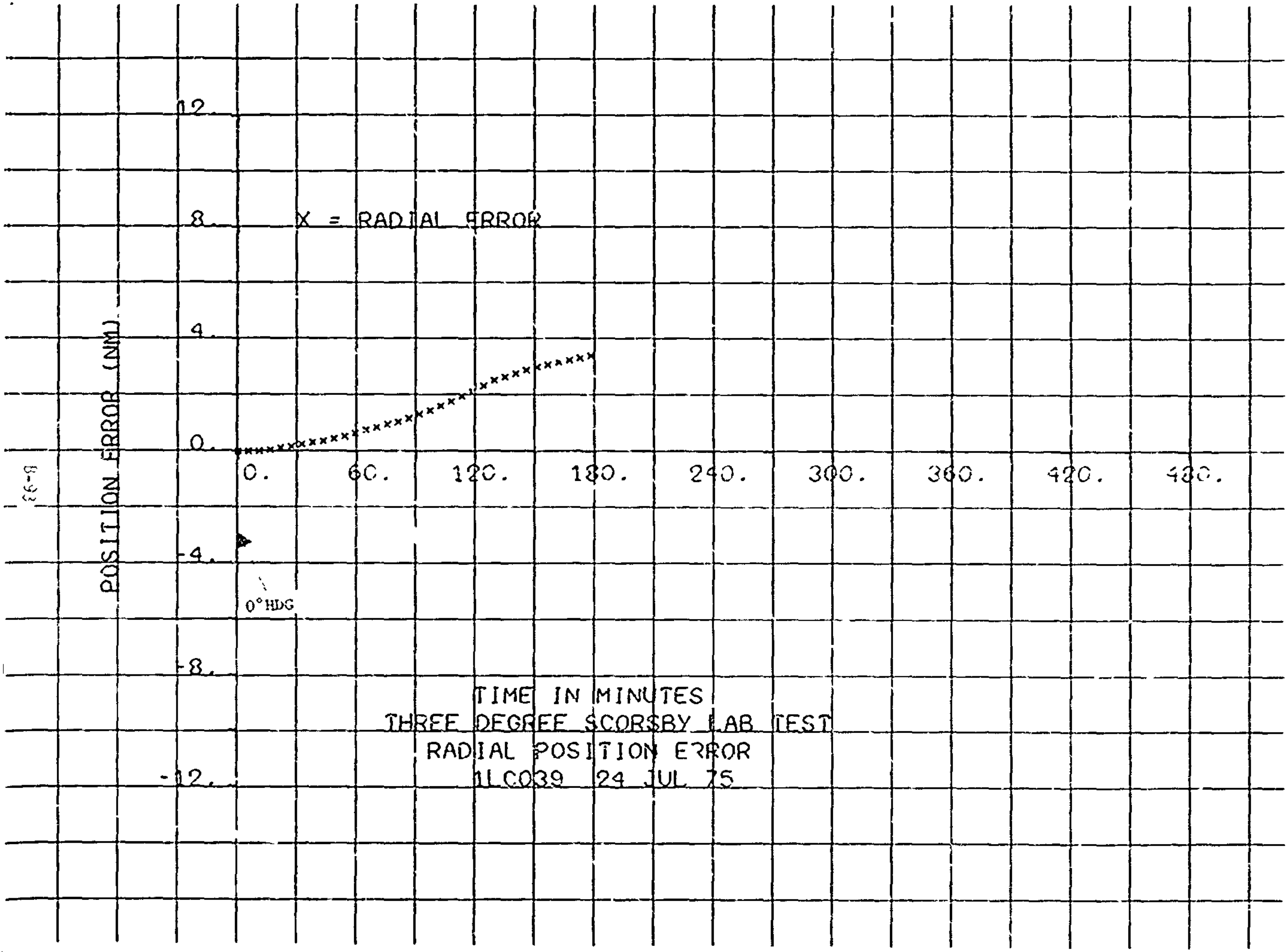


TIME IN MINUTES
SEVEN DEGREE SCORSBY LAB TEST
RADIAL POSITION ERROR
11LC038 24 JUL 75
X = RADIAL ERROR
POSITION ERROR (NM)
0° HDG
0.
60.
120.
180.
240.
300.
360.
420.
480.
12.
8.
4.
0.
-4.
-8.
-12.

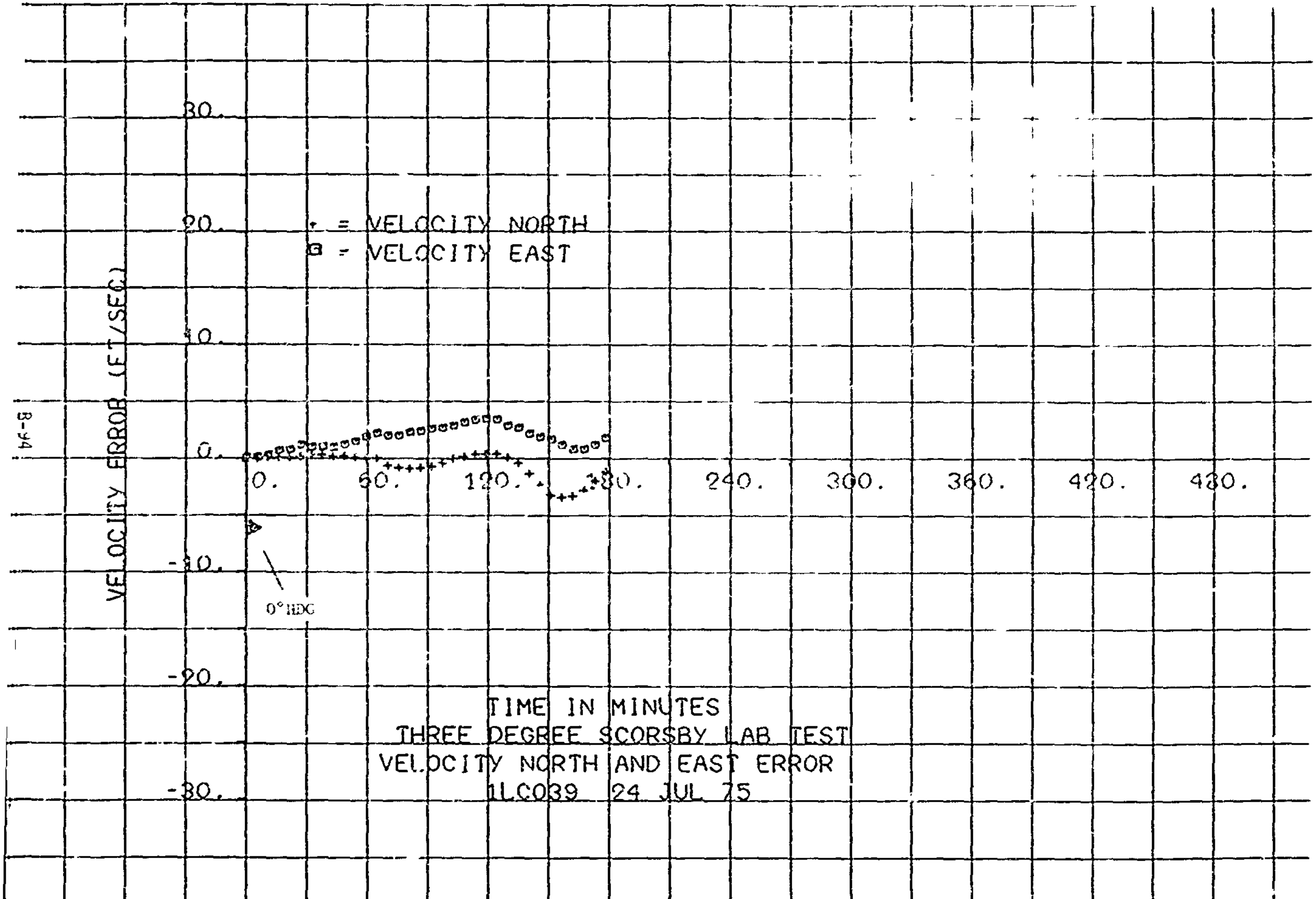

+ = VELOCITY NORTH
□ = VELOCITY EAST
30.
20.
10.
0.
-10.
-20.
-30.
VELOCITY ERROR (FT/SEC)
0.
60.
120.
180.
240.
300.
360.
420.
480.
0° HDG
TIME IN MINUTES
SEVEN DEGREE SCORSBY LAB TEST
VELOCITY NORTH AND EAST ERROR
1LC038 24 JUL 75

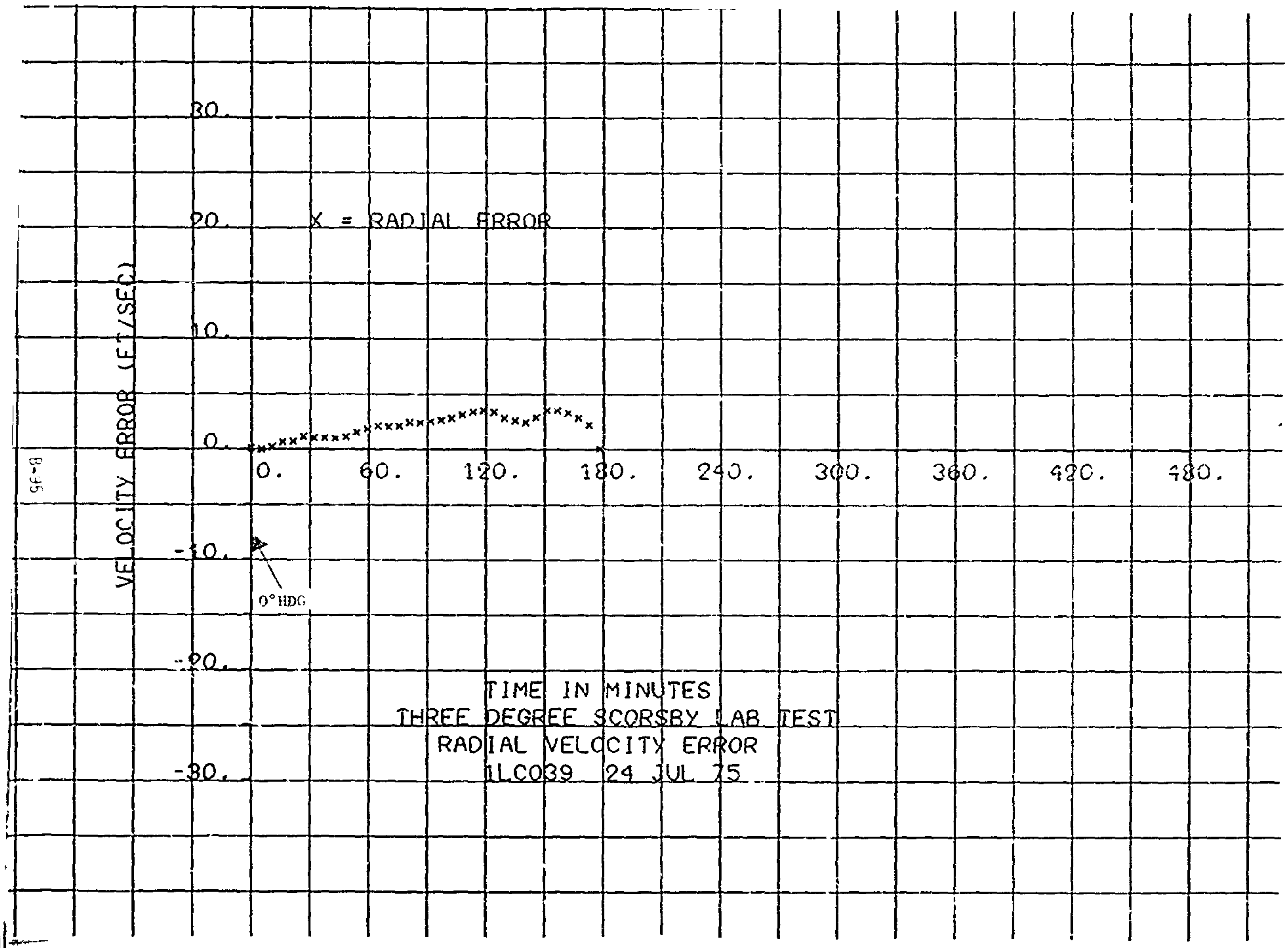

X = RADIAL ERROR
VELOCITY ERROR (FT/SEC)
30.
20.
10.
0.
-10.
-20.
-30.
0.
60.
120.
180.
240.
300.
360.
420.
480.
0° HDG
TIME IN MINUTES
SEVEN DEGREE SCORSBY LAB TEST
RADIAL VELOCITY ERROR
1LC038 24 JUL 75


+ = LATITUDE
⊡ = LONGITUDE
POSITION ERROR (NM)
12.
8.
4.
0.
-4.
-8.
-12.
0.
60.
120.
180.
240.
360.
420.
480.
0° HDG
TIME IN MINUTES
THREE DEGREE SCORSBY LAB TEST
LATITUDE AND LONGITUDE
POSITION ERROR
1LC039 24 JUL 75



THREE DEGREE SCORSBY LAB TEST
RADIAL POSITION ERROR
1LC039 24 JUL 75


30.
20.
10.
0.
-10.
-20.
-30.
+ = VELOCITY NORTH
⊡ = VELOCITY EAST
VELOCITY ERROR (FT/SEC)
0.
60.
120.
180.
240.
300.
360.
420.
480.
0° HDG
TIME IN MINUTES
THREE DEGREE SCORSBY LAB TEST
VELOCITY NORTH AND EAST ERROR
1LC039 24 JUL 75



THREE DEGREE SCORSBY LAB TEST
RADIAL VELOCITY ERROR
1LC039 24 JUL 75

2. NC-141A CARGO AIRCRAFT TEST RECORDS

2.1 Test History

There were seven basic flight profiles used during flight testing. They were west/east/north/south/north/south, north/south, west/north/south/east, west/east, north/west/east/west/east/south, northwest/north, and southeast/east. The flight profiles staged from Holloman AFB, New Mexico included the west/north south/east, (1C010 and 1C012), the north/south, (1C008 and 1C011) and the northeast/north (1C013) profiles. All north/south legs were 84 minutes. The west/east legs of the west/north/south/east profile were approximately 130 minutes. The northwest/north profile was the sortie from Holloman AFB to Elmendorf AFB, Alaska. The northwest leg was approximately seven hours and the north leg approximately two hours. While at Elmendorf three sorties were flown using north/south (1C015 and 1C016) and north/west/east/west/east/south (1C017) profiles. The two north/south flights had 84 minute legs. The third profile, flown from Elmendorf, was quite varied with a north leg of 28 minutes, a west leg of 106 minutes, an east leg of 115 minutes, a west leg of 76 minutes, an east leg of 39 minutes, and a south leg of 44 minutes. Four sorties were staged from Eielson AFB, Alaska. Two (1C018 and 1C019) used a west/east flight profile of 84 minutes per leg. The third flight (1C020) consisted of a west leg of 36 minutes, an east leg of 30 minutes, a north leg of 87 minutes, a south leg of 96 minutes, a north leg of 80 minutes and a south leg of 82 minutes. The final sortie (1C021) from Eielson was the return to Holloman AFB, NM. Due to a digital recorder malfunction no data was recorded for test 1C021; hence only quick look data is included. The general flight path was southwest from

Eielson to Kodiak Island, south overwater to Los Angeles, and east to Holloman. There was one sortie (1C022) flown on White Sands Missile Range after return from Alaska. This sortie relied on the Completely Integrated Reference Instrumentation System (CIRIS) as a reference. After the flight it was determined that CIRIS was inoperative; hence no performance results are presented for Test 1C022. The flight altitude was quite variable throughout the flight testing, ranging from 5000 to 36000 feet (MSL). Reaction times used for the flight tests were 20 minutes.

2.2 System Performance and Analysis Results (Flight Tests)

A total of thirteen flights were made between 14 May 1975 through 27 June 1975. Of these, eleven were used for data analysis. Each test provided from 4.0 to 10.25 hours of system data in the navigation mode.

Table B-III presents individual test results of the eleven NC-141A/776 cargo flight tests used in the analysis, as well as pertinent test parameters. See paragraph 3.5, Appendix A, for definition of position error rate.

Table B-IV presents the radial position error CEP rates, R50 rates and R90 rates for the ensemble of 11 flight tests that were analyzed as a group and are listed in Table B-III. Table B-IV also presents the radial velocity error R50 and R90 rates with Y-intercept for the 11 tests.

TABLE B-III

NC-141A/776 CARGO FLIGHT INDIVIDUAL TEST RESULTS

DATE	FLIGHT PATH DIRECTIONS	TEST LABEL	INITIAL ALIGNMENT HEADING (DEGREE)	NAV TIME (HRS)	RADIAL POSITION ERROR RATES (NM/HR)
14 MAY 75	N/S	1C008	0	4.2	0.71
3 JUN 75	W/N/S/E	1C010	0	7.7	0.47
6 JUN 75	N/S	1C011	0	4.2	0.35
10 JUN 75	W/N/S/E	1C012	0	8.1	0.50
12 JUN 75	N/W/N	1C013	0	10.6	0.89
15 JUN 75	N/S	1C015	90	4.3	2.00
16 JUN 75	N/S	1C016	90	4.7	1.38
20 JUN 75	N/W/E/W/E/S	1C017	0	8.1	0.55
21 JUN 75	W/E	1C018	0	4.4	0.49
22 JUN 75	W/E	1C019	0	3.9	0.77
23 JUN 75	W/E/N/S/N/S	1C020	0	8.4	0.51

TABLE B-IV

FLIGHT TEST ENSEMBLE PERFORMANCE VALUES

TOTAL FLIGHT TESTS	RADIAL POSITION ERROR RATES (NM PER HR)			RADIAL VELOCITY ERROR RATES, Y-INTERCEPT (FPS PER HR, FPS)	
	CEP RATE	R50 RATE	R90 RATE	R50	R90
11	0.89	0.82	1.62	1.86, 2.93	2.66,7.12

NOTES: (1) Radial position error is the root sum square of the latitude and longitude position errors.

(2) Radial velocity error is the root sum square of the north-south and east-west velocity errors derived from the latitude and longitude position errors.

(3) Refer to Appendix A for analysis techniques and to Paragraphs 3.3 and 3.4, Appendix A, for definitions of performance values in Table IV above.

(4) Only those CEP, R50 and R90 values for the first 240 minutes of the 11 flight test ensemble were used in calculating CEP, R50 and R90 rates. This is the approximate point in time where the confidence in these values breaks down due to the rapid decrease in the number of flights that produced performance data beyond that time.

Plots of the R90, R50, CEP, mean and median of the radial position errors for the 11 flight test ensemble are shown in Figures 7 and 8 in the main body of this report.

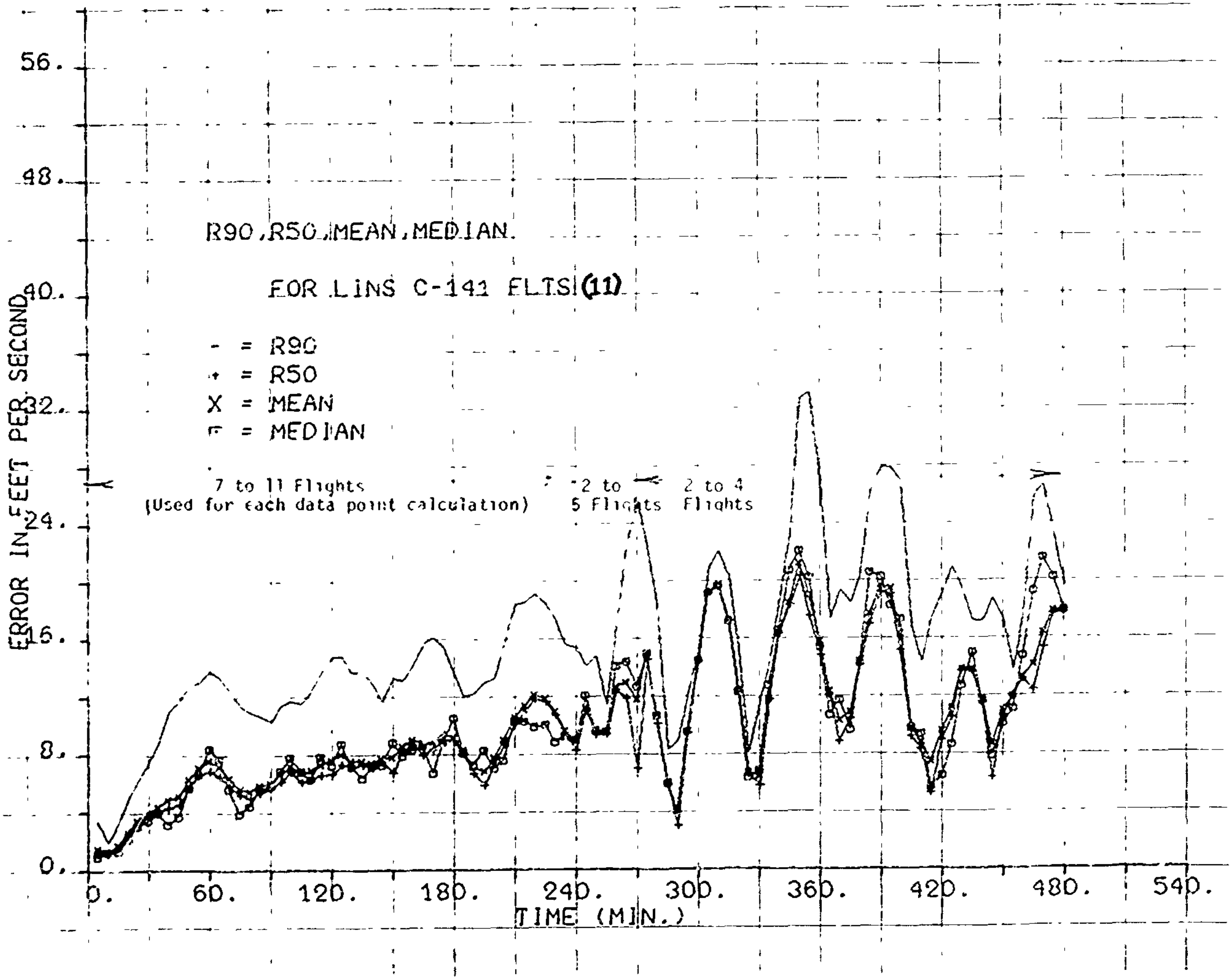
Pages B-101 and B-102 contain plots of the R90, R50, CEP, mean and median of the radial velocity error distribution for the 11 flight test ensemble.

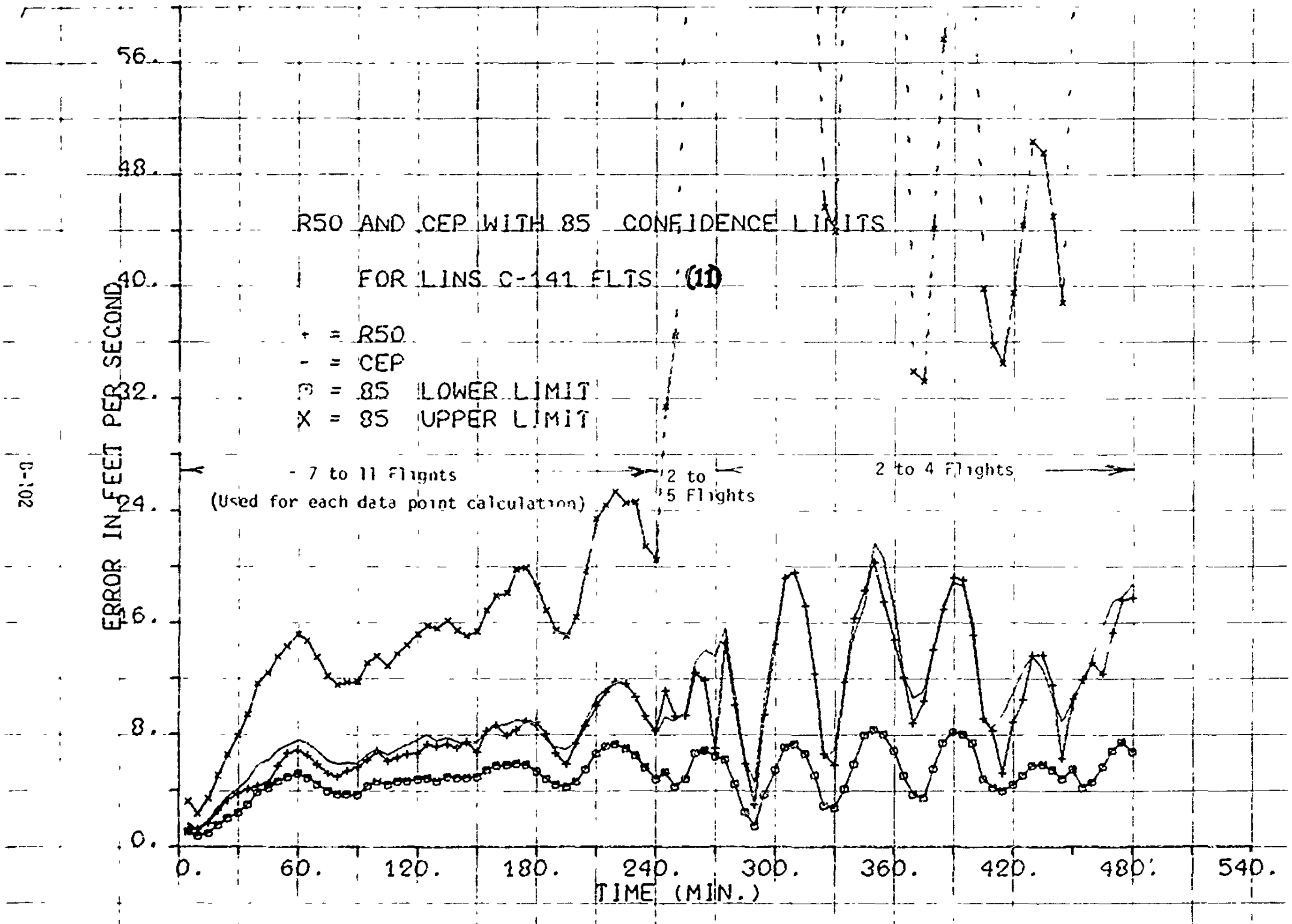
Pages B-103 through B-108 contain composite plots of smoothed position, velocity and radial errors for the 11 flight test ensemble.

