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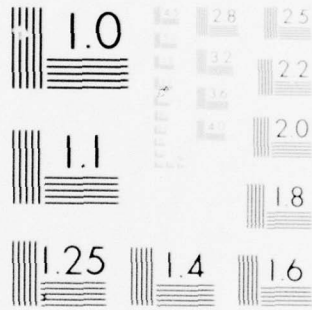
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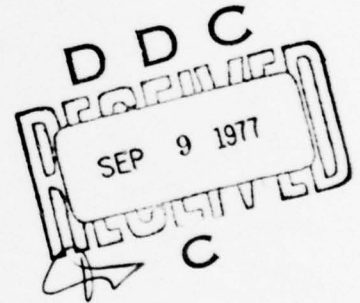
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TECHNICAL REPORT TG-77-16

PERSHING PII INERTIAL MEASUREMENT UNIT
FIELD GYROCOMPASS TEST

Guidance and Control Directorate
Technology Laboratory

June 1977



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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report presents a description of the PERSHING PII Inertial Measurement Unit field gyrocompass test which provided the first accuracy data outside a benign laboratory environment. Results are presented and discussed. It was determined that RMS and average errors increased under field conditions but the standard deviation, about the average at each azimuth heading for which data were taken, was essentially the same as laboratory results. A temperature related anomaly was identified which will be an item for close scrutiny during future tests. → ABSTRACT (Continued)			

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→ No catastrophic performance breakdown occurred; however, since errors tend to grow when the equipment is operated outside a benign laboratory environment, no relaxation of the current gyrocompass accuracy specification is recommended. ↙

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CONTENTS

	Page
I. INTRODUCTION...	3
II. TEST OBJECTIVE.	3
III. DISCUSSION OF TEST SETUP.	3
IV. TEST OPERATIONS AND CONDITIONS.	14
V. TEST DATA	15
VI. DISCUSSION OF RESULTS	15
VII. CONCLUSIONS AND RECOMMENDATION.	20
Appendix A. TEST PROCEDURE.	21
Appendix B. RAW DATA SAMPLE	34
Appendix C. AVERAGE POWER SPECTRA OF ACCELEROMETER DATA	53
Appendix D. SUMMARY OF TEST RESULTS	85

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SP5 Douglas Isaacson of the Atmospheric Sciences Laboratory, US Army Electronics Command, acquired, reduced, and provided meteorological data.

I. INTRODUCTION

The PERSHING PII Inertial Measurement Unit (IMU) features the capability of azimuth self-alignment. This operational mode, often referred to as gyrocompassing, allows determination of the azimuth heading of the X (downrange) accelerometer input axis for targeting purposes without using external reference equipment and operating personnel.

Internal instrument and electronic anomalies and base motions coupled from the outside world through the launcher and missile body to the IMU are among the error sources which degrade gyrocompass performance. The latter error source comes into play in a field environment situation and it is this source which the field test was designed to address.

Two Engineering Models (EM) IMU's have been subjected to extensive gyrocompass tests to determine self-alignment performance within a benign laboratory environment. These tests have provided a good indication of gyrocompass performance in the absence of base motions.

II. TEST OBJECTIVE

The objective of this test was to determine if gyrocompass accuracy degrades by a significant amount when the IMU is exposed to base motions and other environmental stimuli such as may be experienced outdoors with the unit installed in a missile which is mounted on an Erector-Launcher (EL).

The test was designed to provide initial data when operating under essentially ambient, outdoor environmental stimuli and should not be construed to be an all-inclusive, finely controlled test operation. Such a full-scale test will be performed by the prime contractor during the second quarter of CY77 in which actual PII missile body hardware will be utilized.

The early test was designed to provide 3 to 6 months lead time for addressing any problems that may surface while the full-scale test is under preparation by the prime contractor.

III. DISCUSSION OF TEST SETUP

The test was performed using a PERSHING Pla missile system. The Guidance and Control (G&C) section shroud was modified to provide access for interconnecting cables, a cooling air hose, and manual rotation of the IMU case. The ST-120 platform and mount were removed and a specially designed test fixture was installed which housed the PII IMU. Figure 1 shows the modified G&C section with test fixture and IMU installed in the normal operating position.