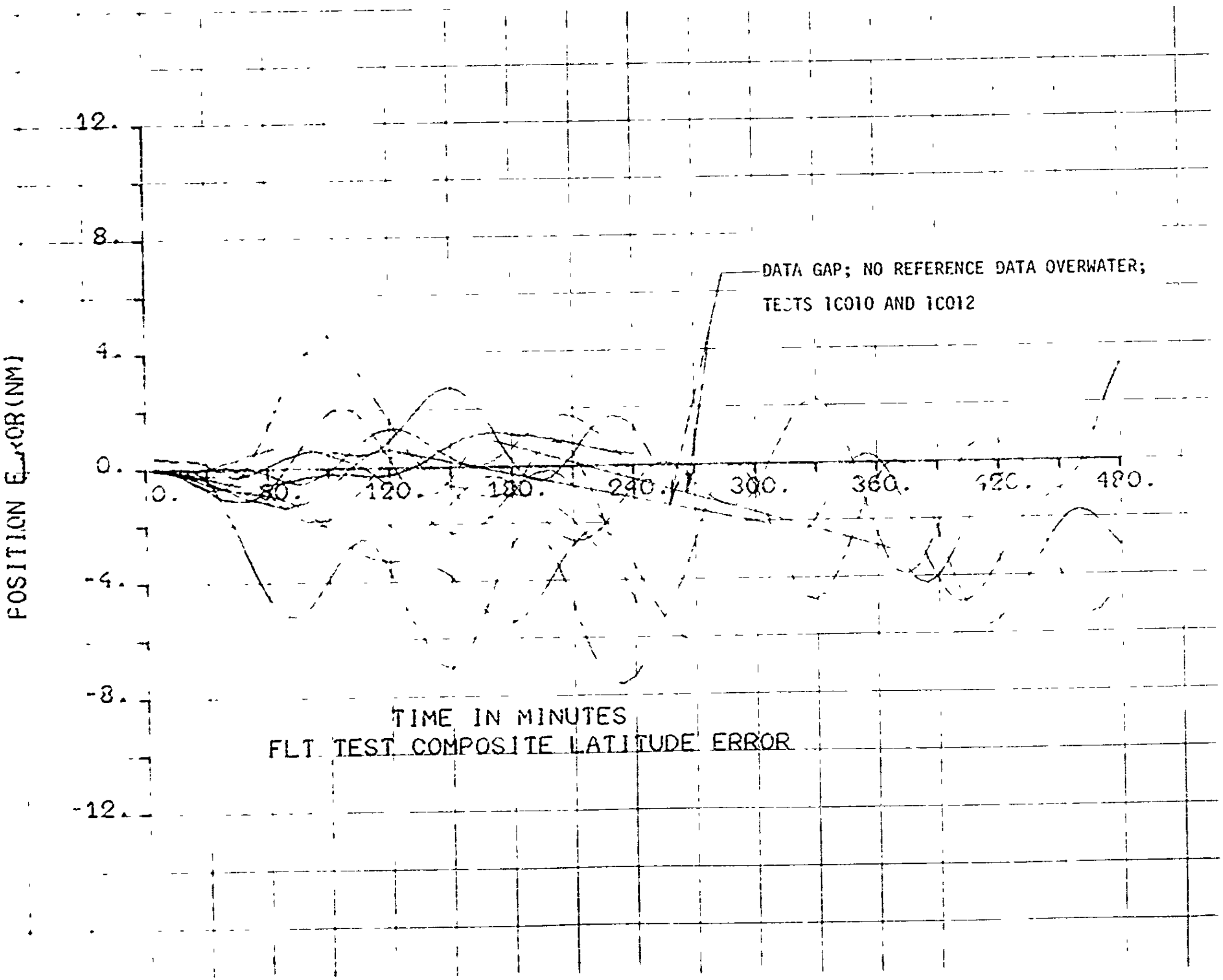
Pages B-109 through B-152 contain the individual unsmoothed latitude/longitude position and smoothed north/east velocity* error plots and the individual unsmoothed radial position and smoothed radial velocity error plots for the 11 flight tests.

Page B-153 contains plots of the quick-look latitude/longitude position errors for flight test 1C021 during which the digital recorder malfunctioned. These plots were made from data recorded manually as the aircraft overflew the ground checkpoints. This data was not used in the performance analysis.

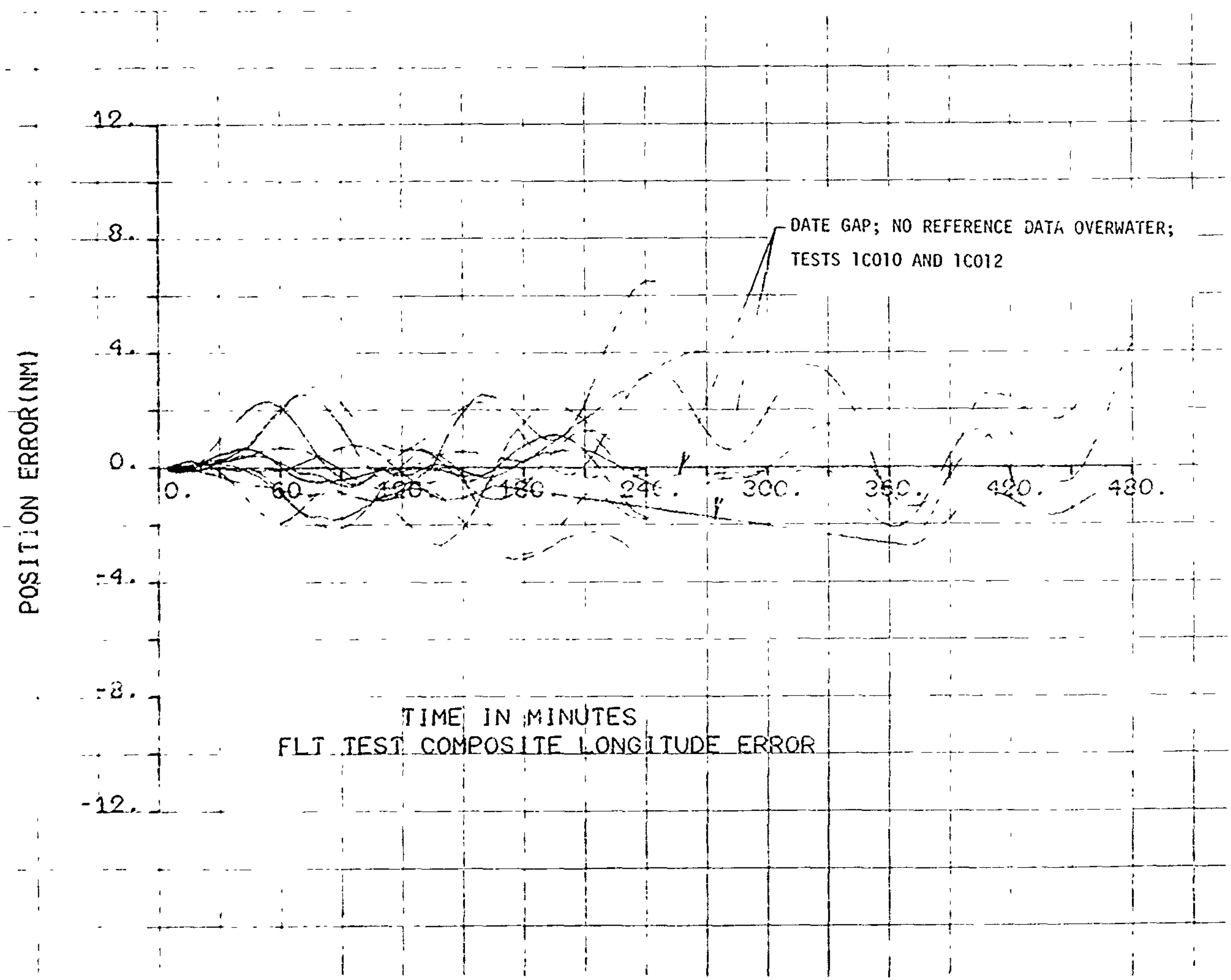
Velocity errors for flight tests were derived from position errors (See Appendix A).


R90, R50, MEAN, MEDIAN.
FOR LINS C-141 FLTS (11)
- = R90
+ = R50
X = MEAN
⌐ = MEDIAN
7 to 11 Flights
(Used for each data point calculation)
2 to 5 Flights
2 to 4 Flights
ERROR IN FEET PER SECOND
56.
48.
40.
32.
24.
16.
8.
0.
0.
60.
120.
180.
240.
300.
360.
420.
480.
540.
TIME (MIN.)

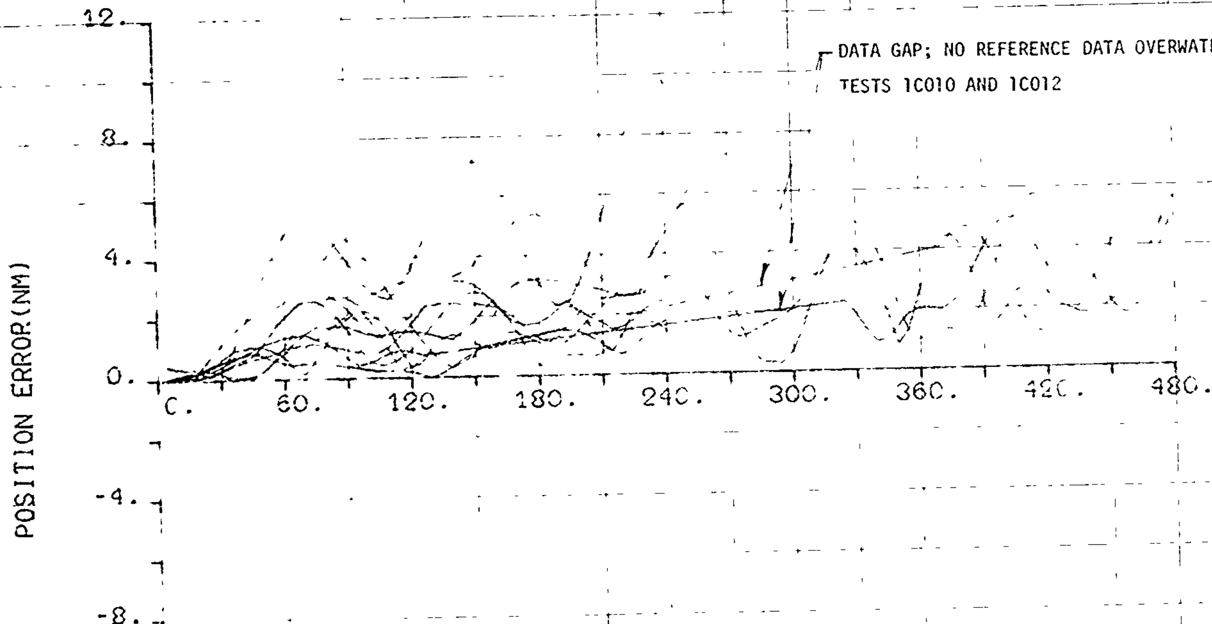

R50 AND CEP WITH 85 CONFIDENCE LIMITS
FOR LINS C-141 FLTS (11)
+ = R50
- = CEP
⊡ = 85 LOWER LIMIT
X = 85 UPPER LIMIT
7 to 11 Flights
(Used for each data point calculation)
2 to 5 Flights
2 to 4 Flights
ERROR IN FEET PER SECOND
TIME (MIN.)
0.
8.
16.
24.
32.
40.
48.
56.
0.
60.
120.
180.
240.
300.
360.
420.
480.
540.



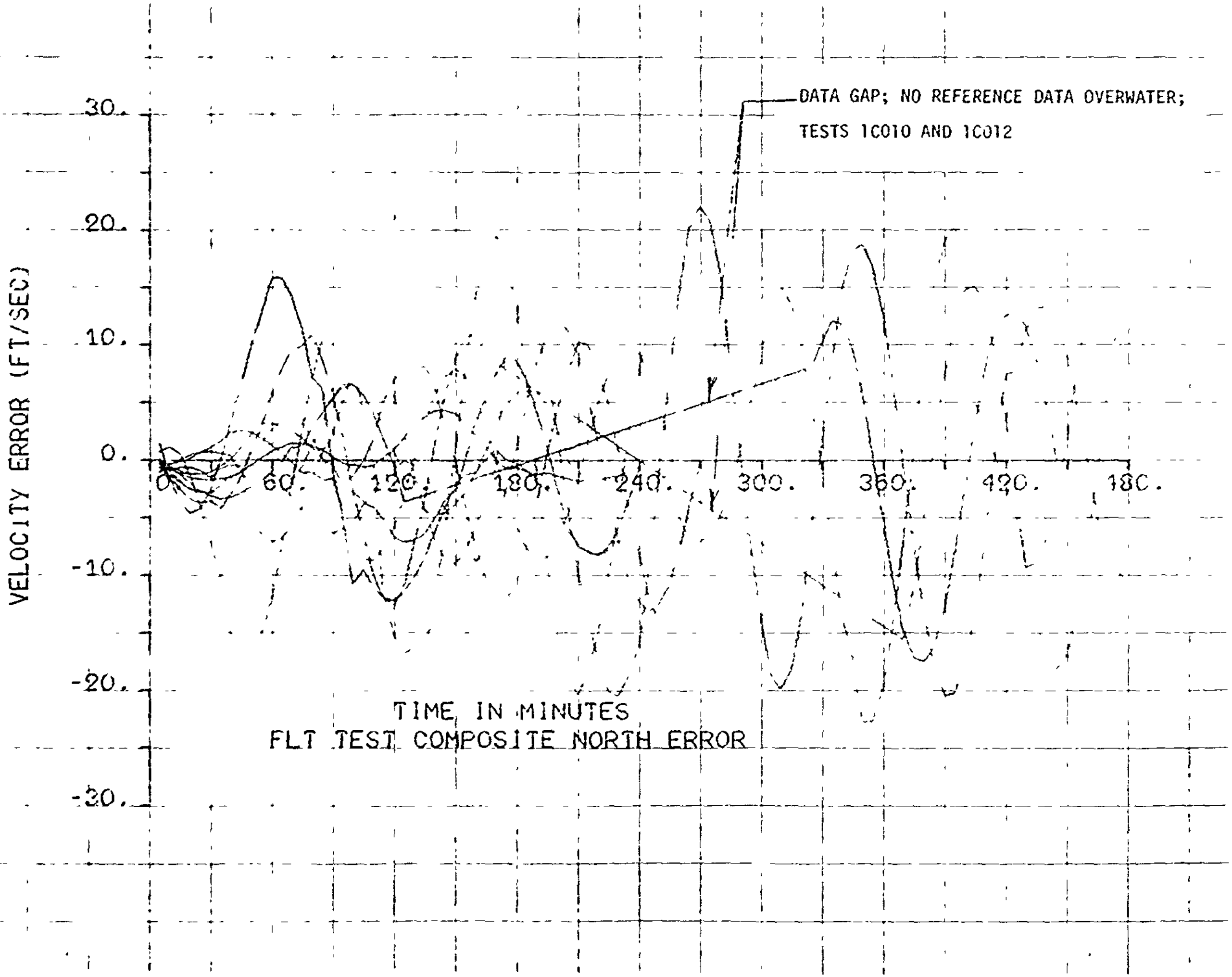
FLT TEST COMPOSITE LATITUDE ERROR



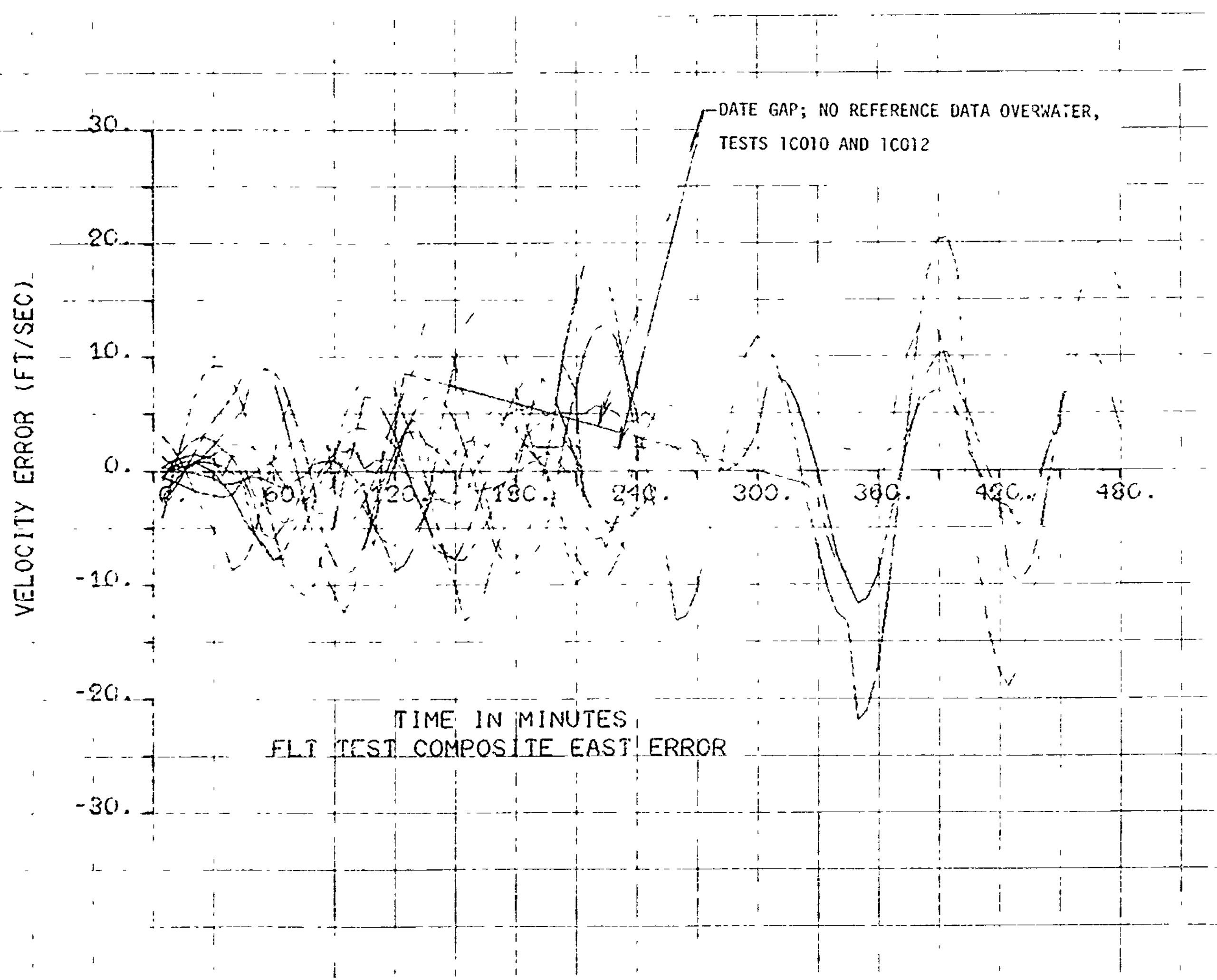
FLT TEST COMPOSITE LONGITUDE ERROR



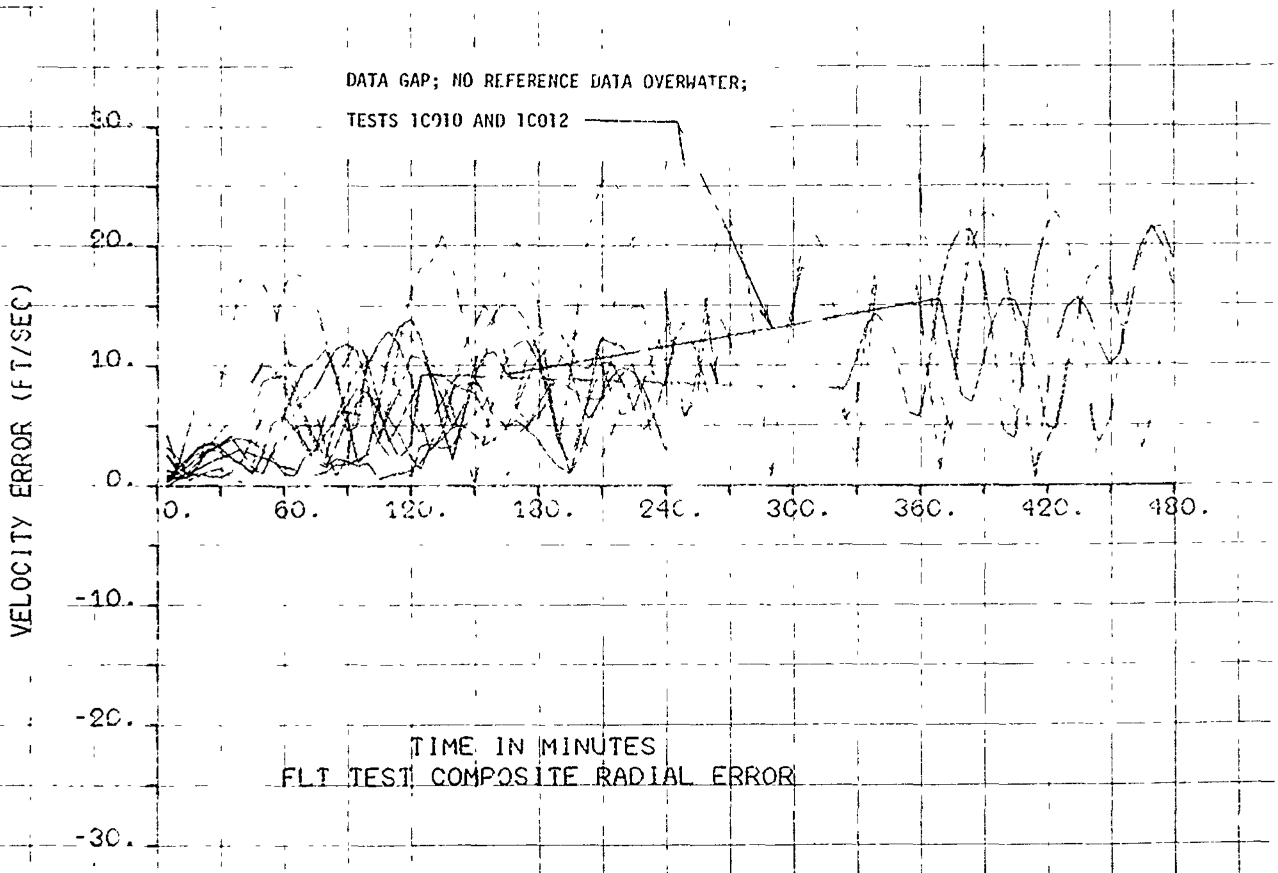
FLT TEST COMPOSITE RADIAL ERROR

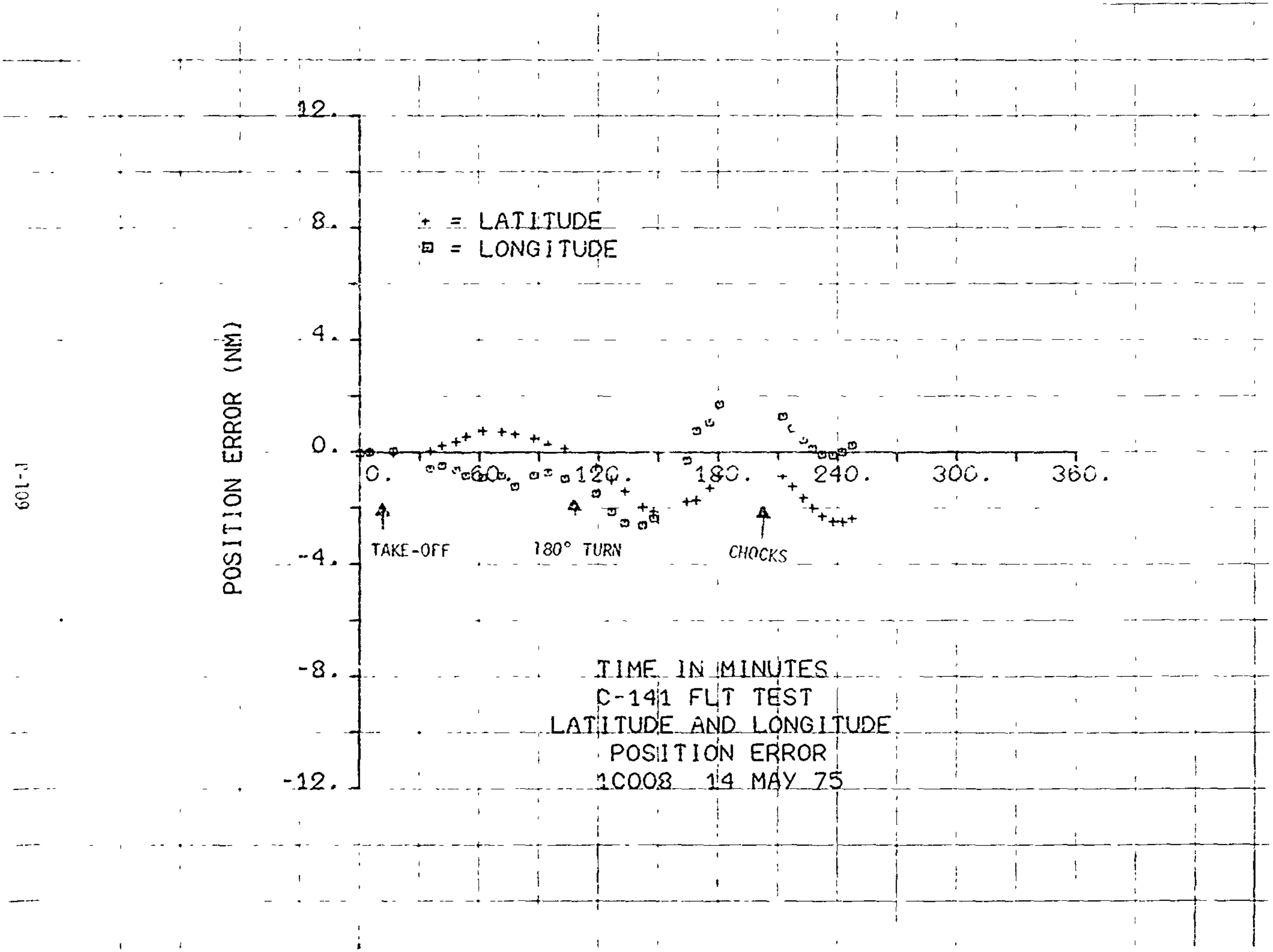


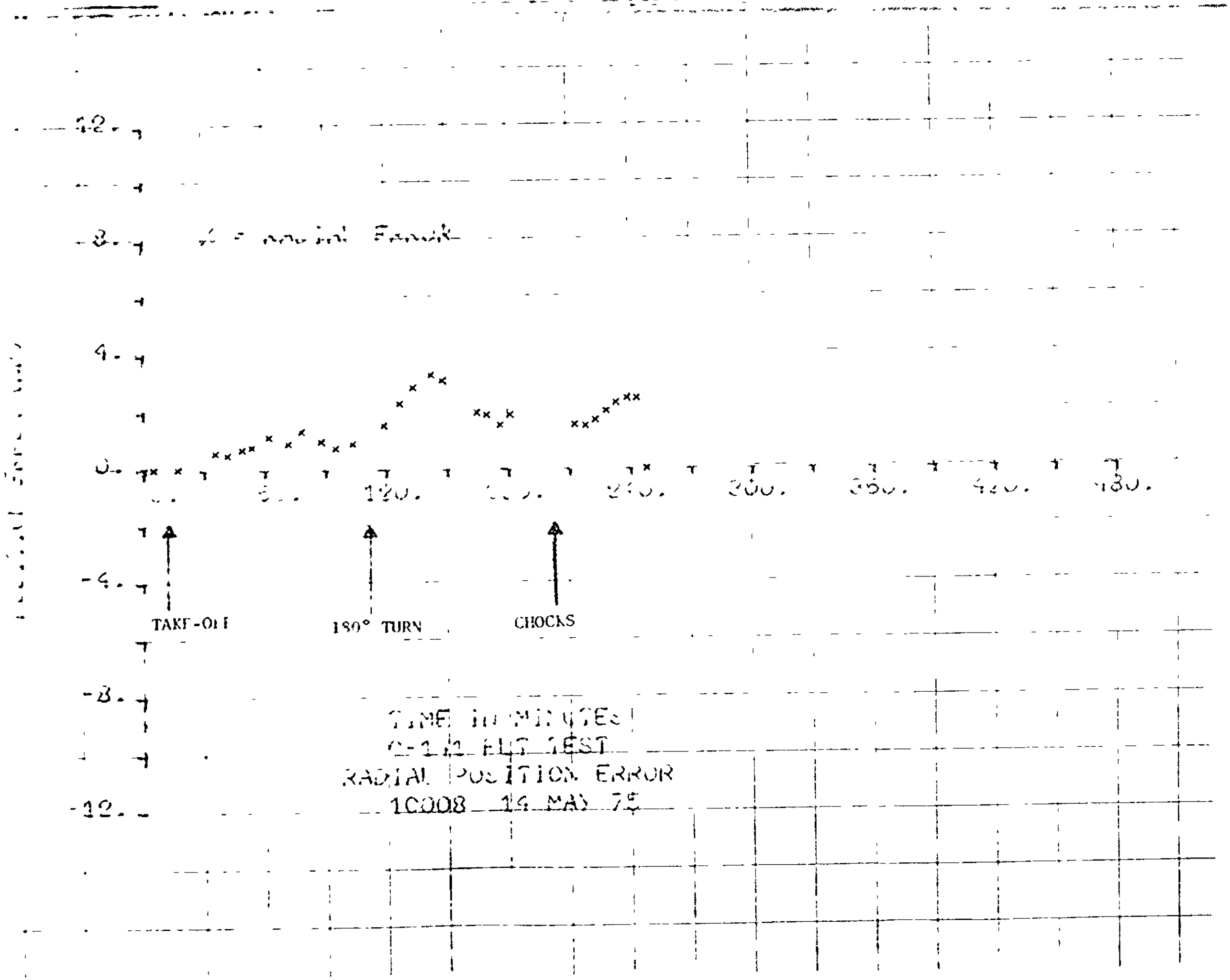
FLT TEST COMPOSITE NORTH ERROR

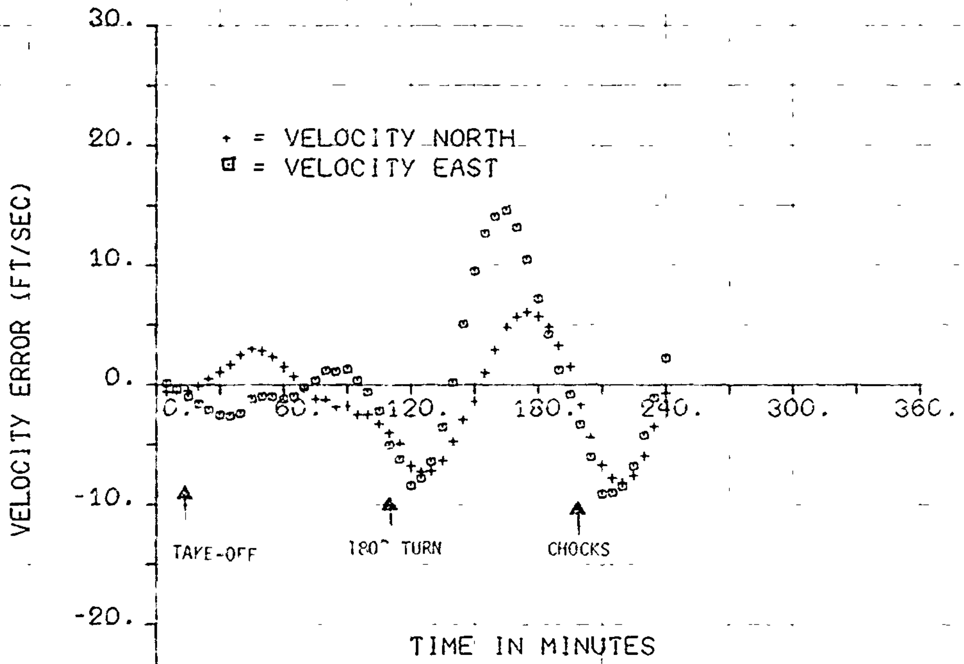


FLT TEST COMPOSITE EAST ERROR

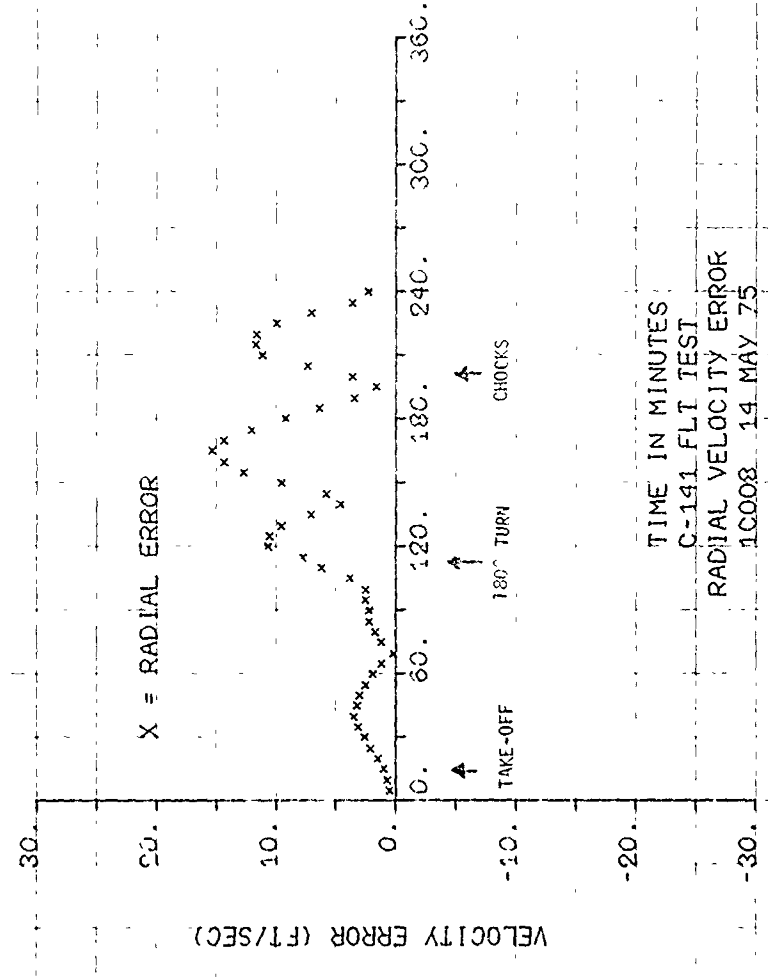

DATA GAP; NO REFERENCE DATA OVERWATER;
TESTS 1C010 AND 1C012
VELOCITY ERROR (FT/SEC)
30.
20.
10.
0.
-10.
-20.
-30.
0.
60.
120.
180.
240.
300.
360.
420.
480.
TIME IN MINUTES
FLT TEST COMPOSITE RADIAL ERROR

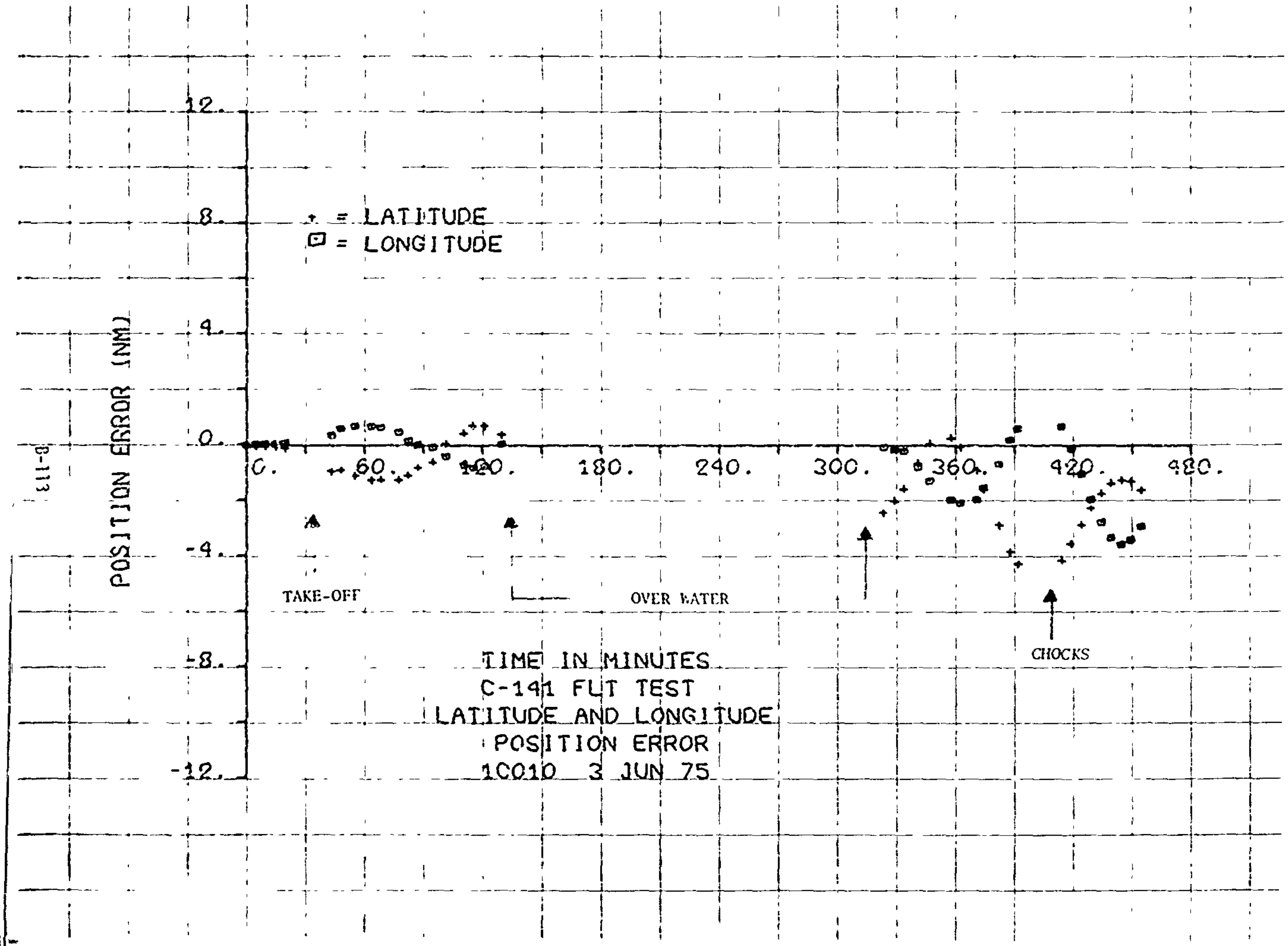

+ = LATITUDE
⊡ = LONGITUDE
POSITION ERROR (NM)
12.
8.
4.
0.
-4.
-8.
-12.
0.
60.
120.
180.
240.
300.
360.
TAKE-OFF
180° TURN
CHOCKS
TIME IN MINUTES
C-141 FLT TEST
LATITUDE AND LONGITUDE
POSITION ERROR
1C008 14 MAY 75


12.
8.
4.
0.
-4.
-8.
-12.
120.
300.
480.
TAKE-OFF
180° TURN
CHOCKS
RADIAL POSITION ERROR
10008 14 MAY 75

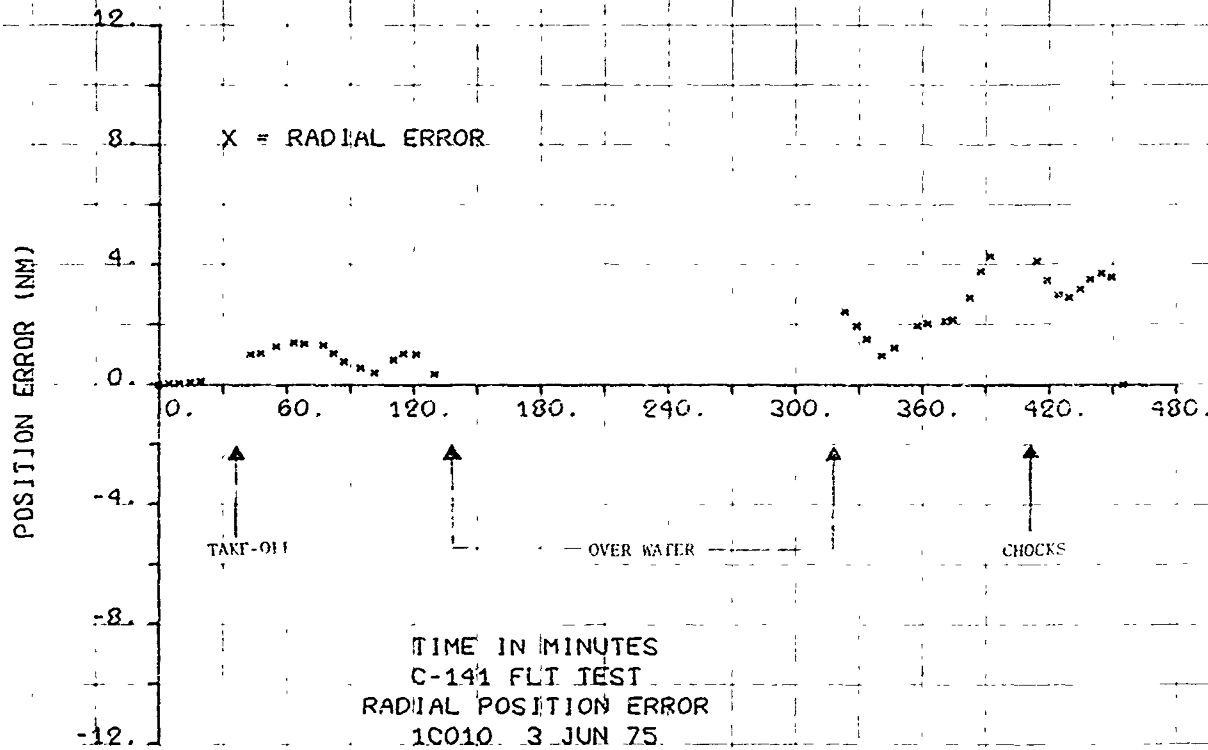


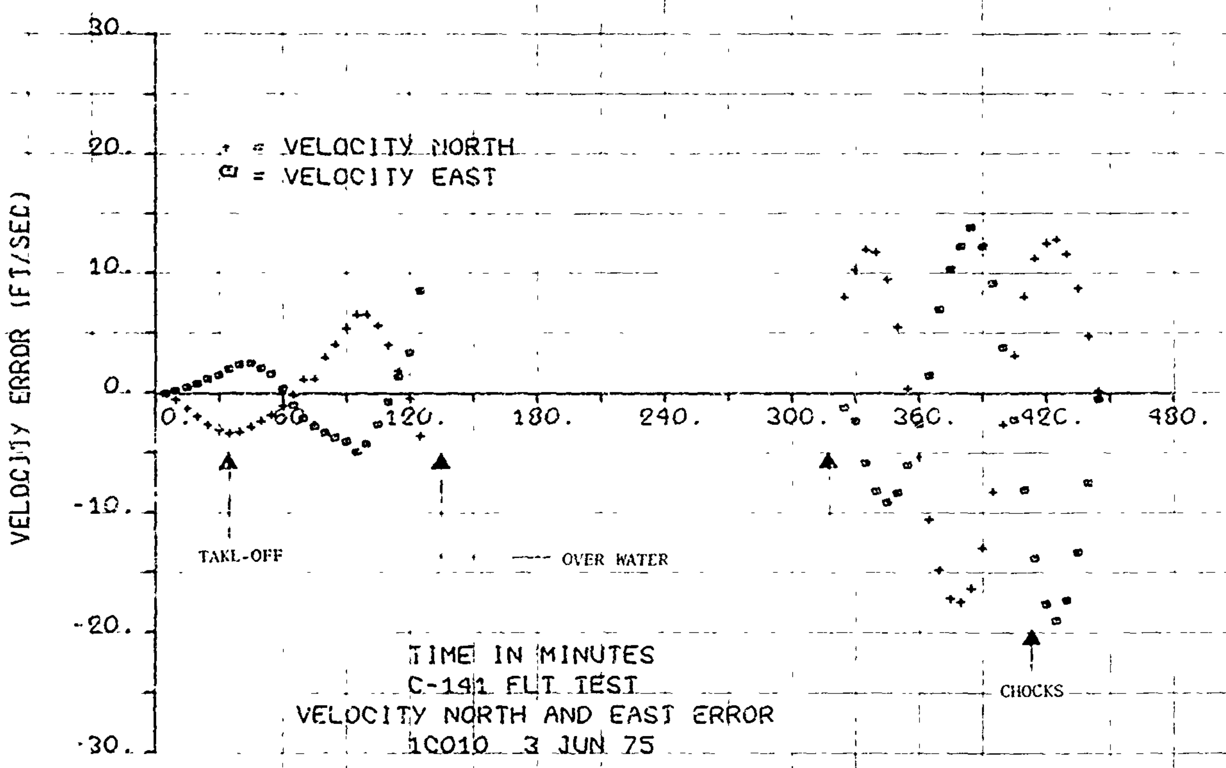
C-141 FLT TEST
VELOCITY NORTH AND EAST ERROR
1C008 14 MAY 75

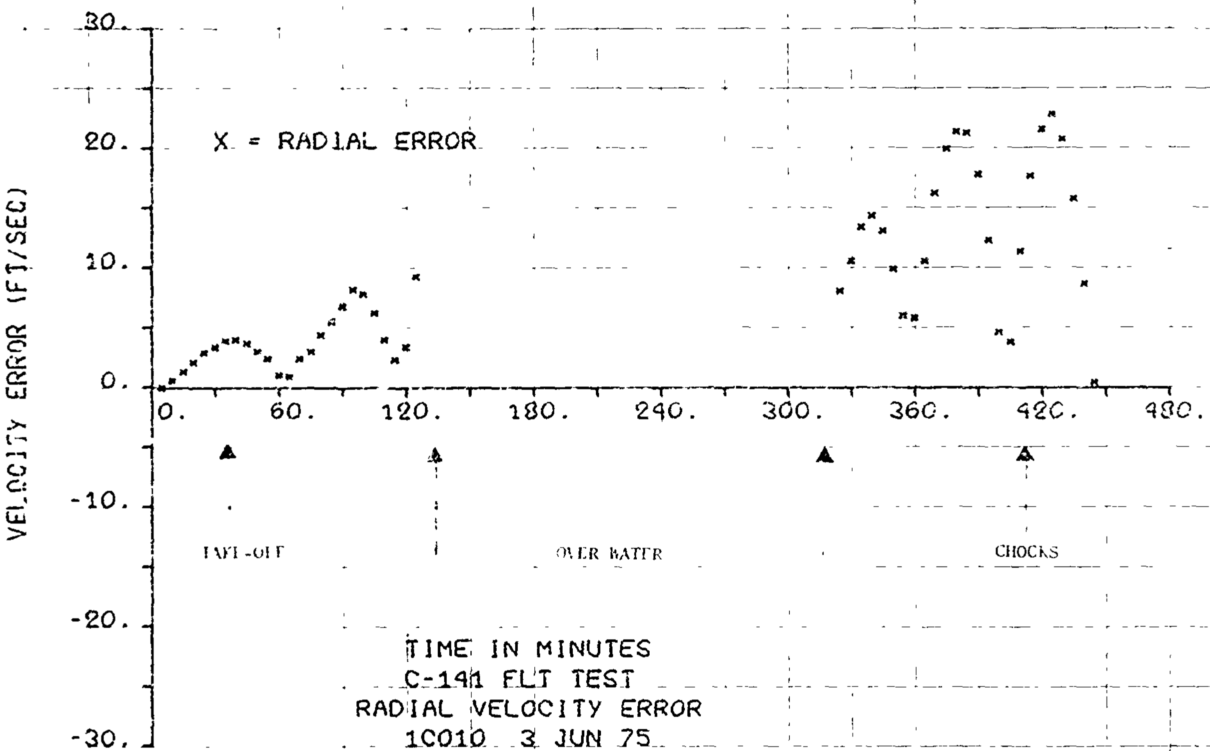

X = RADIAL ERROR
30.
20.
10.
0.
-10.
-20.
-30.
VELOCITY ERROR (FT/SEC)
0.
60.
120.
180.
240.
300.
360.
TAKE-OFF
180° TURN
CHOCKS
TIME IN MINUTES
C-141 FLT TEST
RADIAL VELOCITY ERROR
1C008 14 MAY 75

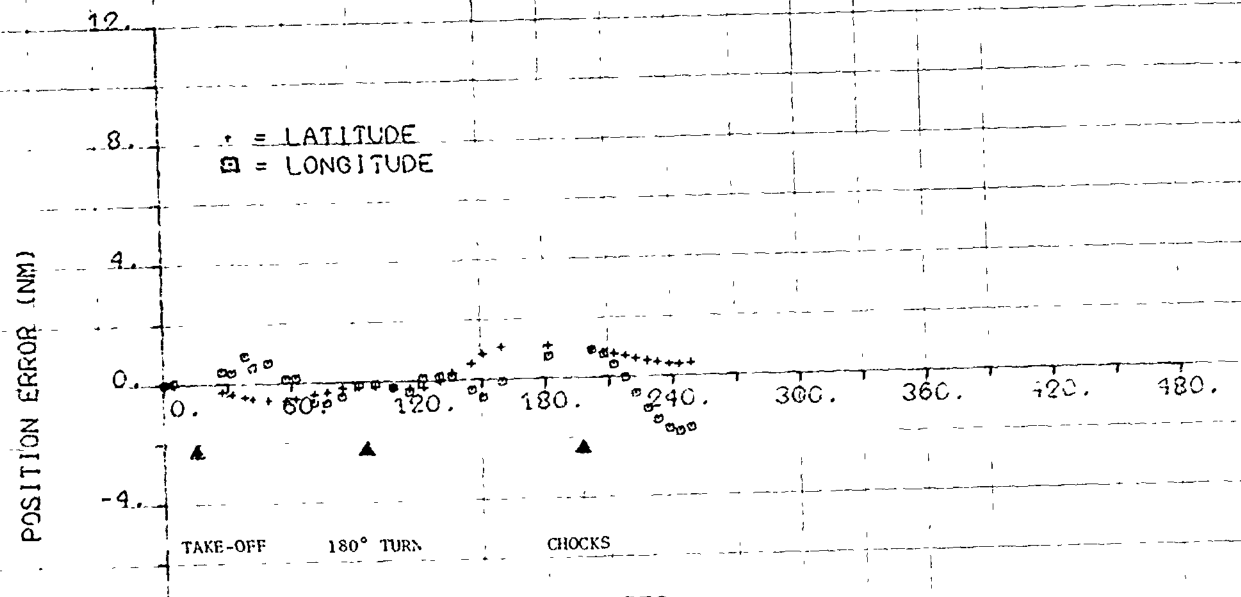


POSITION ERROR (NM)
12.
8.
4.
0.
-4.
-8.
-12.
+ = LATITUDE
□ = LONGITUDE
0.
60.
120.
180.
240.
300.
360.
420.
480.
TAKE-OFF
OVER WATER
CHOCKS
TIME IN MINUTES
C-141 FLT TEST
LATITUDE AND LONGITUDE
POSITION ERROR
1C010 3 JUN 75

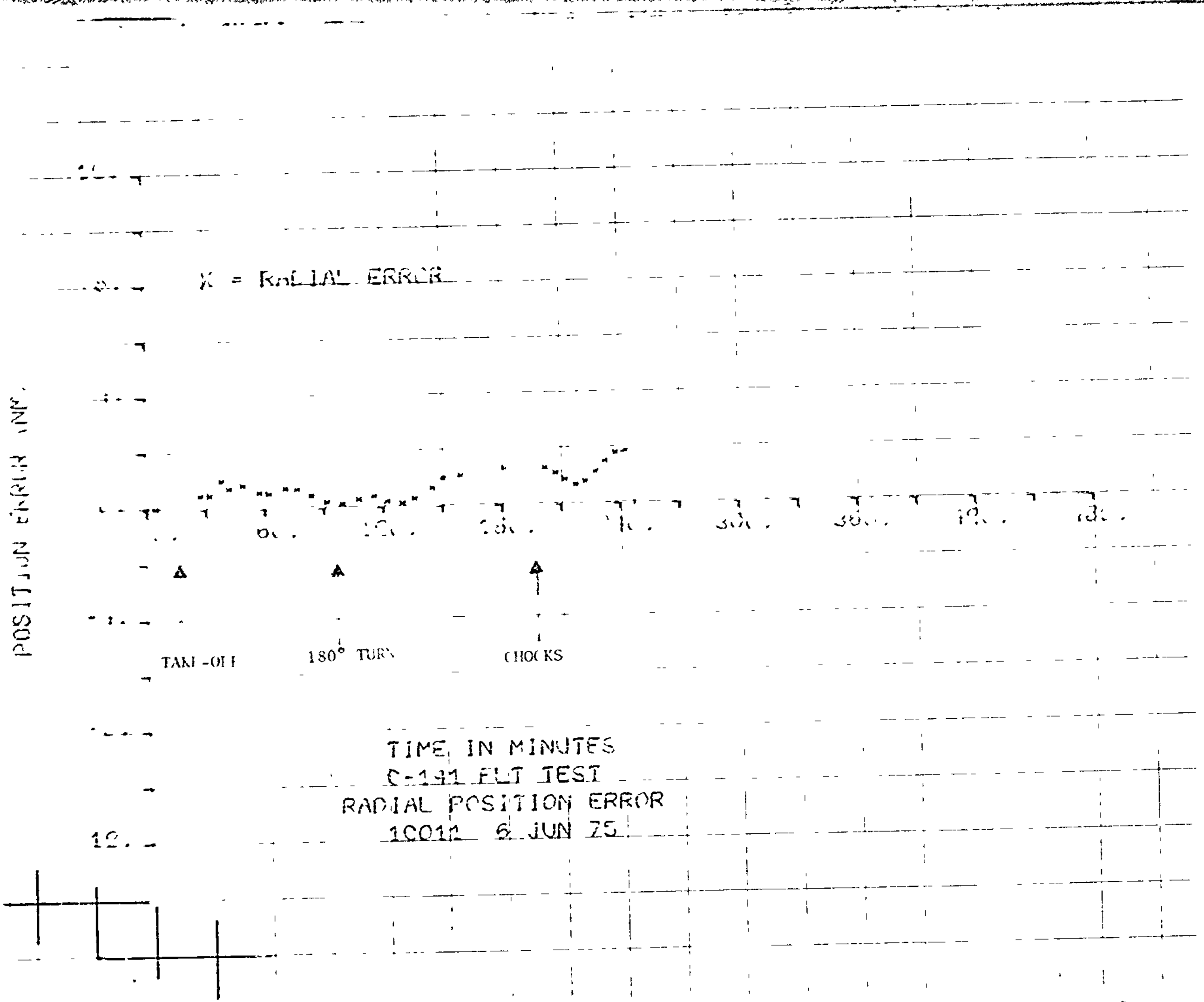

POSITION ERROR (NM)
12.
8.
4.
0.
-4.
-8.
-12.
X = RADIAL ERROR
0.
60.
120.
180.
240.
300.
360.
420.
480.
TAKE-OFF
OVER WATER
CHOCKS
TIME IN MINUTES
C-141 FLT TEST
RADIAL POSITION ERROR
1C010 3 JUN 75

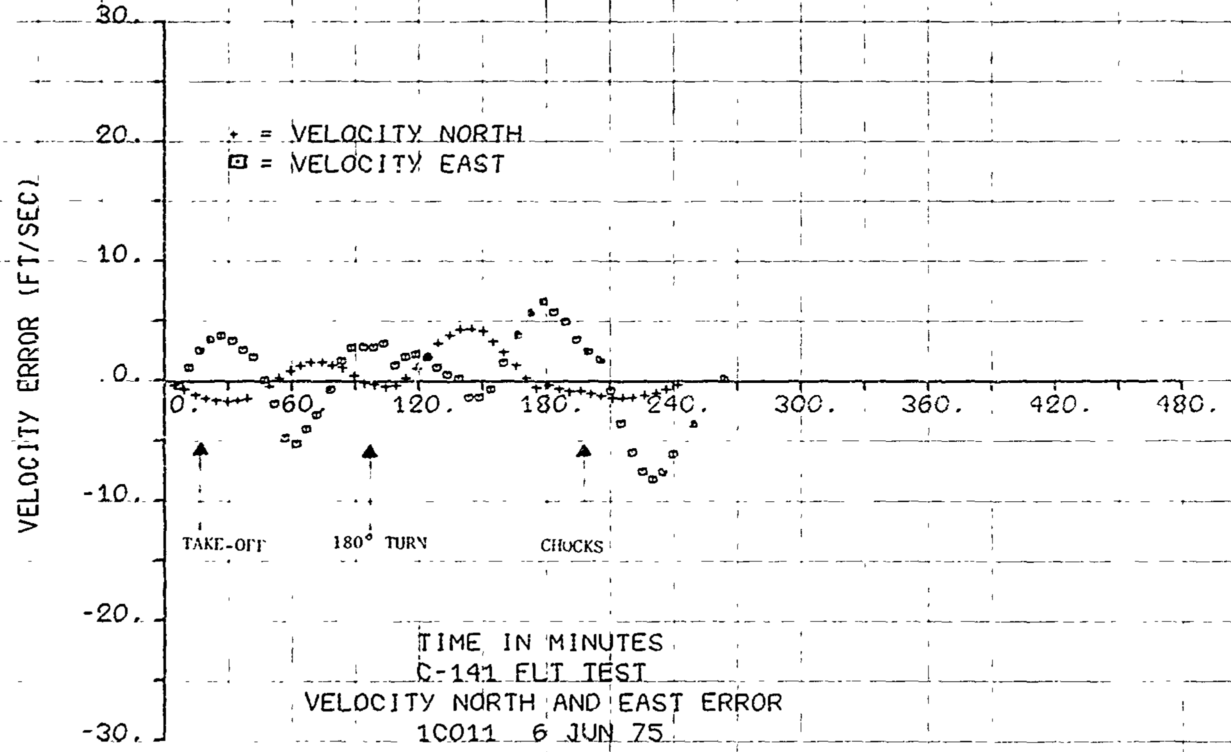

VELOCITY ERROR (FT/SEC)
+ = VELOCITY NORTH
⊡ = VELOCITY EAST
30.
20.
10.
0.
-10.
-20.
-30.
0.
60.
120.
180.
240.
300.
360.
420.
480.
TAKE-OFF
OVER WATER
CHOCKS
TIME IN MINUTES
C-141 FLT TEST
VELOCITY NORTH AND EAST ERROR
1C010 3 JUN 75


X = RADIAL ERROR
VELOCITY ERROR (FT/SEC)
30.
20.
10.
0.
-10.
-20.
-30.
0.
60.
120.
180.
240.
300.
360.
420.
480.
TAKE-OFF
OVER WATER
CHOCKS
TIME IN MINUTES
C-141 FLT TEST
RADIAL VELOCITY ERROR
1C010 3 JUN 75

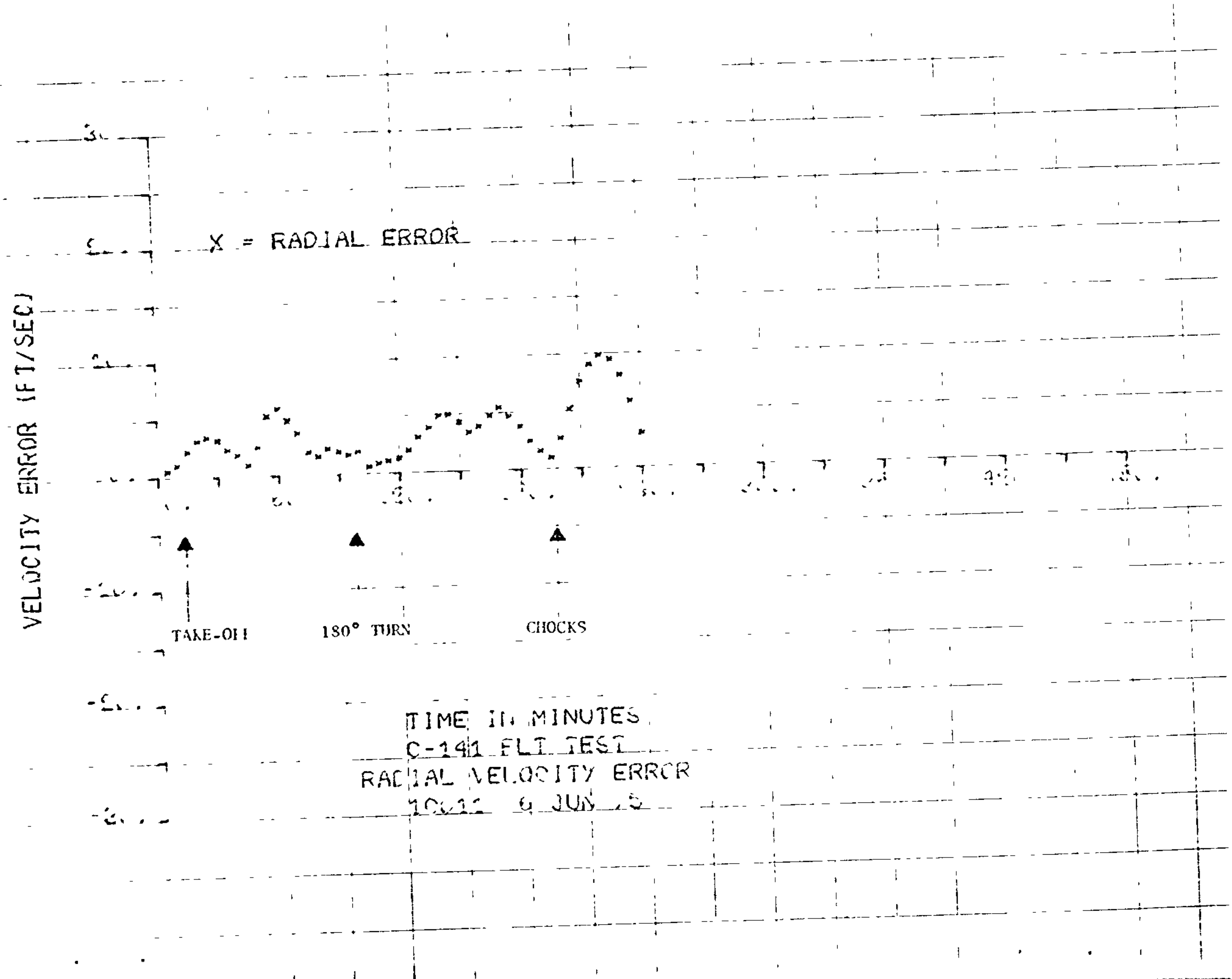


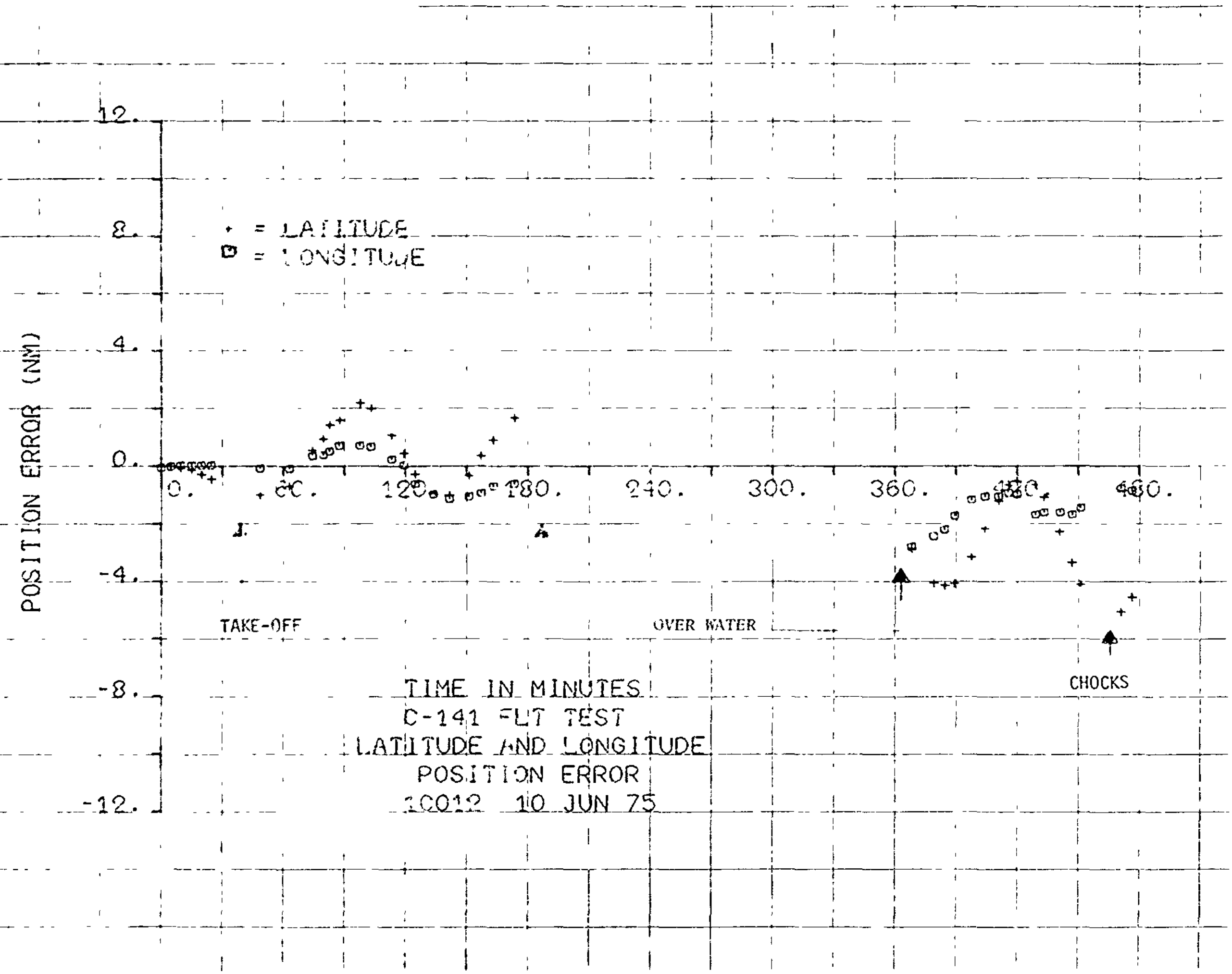
C-141 FLT TEST
LATITUDE AND LONGITUDE
POSITION ERROR
1C011 6 JUN 75

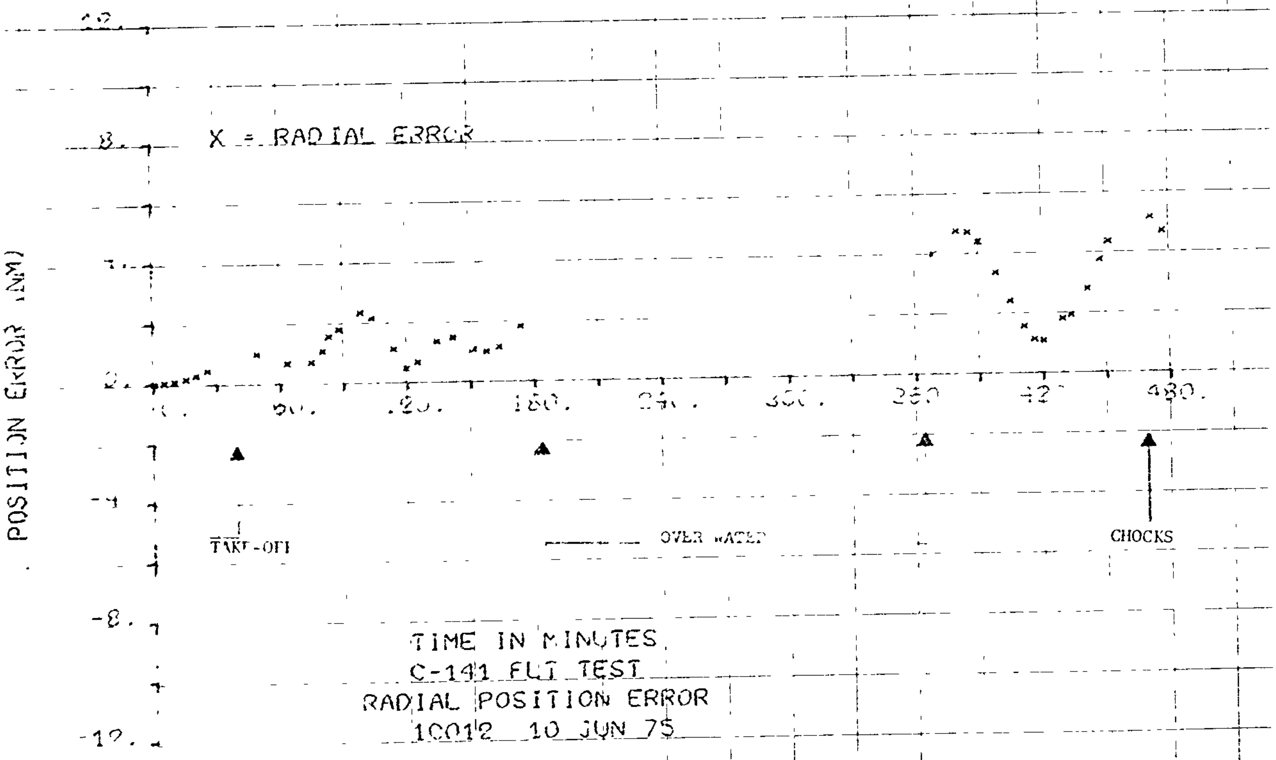

X = RADIAL ERROR
POSITION ERROR (NM)
TAXI-OFF
180° TURN
CHOCKS
12.
TIME IN MINUTES
C-141 FLT TEST
RADIAL POSITION ERROR
1C011 6 JUN 75

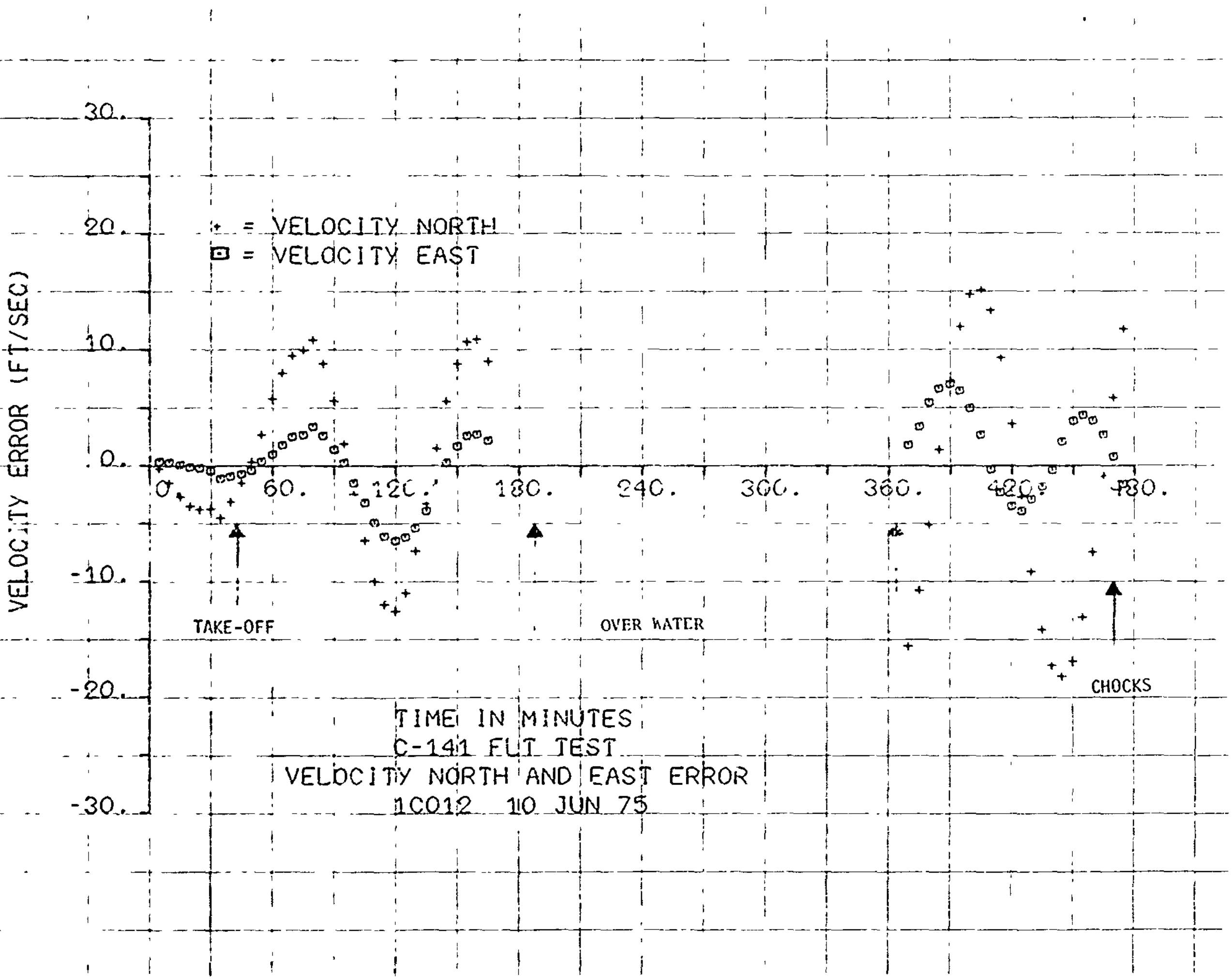


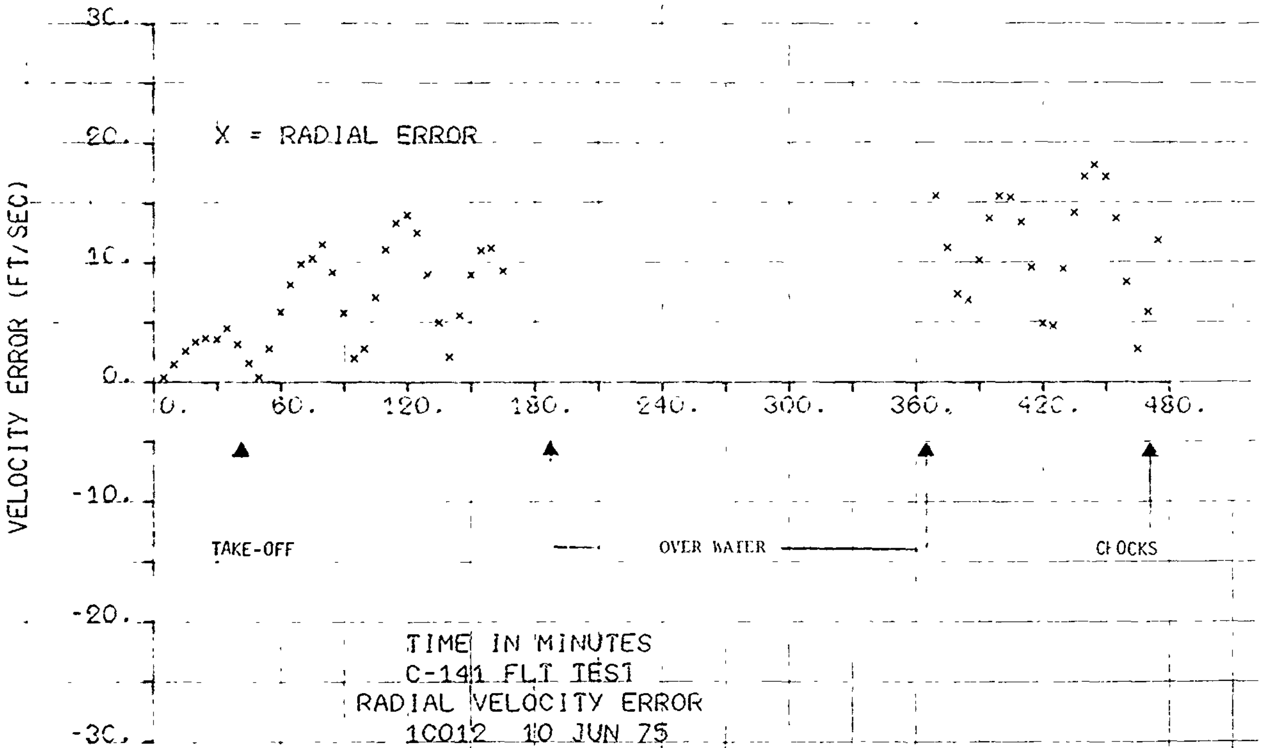
C-141 FLT TEST
VELOCITY NORTH AND EAST ERROR
1C011 6 JUN 75

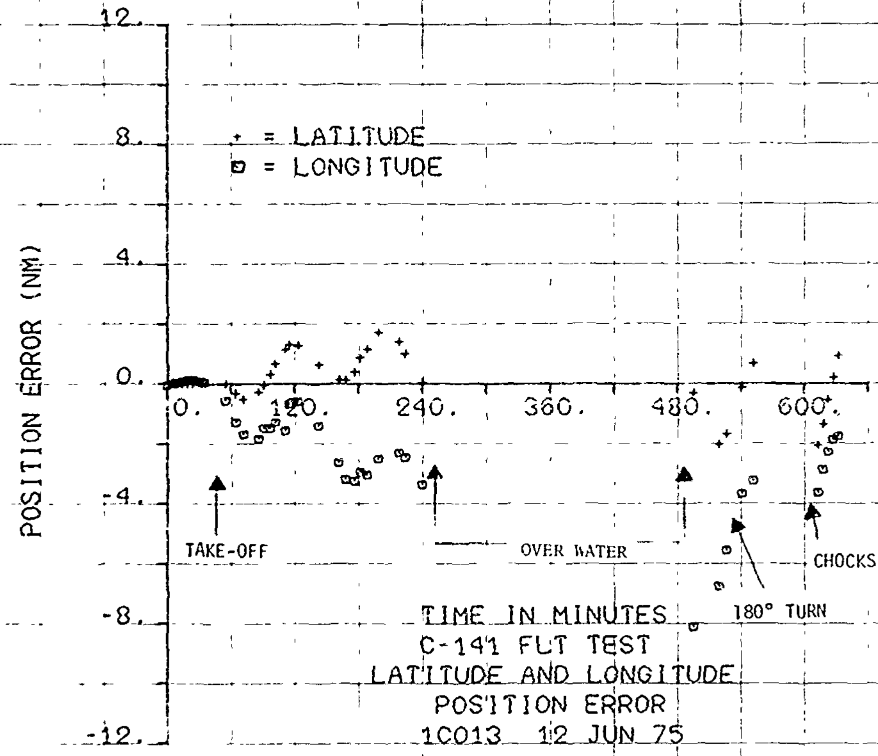

X = RADIAL ERROR
VELOCITY ERROR (FT/SEC)
TAKE-OFF
180° TURN
CHOCKS
TIME IN MINUTES
C-141 FLT TEST
RADIAL VELOCITY ERROR


+ = LATITUDE
▫ = LONGITUDE
POSITION ERROR (NM)
12.
8.
4.
0.
-4.
-8.
-12.
0.
60.
120.
180.
240.
300.
360.
420.
480.
TAKE-OFF
OVER WATER
CHOCKS
TIME IN MINUTES
C-141 FLT TEST
LATITUDE AND LONGITUDE
POSITION ERROR
1C012 10 JUN 75

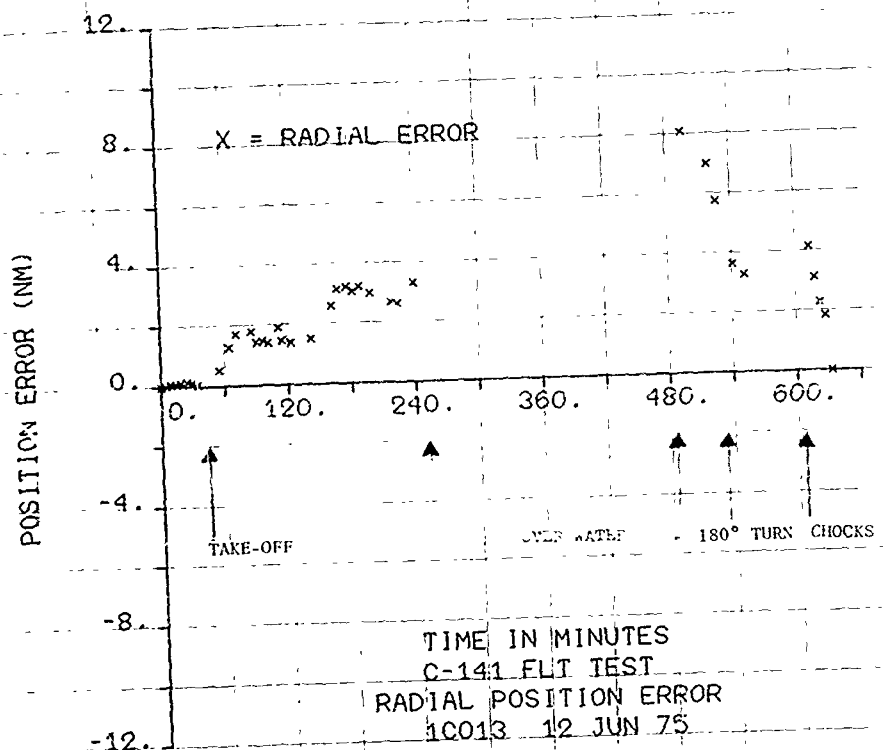

X = RADIAL ERROR
POSITION ERROR (NM)
TAKE-OFF
OVER WATER
CHOCKS
TIME IN MINUTES
C-141 FLT TEST
RADIAL POSITION ERROR
10012 10 JUN 75


+ = VELOCITY NORTH
⊡ = VELOCITY EAST
VELOCITY ERROR (FT/SEC)
30.
20.
10.
0.
-10.
-20.
-30.
0.
60.
120.
180.
240.
300.
360.
420.
480.
TAKE-OFF
OVER WATER
CHOCKS
TIME IN MINUTES
C-141 FLT TEST
VELOCITY NORTH AND EAST ERROR
1C012 10 JUN 75

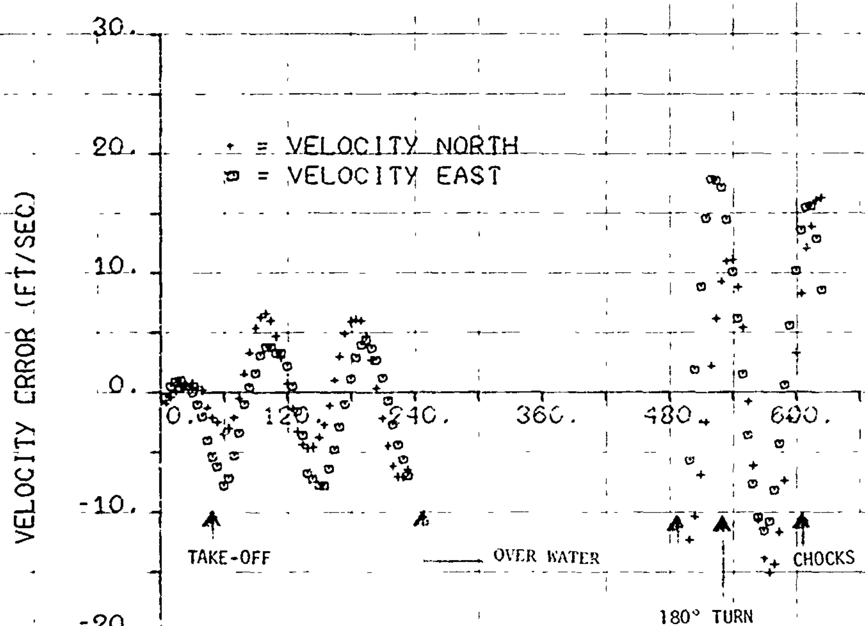

X = RADIAL ERROR
VELOCITY ERROR (FT/SEC)
30.
20.
10.
0.
-10.
-20.
-30.
0.
60.
120.
180.
240.
300.
360.
420.
480.
TAKE-OFF
OVER WATER
CHOCKS
TIME IN MINUTES
C-141 FLT TEST
RADIAL VELOCITY ERROR
1C012 10 JUN 75



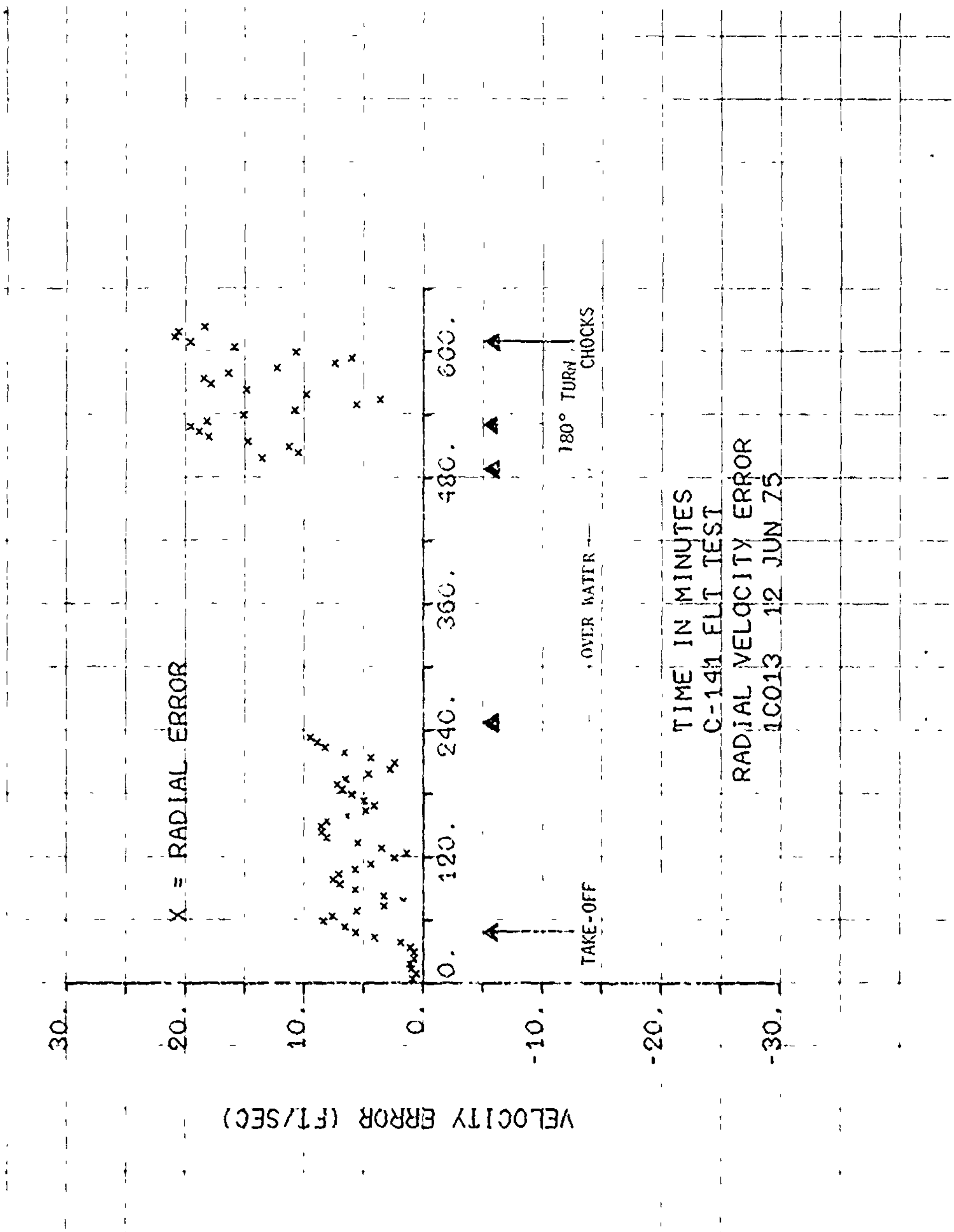
TIME IN MINUTES
C-141 FLT TEST
LATITUDE AND LONGITUDE
POSITION ERROR
1C013 12 JUN 75



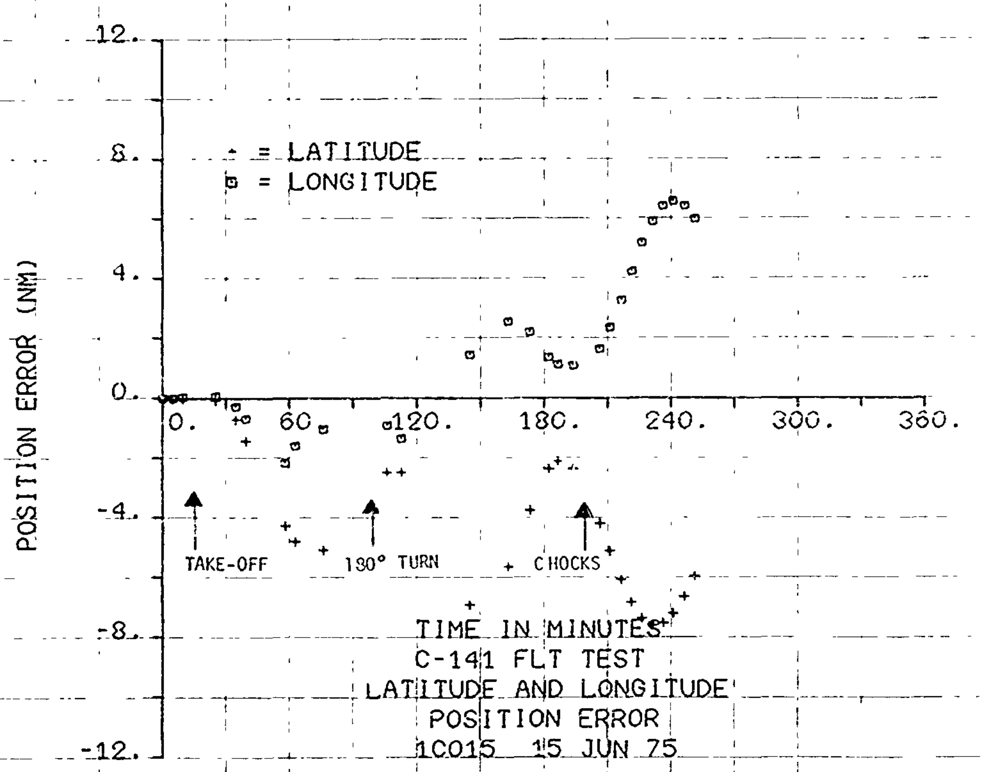
X = RADIAL ERROR
POSITION ERROR (NM)
12.
8.
4.
0.
-4.
-8.
-12.
0.
120.
240.
360.
480.
600.
TAKE-OFF
180° TURN
CHOCKS
TIME IN MINUTES
C-141 FLT TEST
RADIAL POSITION ERROR
1C013 12 JUN 75

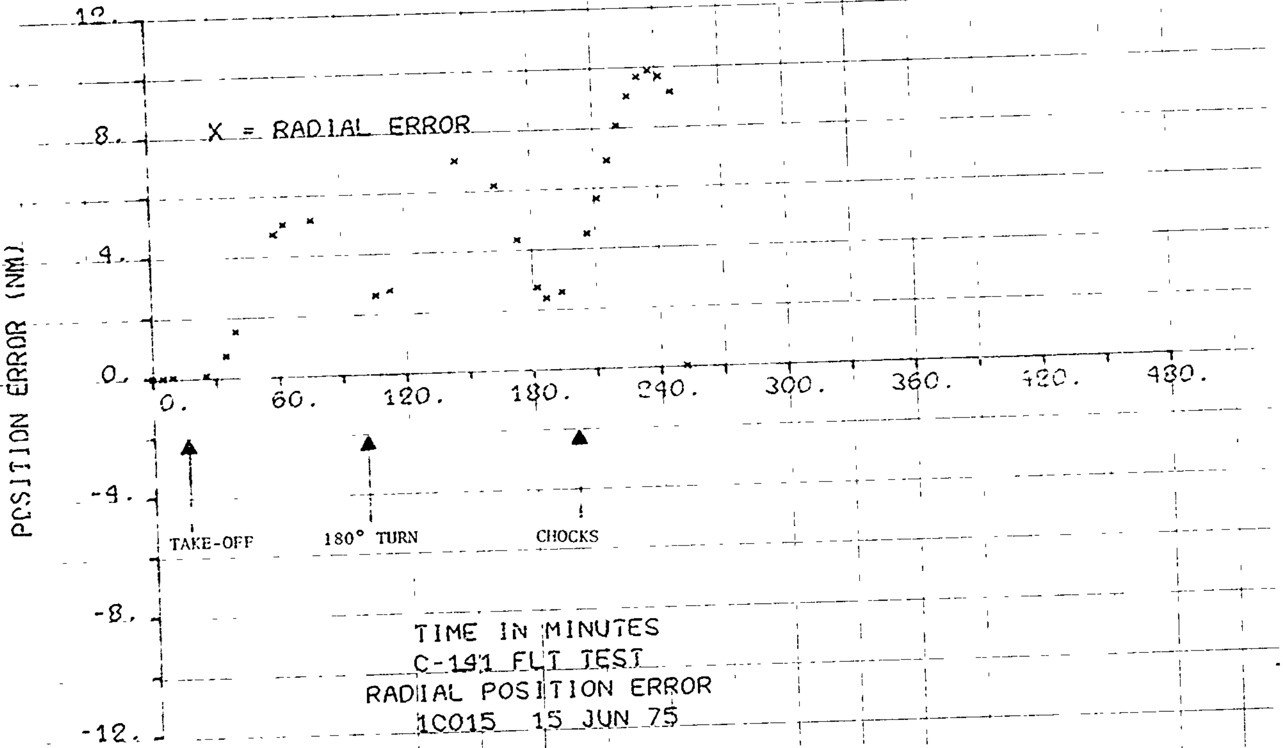


TIME IN MINUTES
C-141 FLT TEST
VELOCITY NORTH AND EAST ERROR
1C013 12 JUN 75

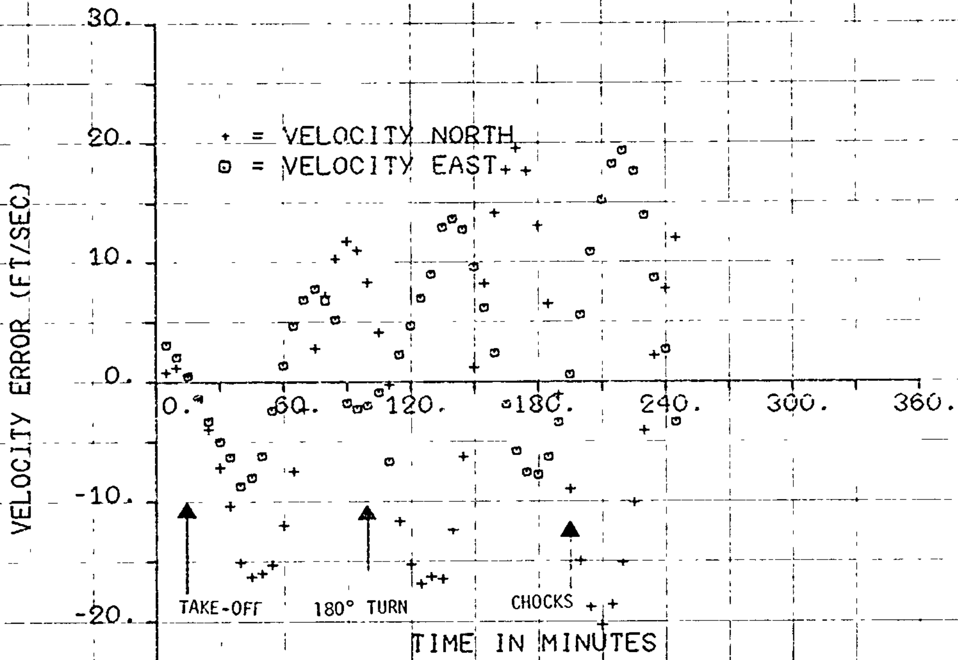


X = RADIAL ERROR
VELOCITY ERROR (FT/SEC)
30.
20.
10.
0.
-10.
-20.
-30.
0.
120.
240.
360.
480.
600.
TAKE-OFF
OVER WATER
180° TURN
CHOCKS
TIME IN MINUTES
C-141 ELT TEST
RADIAL VELOCITY ERROR
1C013 12 JUN 75


12.
8.
4.
0.
-4.
-8.
-12.
POSITION ERROR (NM)
+ = LATITUDE
□ = LONGITUDE
0.
60.
120.
180.
240.
300.
360.
TAKE-OFF
180° TURN
CHOCKS
TIME IN MINUTES
C-141 FLT TEST
LATITUDE AND LONGITUDE
POSITION ERROR
1C015 15 JUN 75



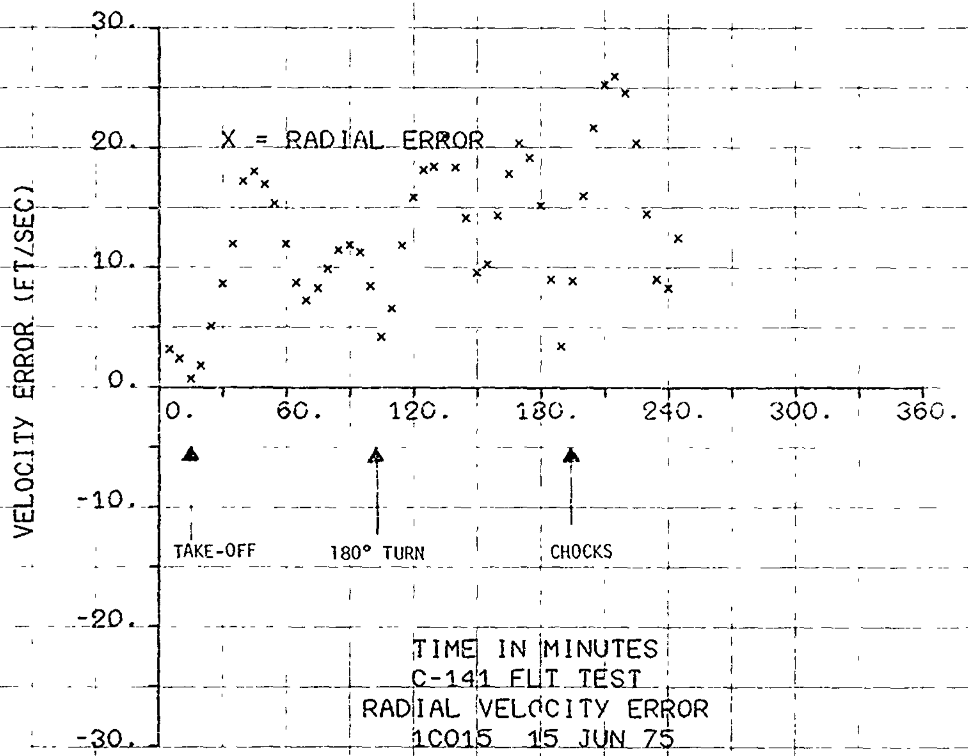
POSITION ERROR (NM)
12.
8.
4.
0.
-4.
-8.
-12.
0.
60.
120.
180.
240.
300.
360.
420.
480.
X = RADIAL ERROR
TAKE-OFF
180° TURN
CHOCKS
TIME IN MINUTES
C-141 FLT TEST
RADIAL POSITION ERROR
1C015 15 JUN 75

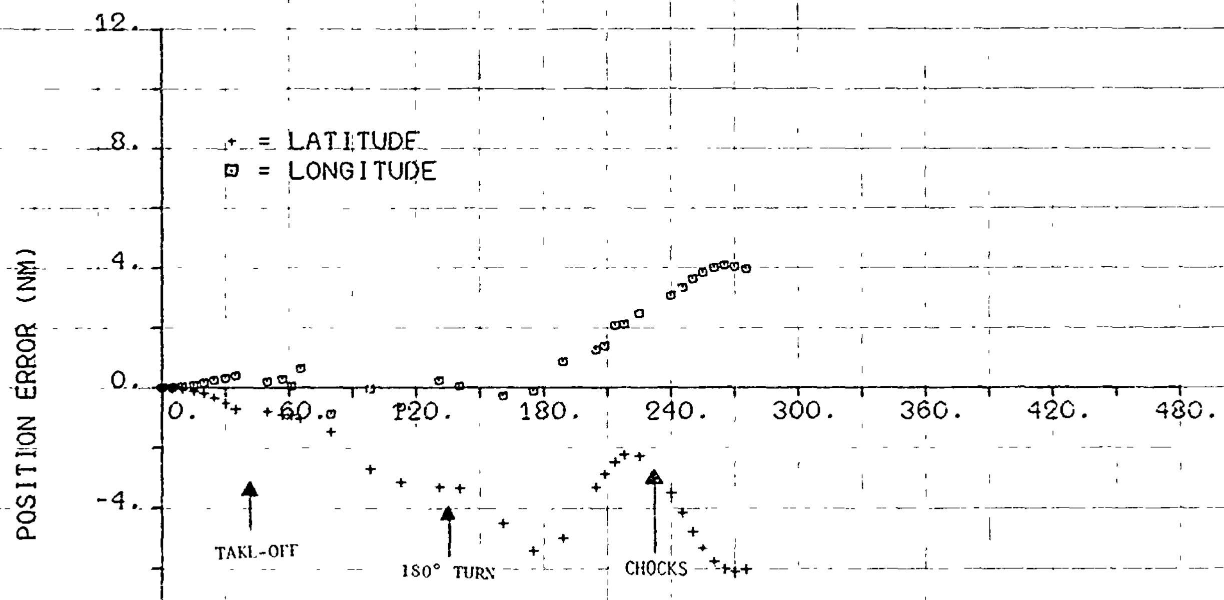


C-141 FLT TEST

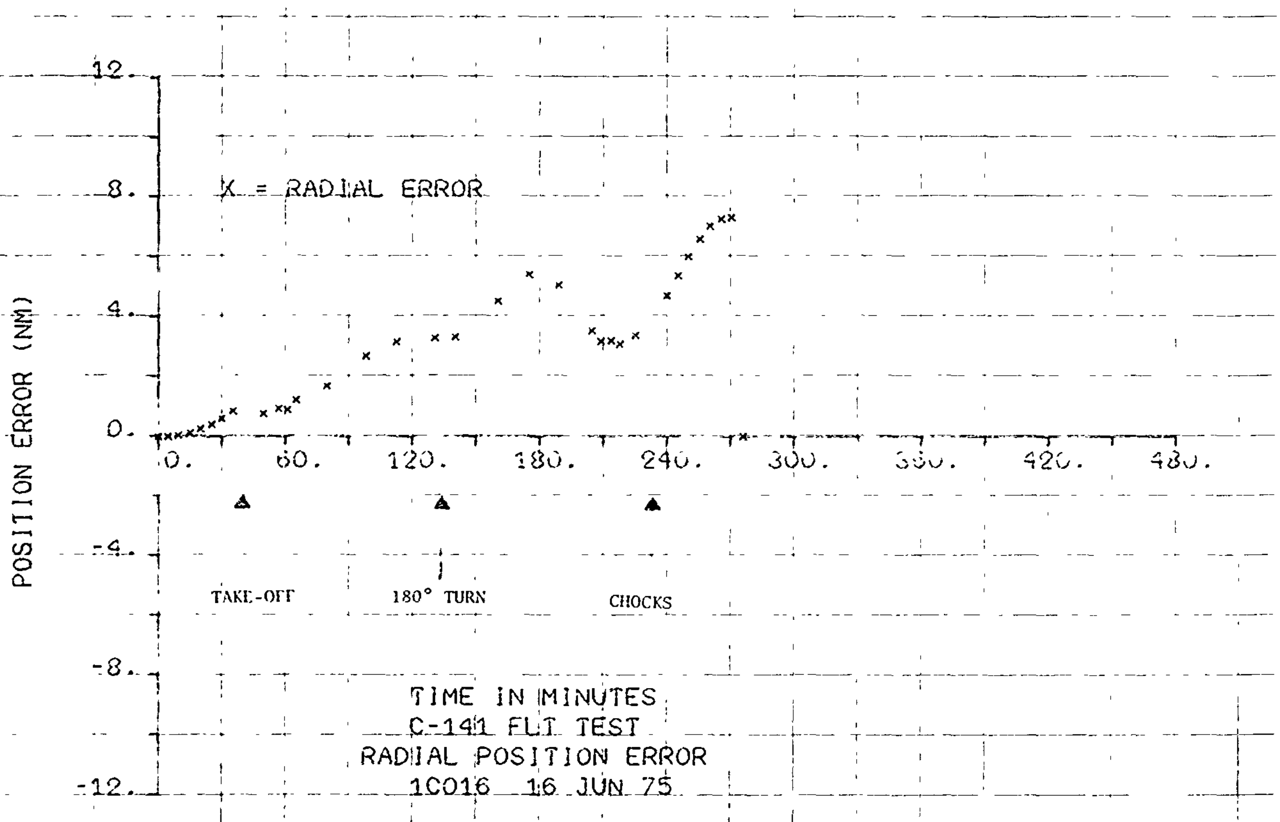
VELOCITY NORTH AND EAST ERROR

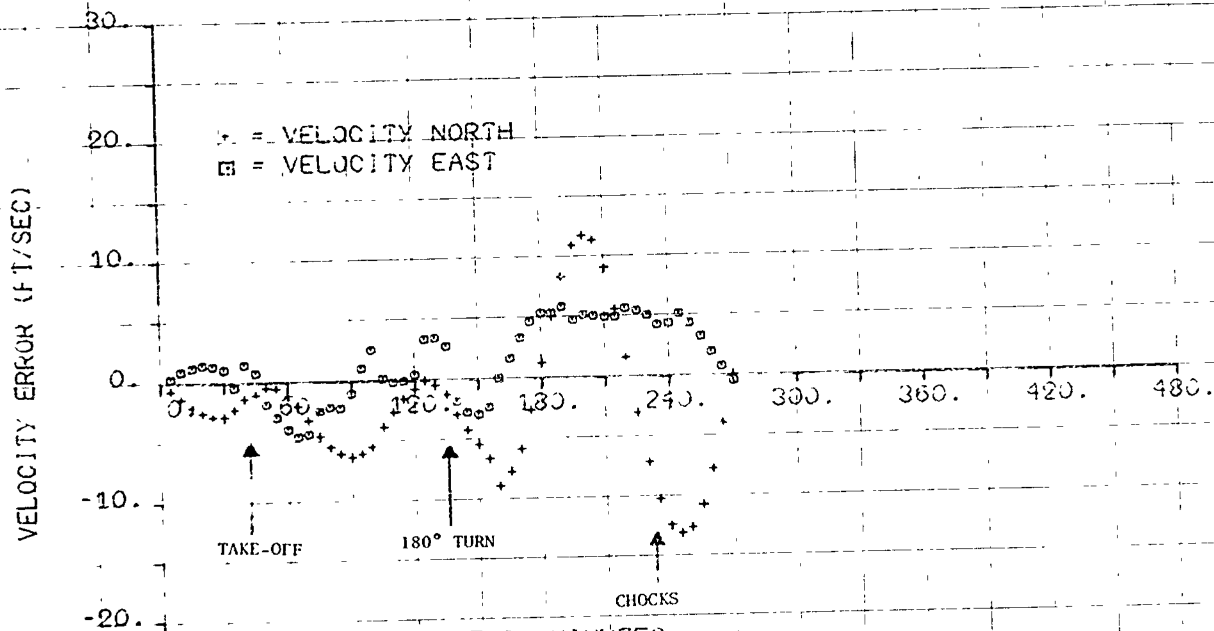
1C015 15 JUN 75


X = RADIAL ERROR
VELOCITY ERROR (FT/SEC)
30.
20.
10.
0.
-10.
-20.
-30.
0.
60.
120.
180.
240.
300.
360.
TAKE-OFF
180° TURN
CHOCKS
TIME IN MINUTES
C-141 FLT TEST
RADIAL VELOCITY ERROR
1C015 15 JUN 75

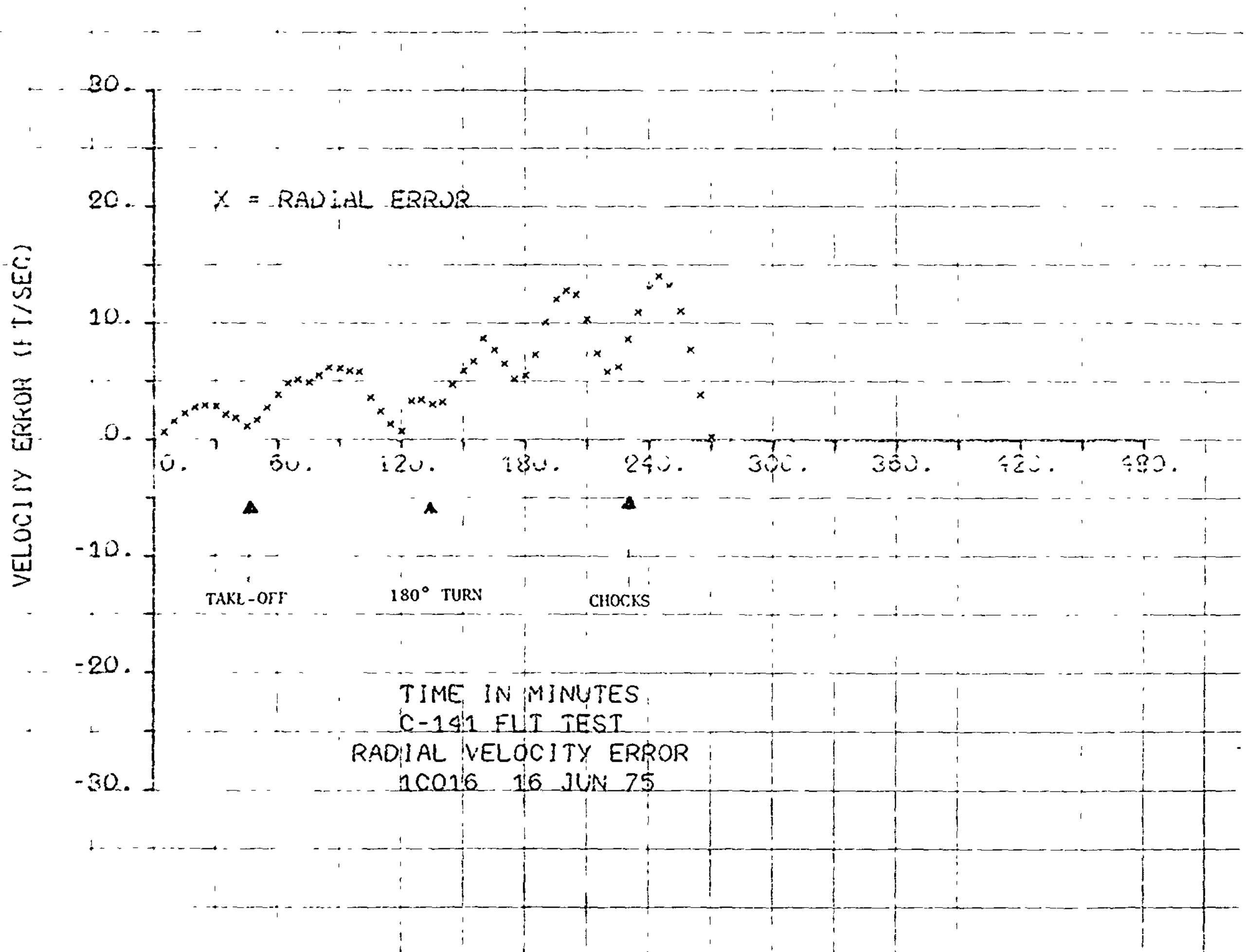


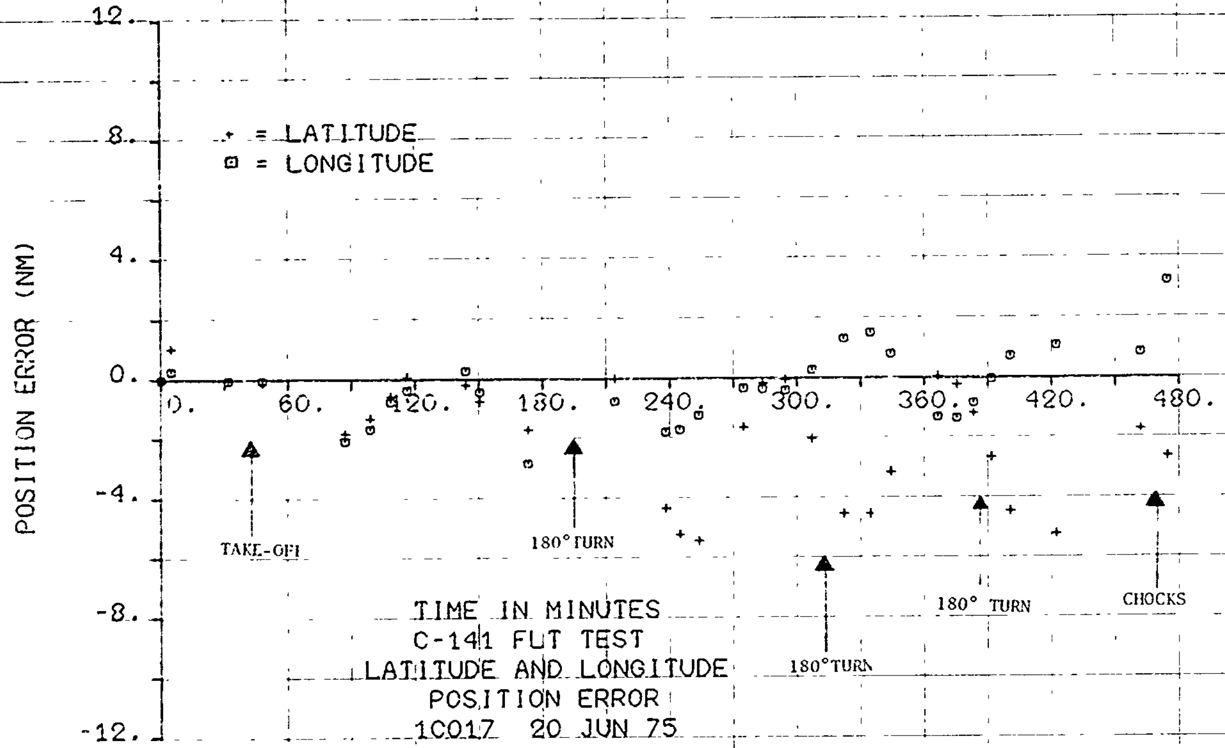
TIME IN MINUTES
C-141 FLT TEST
LATITUDE AND LONGITUDE
POSITION ERROR
1C016 16 JUN 75

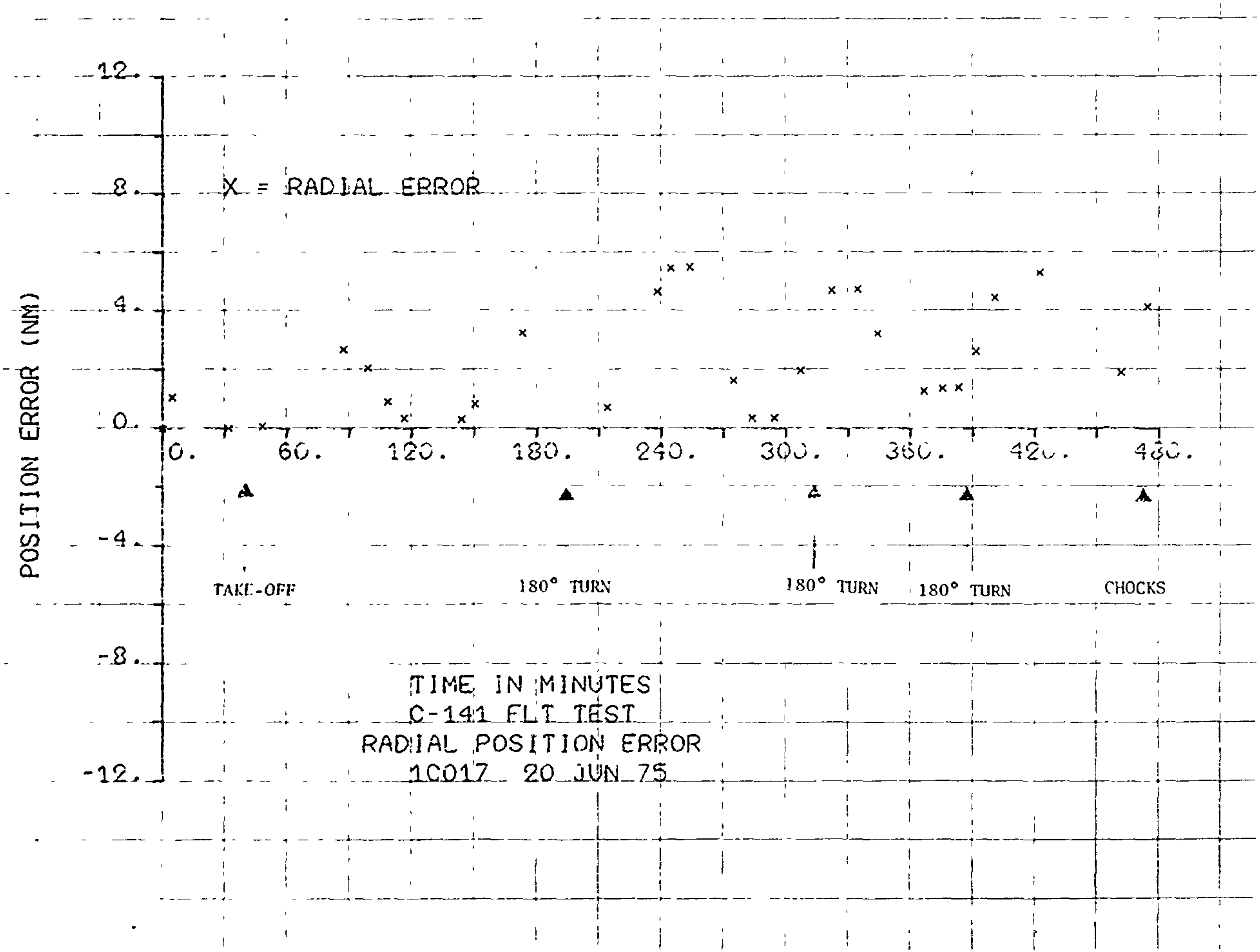

X = RADIAL ERROR
POSITION ERROR (NM)
12.
8.
4.
0.
-4.
-8.
-12.
0.
60.
120.
180.
240.
300.
360.
420.
480.
TAKE-OFF
180° TURN
CHOCKS
TIME IN MINUTES
C-141 FLT TEST
RADIAL POSITION ERROR
1C016 16 JUN 75

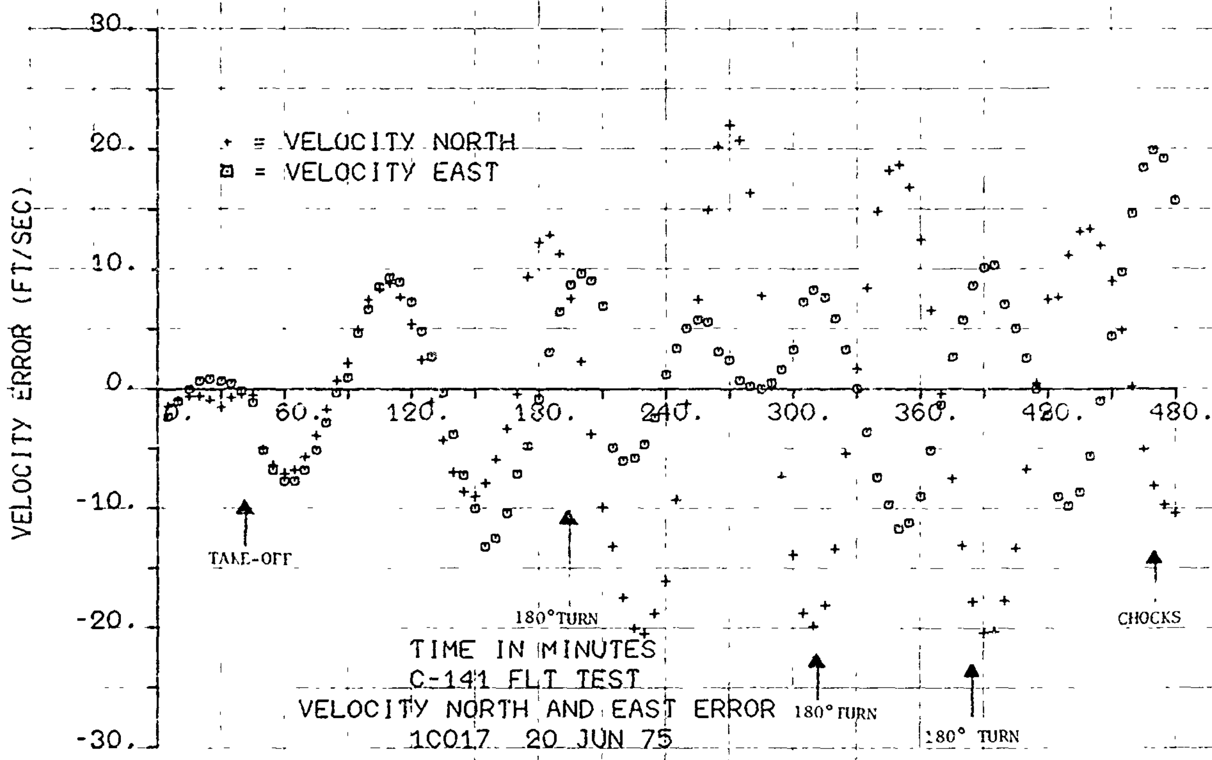


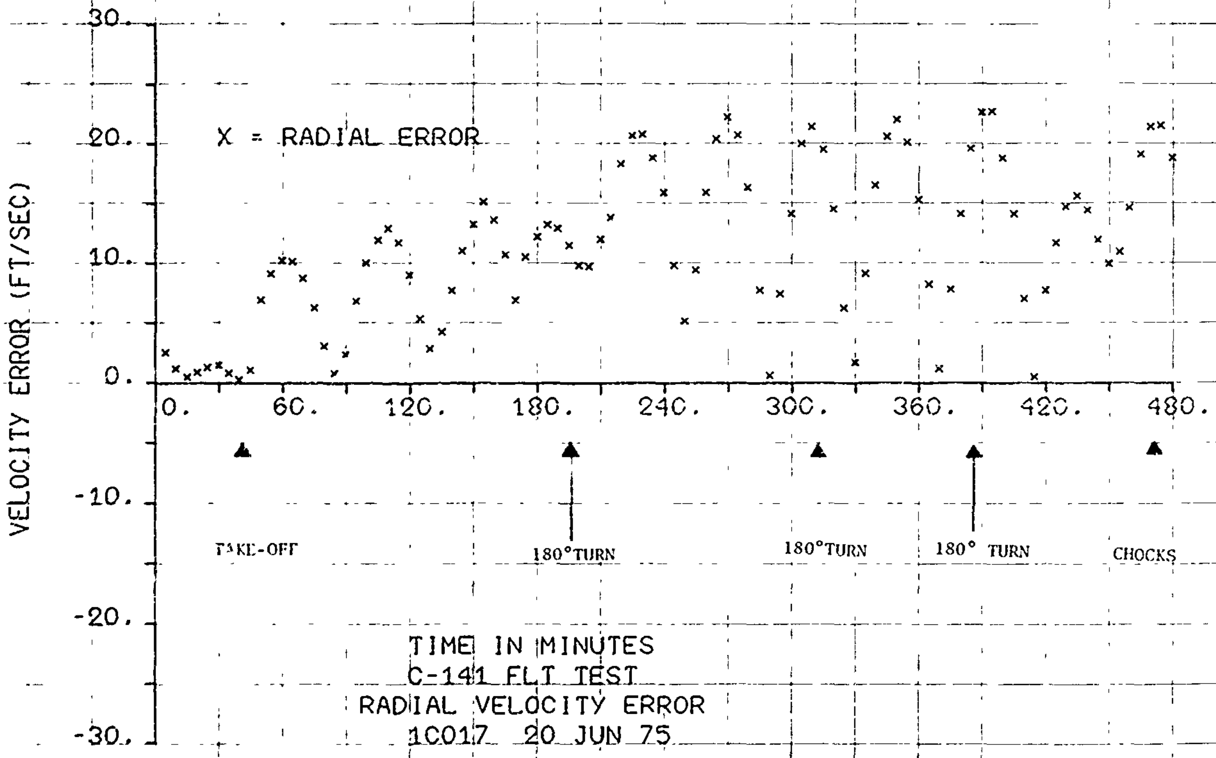
C-141 FLT TEST
VELOCITY NORTH AND EAST ERROR
1C016 16 JUN 75


X = RADIAL ERROR
VELOCITY ERROR (FT/SEC)
30.
20.
10.
0.
-10.
-20.
-30.
0.
60.
120.
180.
240.
300.
360.
420.
480.
TAKE-OFF
180° TURN
CHOCKS
TIME IN MINUTES
C-141 FLT TEST
RADIAL VELOCITY ERROR
1C016 16 JUN 75

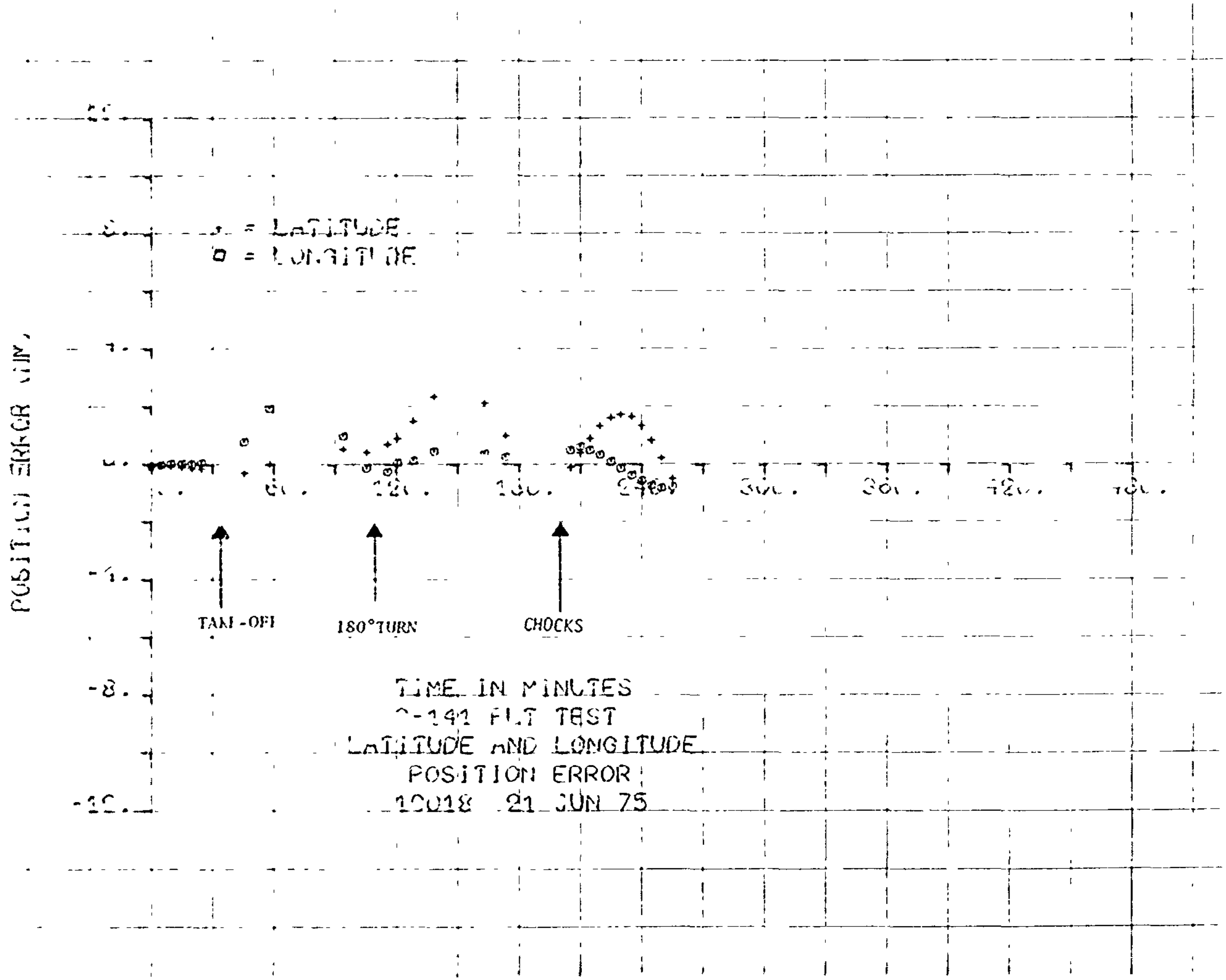

+ = LATITUDE
□ = LONGITUDE
POSITION ERROR (NM)
12.
8.
4.
0.
-4.
-8.
-12.
0.
60.
120.
180.
240.
300.
360.
420.
480.
TAKE-OFF
180° TURN
180° TURN
180° TURN
CHOCKS
TIME IN MINUTES
C-141 FLT TEST
LATITUDE AND LONGITUDE
POSITION ERROR
1C017 20 JUN 75

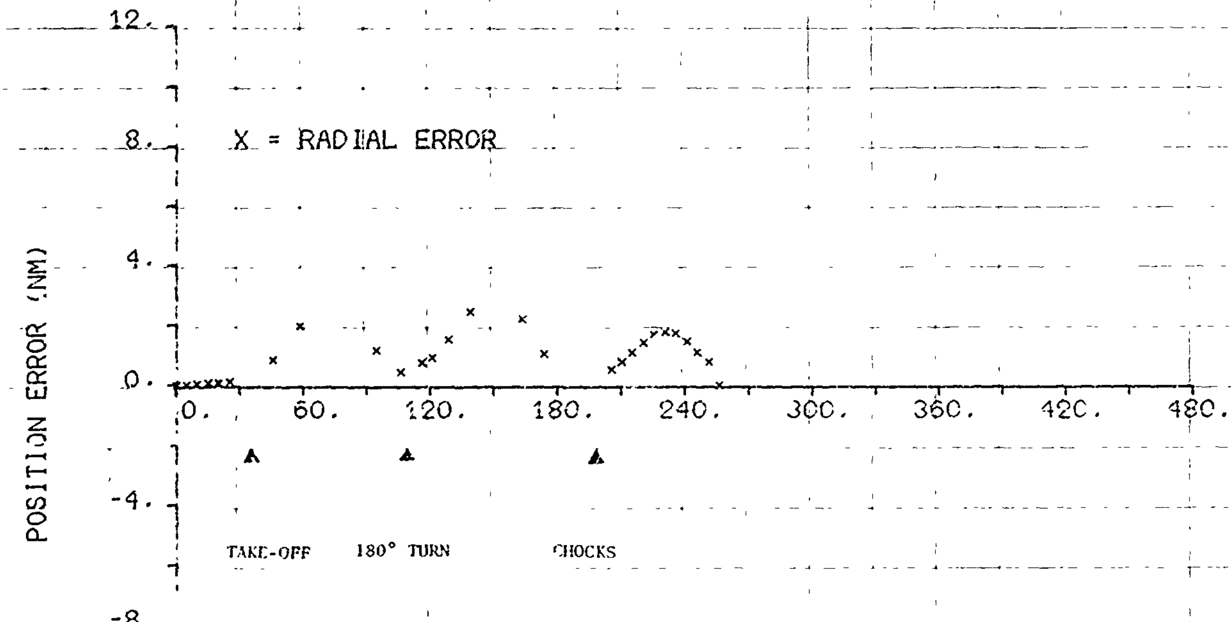

X = RADIAL ERROR
POSITION ERROR (NM)
12.
8.
4.
0.
-4.
-8.
-12.
0.
60.
120.
180.
240.
300.
360.
420.
480.
TAKE-OFF
180° TURN
180° TURN
180° TURN
CHOCKS
TIME IN MINUTES
C-141 FLT TEST
RADIAL POSITION ERROR
1C017 20 JUN 75


+ = VELOCITY NORTH
⊡ = VELOCITY EAST
VELOCITY ERROR (FT/SEC)
30.
20.
10.
0.
-10.
-20.
-30.
0.
60.
120.
180.
240.
300.
360.
420.
480.
TAKE-OFF
180°TURN
180°TURN
180° TURN
CHOCKS
TIME IN MINUTES
C-141 FLT TEST
VELOCITY NORTH AND EAST ERROR
1C017 20 JUN 75

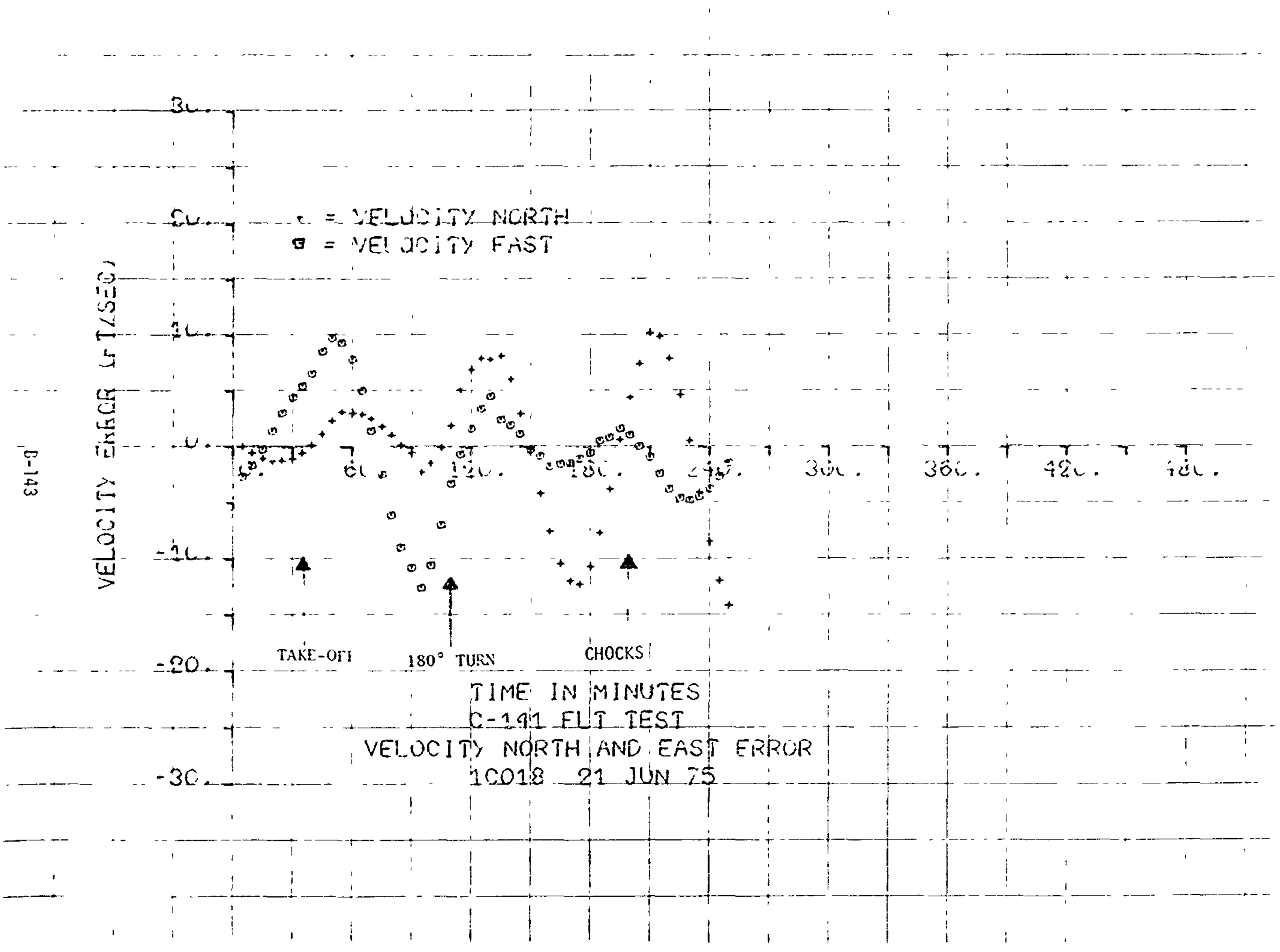


VELOCITY ERROR (FT/SEC)
30.
20.
10.
0.
-10.
-20.
-30.
X = RADIAL ERROR
0.
60.
120.
180.
240.
300.
360.
420.
480.
TAKE-OFF
180°TURN
180°TURN
180° TURN
CHOCKS
TIME IN MINUTES
C-141 FLT TEST
RADIAL VELOCITY ERROR
1C017 20 JUN 75

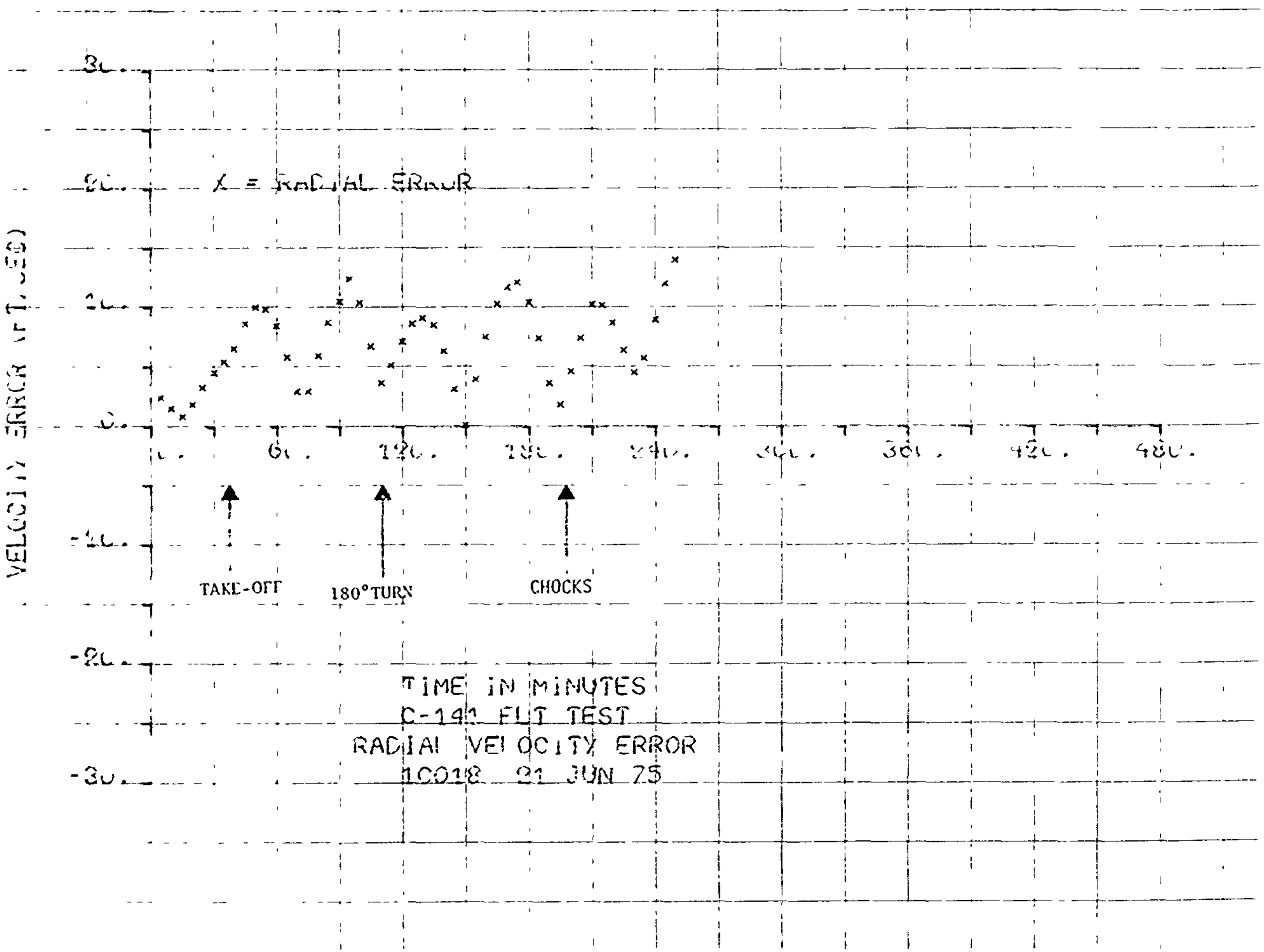

POSITION ERROR (NM)
+ = LATITUDE
□ = LONGITUDE
TAXI-OFF
180°TURN
CHOCKS
-8.
TIME IN MINUTES
C-141 FLT TEST
LATITUDE AND LONGITUDE
POSITION ERROR
10018 21 JUN 75

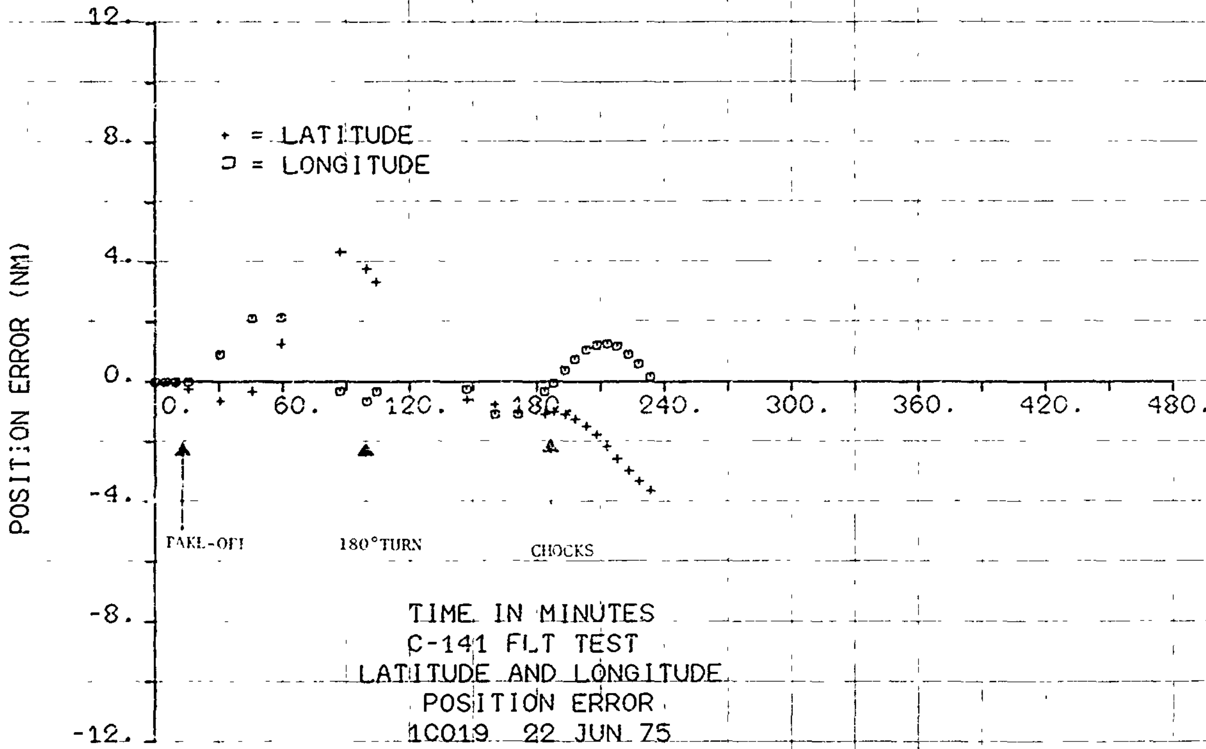


TIME IN MINUTES
C-141 FLT TEST
RADIAL POSITION ERROR
1C018 21 JUN 75

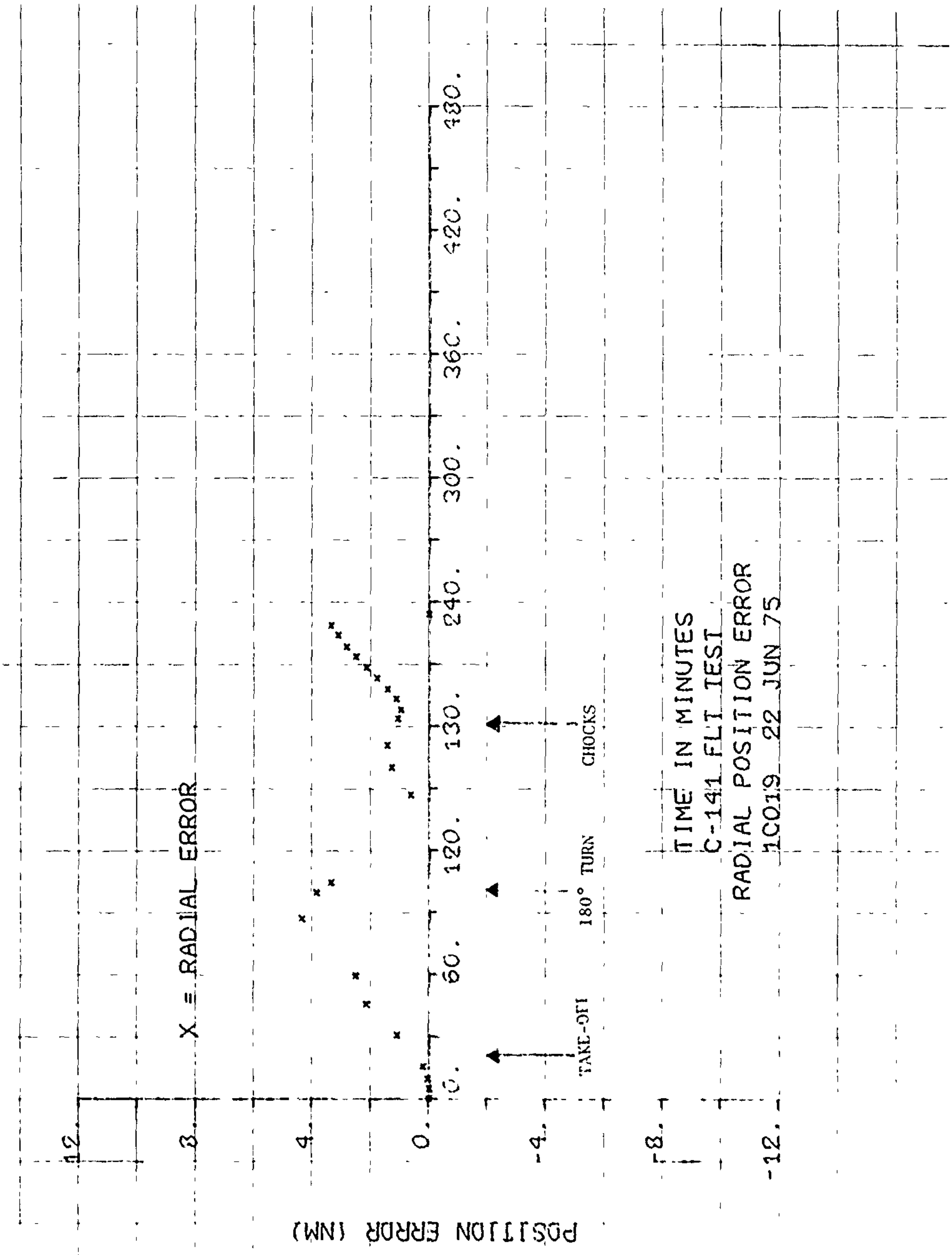


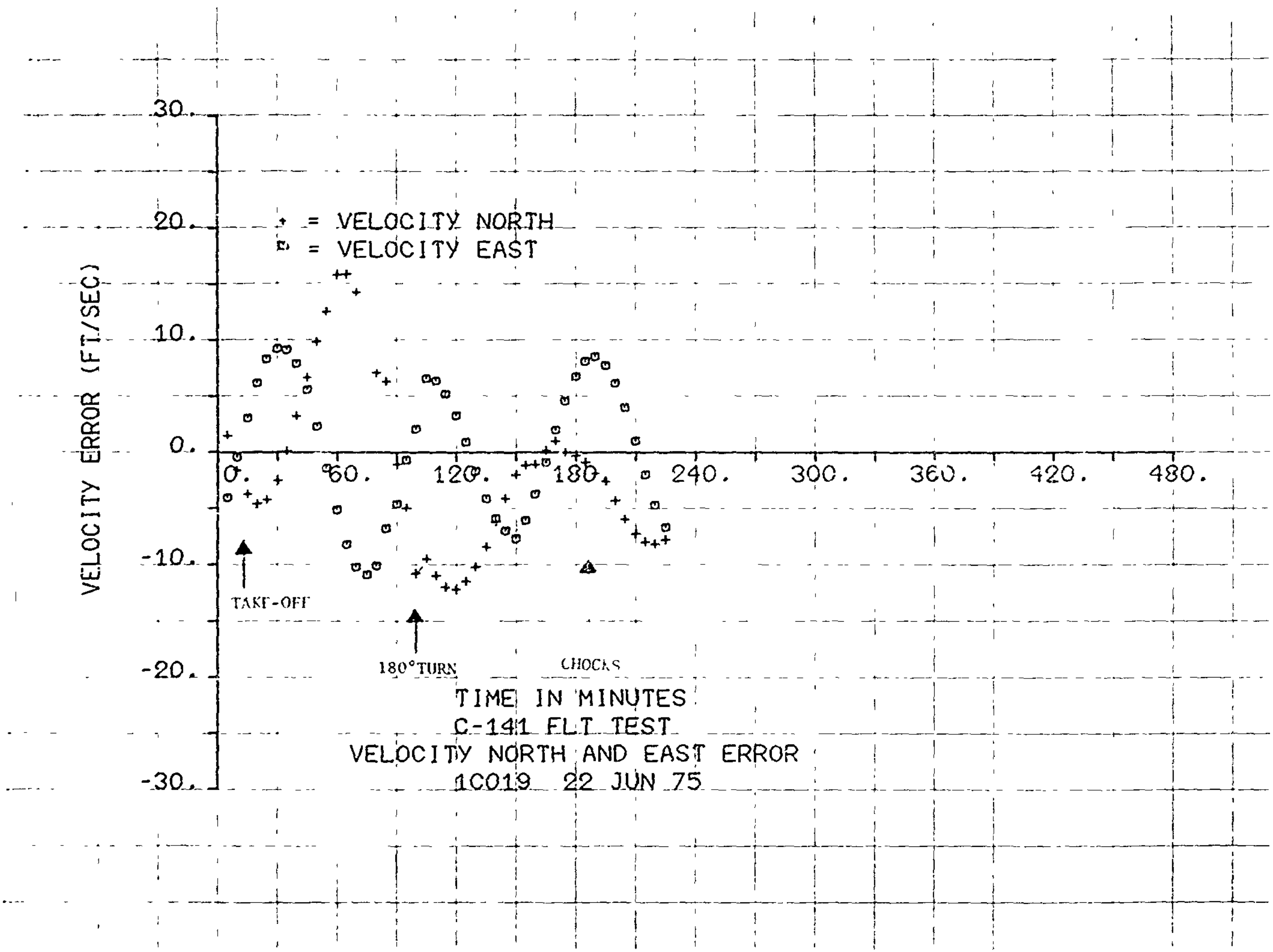
C-141 FLT TEST
VELOCITY NORTH AND EAST ERROR
1C018 21 JUN 75

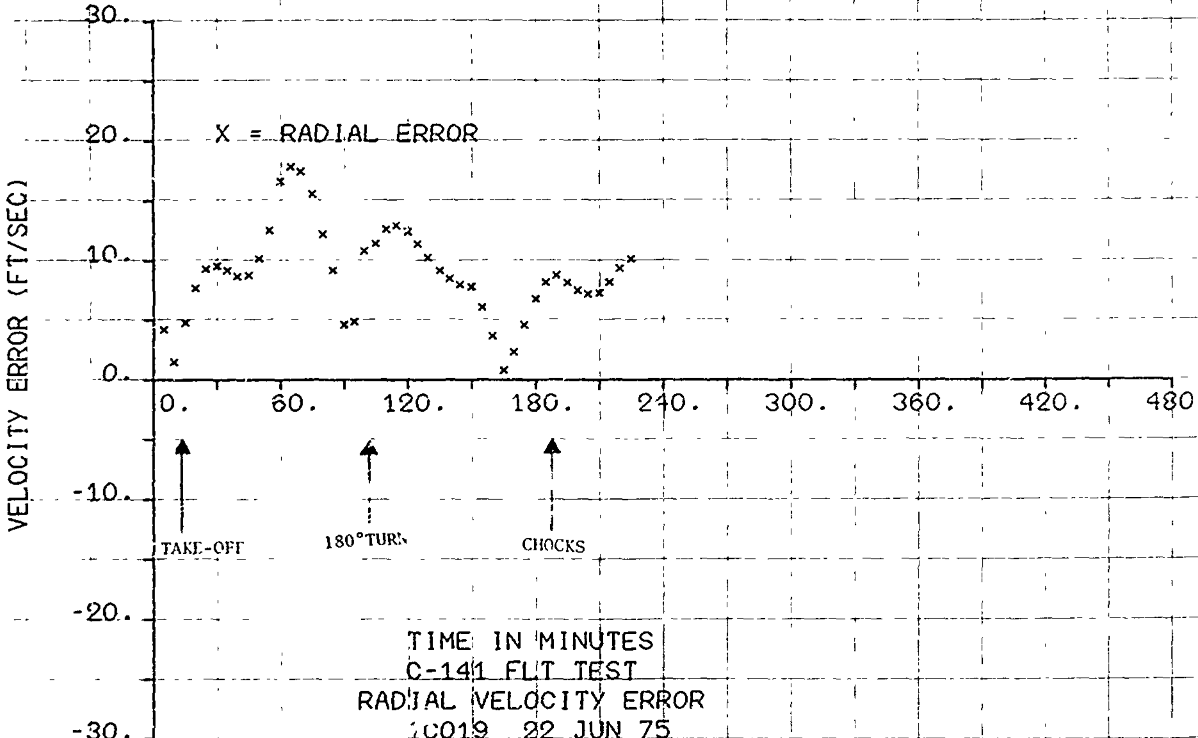

VELOCITY ERROR (FT/SEC)
30.
20.
10.
0.
-10.
-20.
-30.
X = RADIAL ERROR
0.
60.
120.
180.
240.
300.
360.
420.
480.
TAKE-OFF
180° TURN
CHOCKS
TIME IN MINUTES
C-141 FLT TEST
RADIAL VELOCITY ERROR
1C018 21 JUN 75

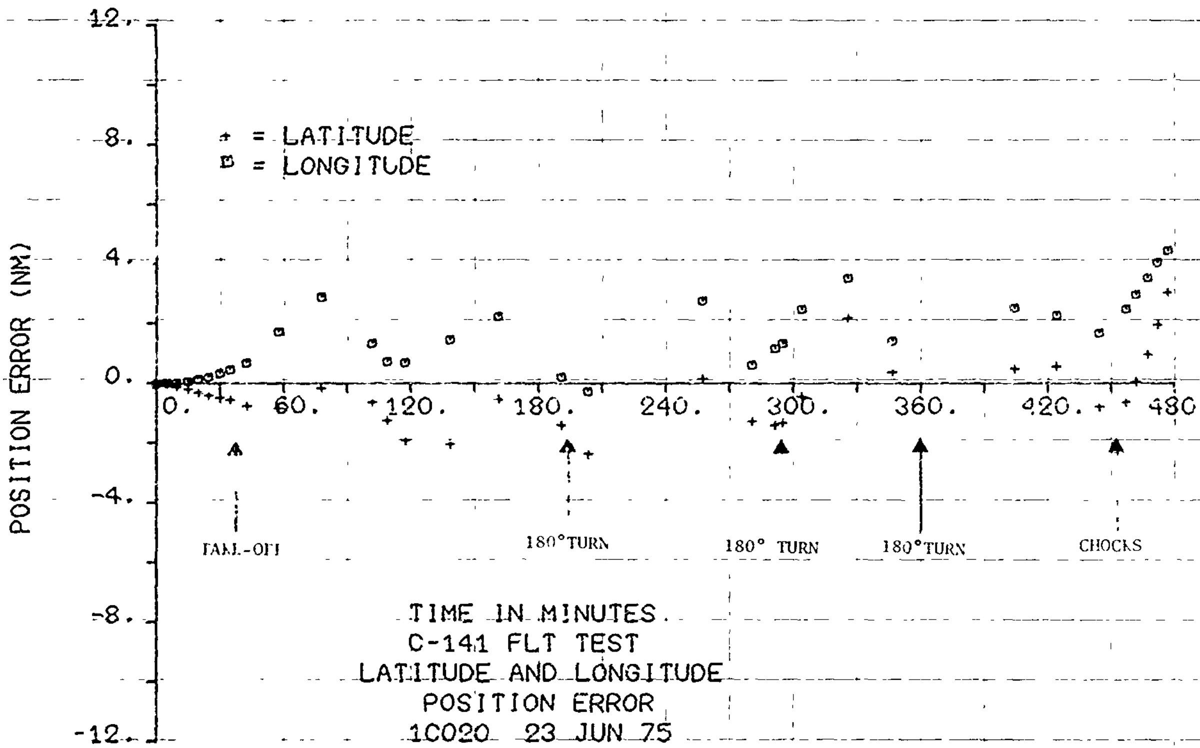


+ = LATITUDE
□ = LONGITUDE
POSITION ERROR (NM)
12.
8.
4.
0.
-4.
-8.
-12.
0.
60.
120.
180.
240.
300.
360.
420.
480.
TAKE-OFF
180°TURN
CHOCKS
TIME IN MINUTES
C-141 FLT TEST
LATITUDE AND LONGITUDE
POSITION ERROR
1C019 22 JUN 75

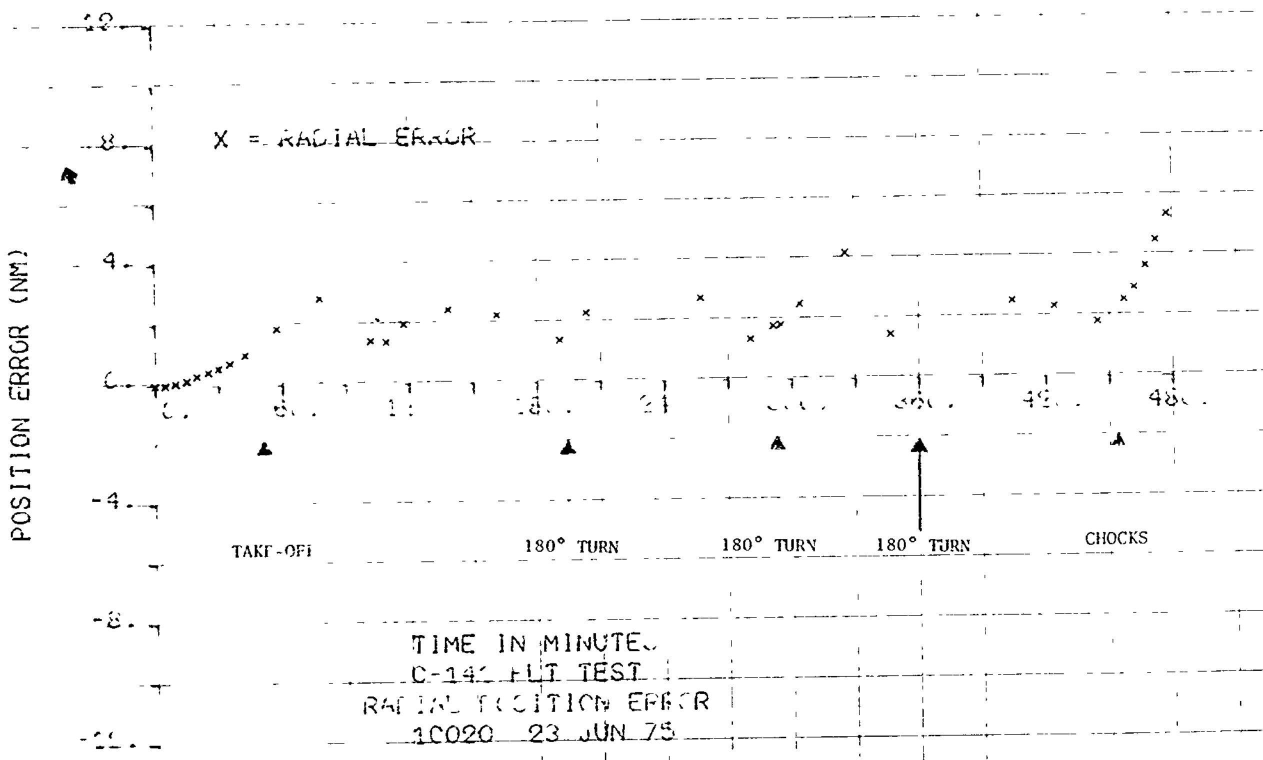

X = RADIAL ERROR
POSITION ERROR (NM)
12.
8.
4.
0.
-4.
-8.
-12.
0.
60.
120.
180.
240.
300.
360.
420.
480.
TAKE-OFF
180° TURN
CHOCKS
TIME IN MINUTES
C-141 FLT TEST
RADIAL POSITION ERROR
1C019 22 JUN 75

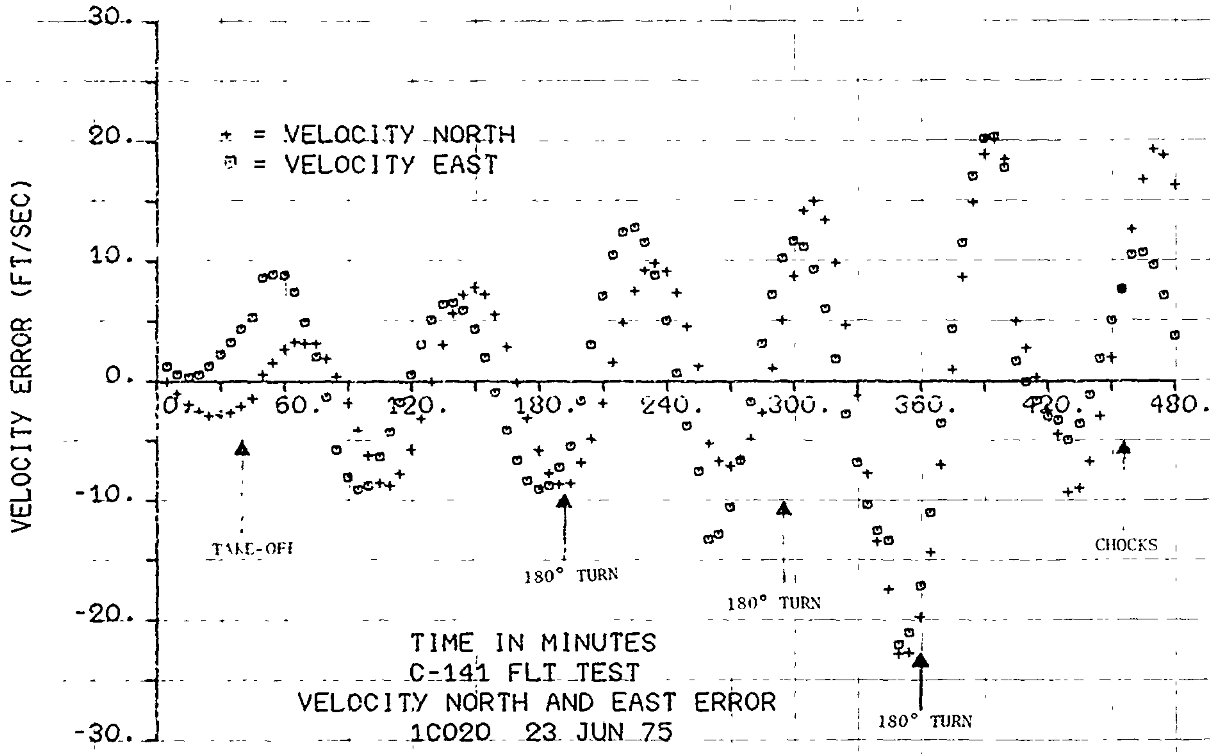

VELOCITY ERROR (FT/SEC)
30.
20.
10.
0.
-10.
-20.
-30.
0.
60.
120.
180.
240.
300.
360.
420.
480.
+ = VELOCITY NORTH
¤ = VELOCITY EAST
TAKE-OFF
180° TURN
CHOCKS
TIME IN MINUTES
C-141 FLT TEST
VELOCITY NORTH AND EAST ERROR
1C019 22 JUN 75

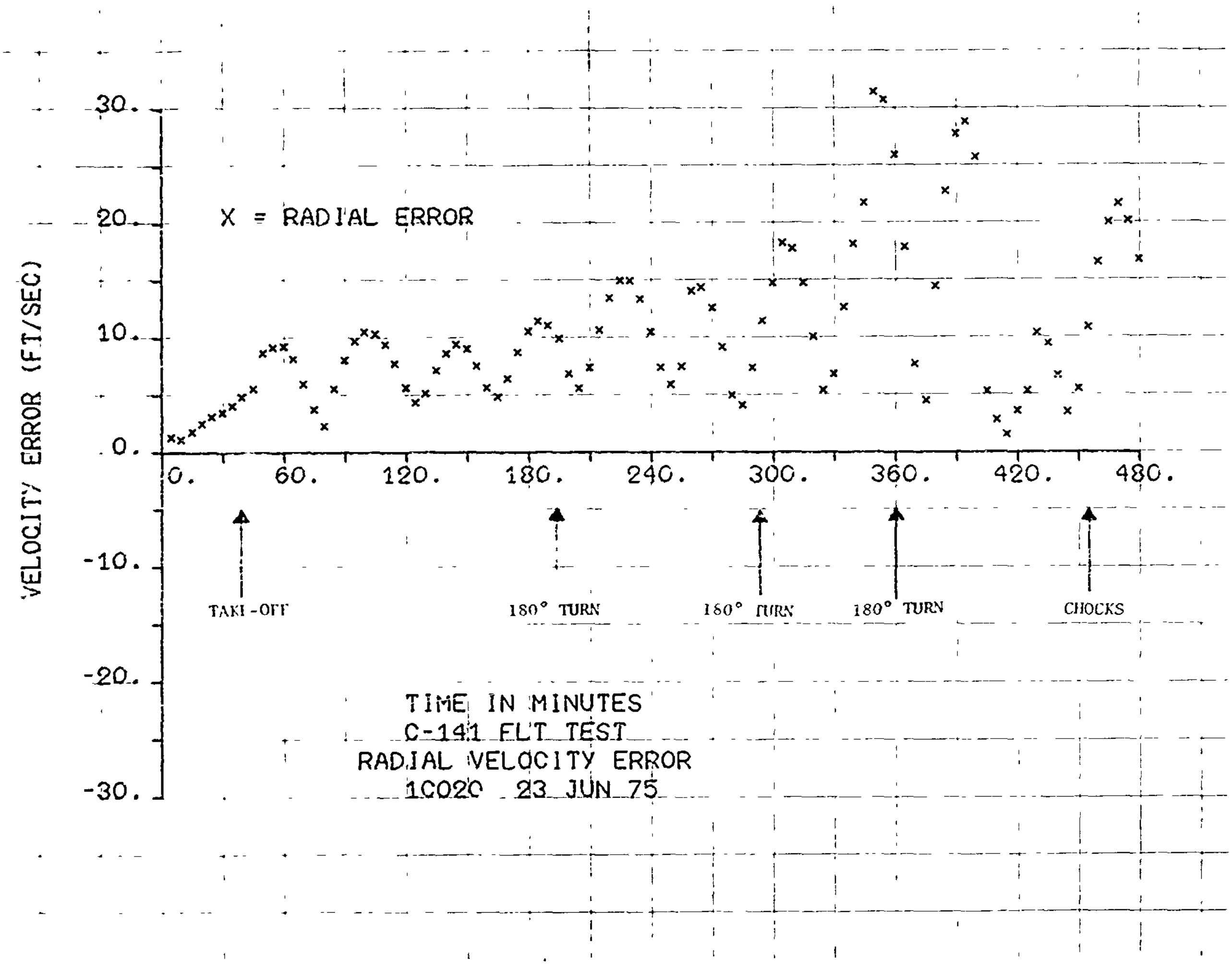

VELOCITY ERROR (FT/SEC)
30.
20.
10.
0.
-10.
-20.
-30.
X = RADIAL ERROR
0.
60.
120.
180.
240.
300.
360.
420.
480.
TAKE-OFF
180°TURN
CHOCKS
TIME IN MINUTES
C-141 FLT TEST
RADIAL VELOCITY ERROR
CO19 22 JUN 75

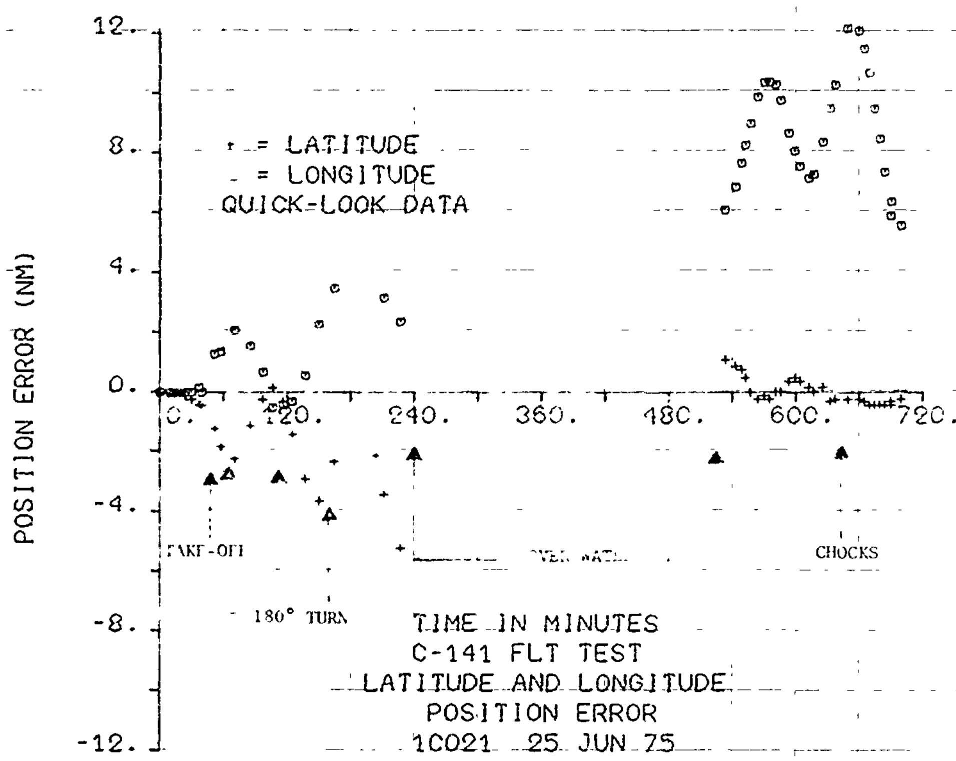


C-141 FLT TEST
LATITUDE AND LONGITUDE
POSITION ERROR
1C020 23 JUN 75


POSITION ERROR (NM)
X = RADIAL ERROR
TAKE-OFF
180° TURN
180° TURN
180° TURN
CHOCKS
TIME IN MINUTES
C-141 FLT TEST
RADIAL POSITION ERROR
10020 23 JUN 75


+ = VELOCITY NORTH
⊡ = VELOCITY EAST
VELOCITY ERROR (FT/SEC)
30.
20.
10.
0.
-10.
-20.
-30.
0
60.
120.
180.
240.
300.
360.
420.
480.
TAKE-OFF
180° TURN
180° TURN
180° TURN
CHOCKS
TIME IN MINUTES
C-141 FLT TEST
VELOCITY NORTH AND EAST ERROR
1C020 23 JUN 75

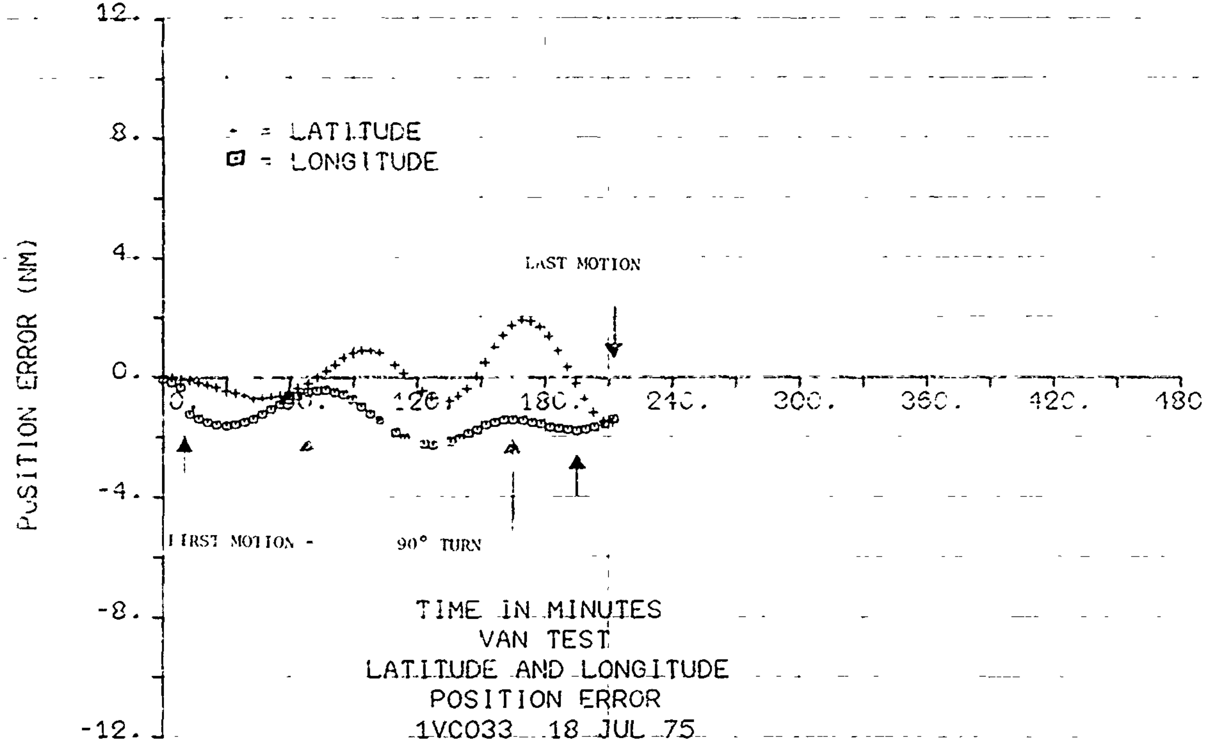

VELOCITY ERROR (FT/SEC)
30.
20.
10.
0.
-10.
-20.
-30.
X = RADIAL ERROR
0.
60.
120.
180.
240.
300.
360.
420.
480.
TAKE-OFF
180° TURN
180° TURN
180° TURN
CHOCKS
TIME IN MINUTES
C-141 FLT TEST
RADIAL VELOCITY ERROR
1C020 23 JUN 75


+ = LATITUDE
= LONGITUDE
QUICK-LOOK DATA
POSITION ERROR (NM)
12.
8.
4.
0.
-4.
-8.
-12.
0.
120.
240.
360.
480.
600.
720.
TAKE-OFF
180° TURN
CHOCKS
TIME IN MINUTES
C-141 FLT TEST
LATITUDE AND LONGITUDE
POSITION ERROR
1C021 25 JUN 75

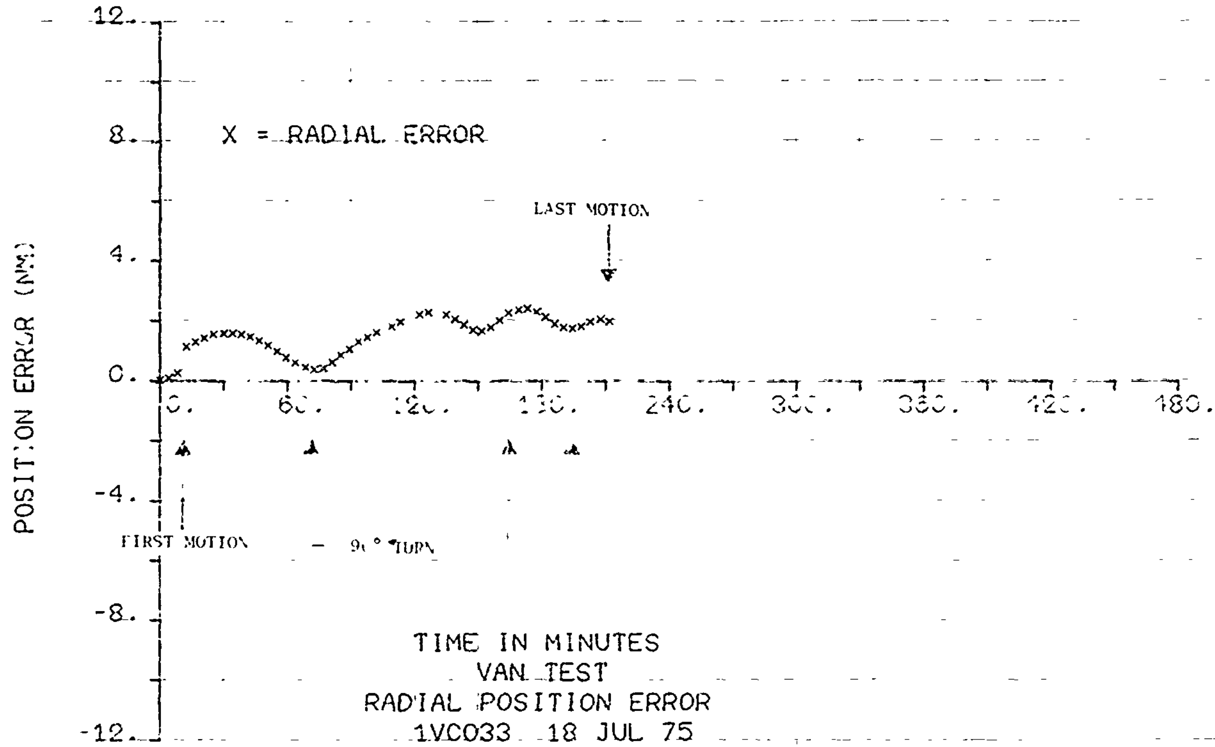
3. <u>VAN TEST RECORDS</u>

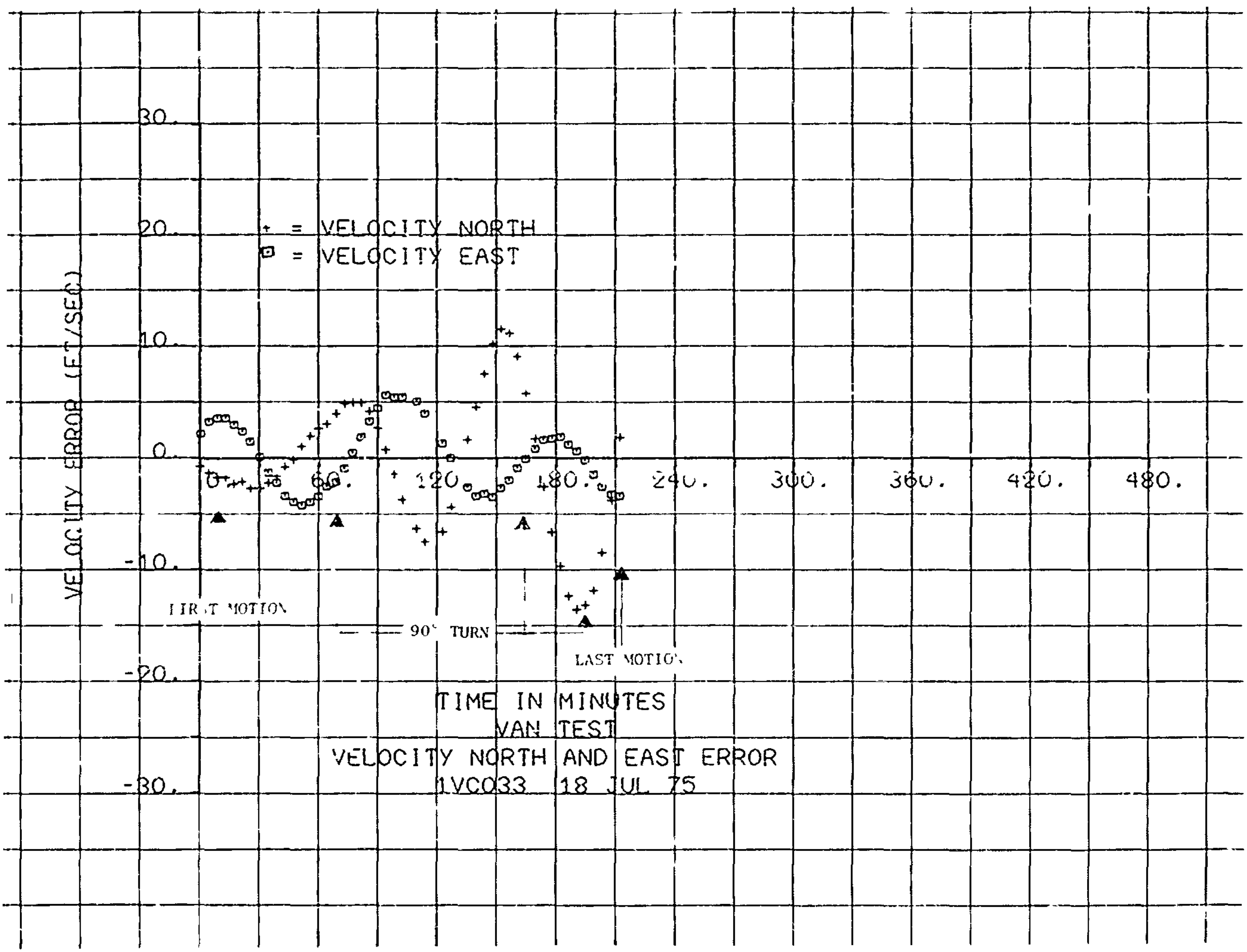
3.1 One van test (IVC033) was conducted on 18 July 1975 using CIRIS as a reference. The route traveled began at Holloman AFB, proceeding southwest for 100 minutes, north for 30 minutes and east for 27 minutes. The duration of the test, when the van was in motion, was 3.6 hours with a total navigation time of 3.7 hours. The radial position error rate was 0.75 nautical miles per hour. See paragraph 3.5, Appendix A, for definition of radial position error rate.

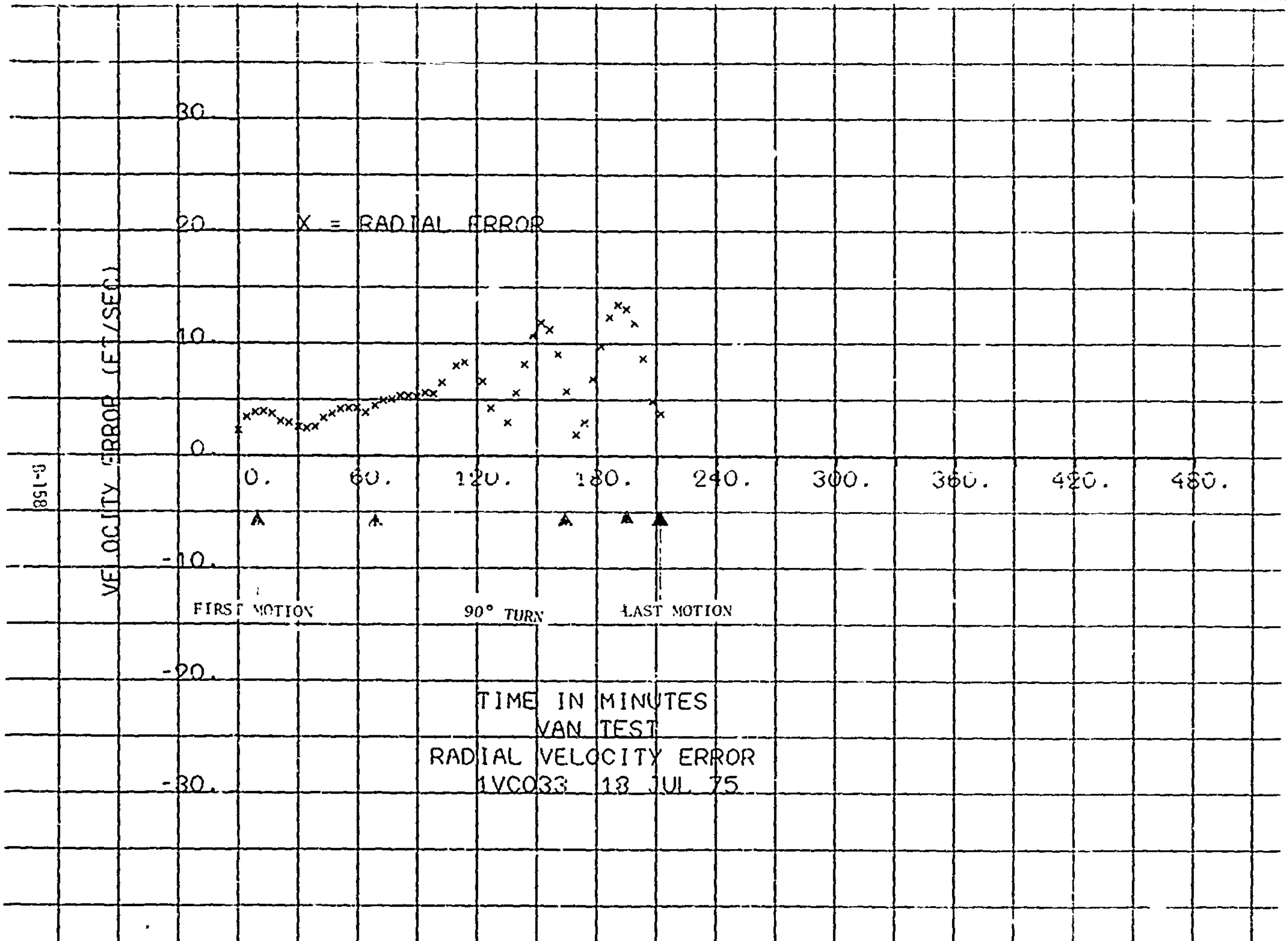
Pages B-155 through B-158 contain plots of the latitude/longitude position errors, the north/east velocity errors, and the radial errors for the one van test.



VAN TEST
LATITUDE AND LONGITUDE
POSITION ERROR
1VC033 18 JUL 75


POSITION ERROR (NM)
12.
8.
4.
0.
-4.
-8.
-12.
X = RADIAL ERROR
LAST MOTION
FIRST MOTION
90° TURN
0.
60.
240.
480.
TIME IN MINUTES
VAN TEST
RADIAL POSITION ERROR
1VC033 18 JUL 75


+ = VELOCITY NORTH
⊡ = VELOCITY EAST
VELOCITY ERROR (FT/SEC)
30.
20.
10.
0.
-10.
-20.
-30.
0.
60.
120.
180.
240.
300.
360.
420.
480.
FIRST MOTION
90° TURN
LAST MOTION
TIME IN MINUTES
VAN TEST
VELOCITY NORTH AND EAST ERROR
1VC033 18 JUL 75


30.
20.
10.
0.
-10.
-20.
-30.
VELOCITY ERROR (FT/SEC)
X = RADIAL ERROR
0.
60.
120.
180.
240.
300.
360.
420.
480.
FIRST MOTION
90° TURN
LAST MOTION
TIME IN MINUTES
VAN TEST
RADIAL VELOCITY ERROR
1VC033 18 JUL 75

REFERENCES

1. "Maximum Likelihood Estimation of the Distribution of Radial Error" by Francis J. Mason, Lt, USAF, CIGTF Working Paper WP-MDSGA-65-4, dated September 1965, Revised 1 October 1969.

2. "Inertial System Performance" by L. L. Rosen and D. L. Harmer, Autonetics Corporation, Third Inertial Guidance Test Symposium Proceedings, MDC-TR-66-106, Volume I, 19-21 October 1966.

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