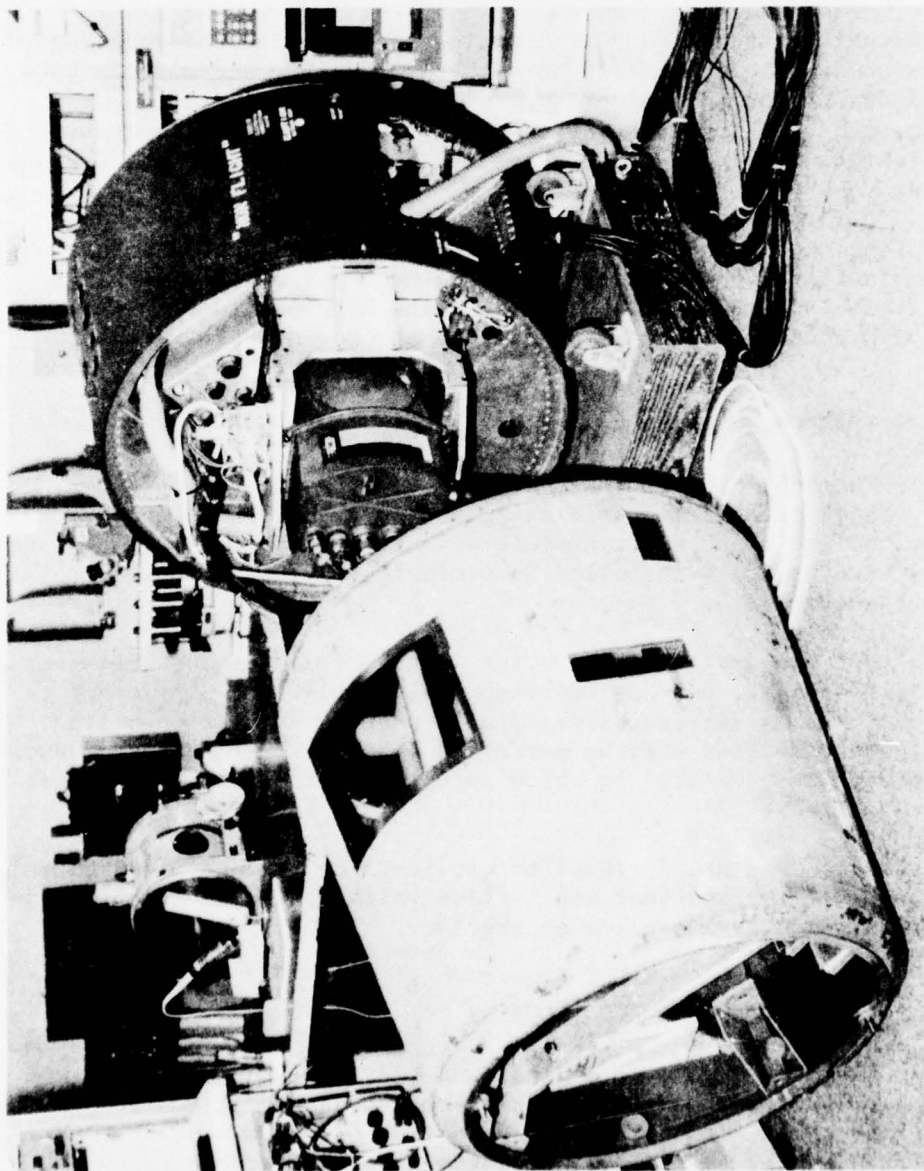


Figure 1. IMU installed in modified G&C section, normal position.

The test fixture incorporates a rotatable member which is dowel-pinned and fastened with bolts at the nominal azimuth orientation of the IMU case prior to entering the gyrocompass mode. At the completion of a gyrocompass run, the test fixture can be manually rotated through approximately 103° and dowel-pinned at this point. This rotation of the IMU allows acquisition of the cluster mounted mirror for obtaining accuracy data by optical means. Figure 2 shows the IMU at the 103° position with the optical access port in view.

The G&C section weight and center of gravity were adjusted to approximate that of an unmodified Pla G&C section with standard equipment on board, by the use of lead weights.

The section was installed on an EL-mounted missile. The system, complete with dummy warhead, is shown in Figure 3.

The test was performed in the vicinity of the PERSHING Modification Shop (Mod Shop), Building 5671.

Figure 4 shows a typical test setup in the Mod Shop area. A concrete pad, approximately 5 feet \times 5 feet and 2 feet high, was installed to serve as a stable base for theodolite No. 2 (T2). T2 was used in conjunction with Theodolite No. 1 (T1) and the Reference Monument Prism (RMP) to determine azimuth orientation of the X accelerometer input axis, via use of the IMU cluster mirror (CM) at the end of each gyrocompass run.

Figure 5 shows the missile G&C section as viewed from the T2 position. Figure 6 shows the RMP in the left foreground and the missile nose in the center background as viewed from the T1 area.

The complete test setup, except for meteorological instrumentation, is shown in Figure 7.

The test equipment van (TEV) in the foreground of Figure 7 housed all IMU test and instrumentation equipment. An interior view of the TEV is shown in Figure 8.

The heavy vehicle in Figure 7 was driven in the vicinity of the EL during certain of the test runs to impart disturbances to the system.

Meteorological instrumentation equipment used to provide ambient wind speed and direction is shown in Figure 9.

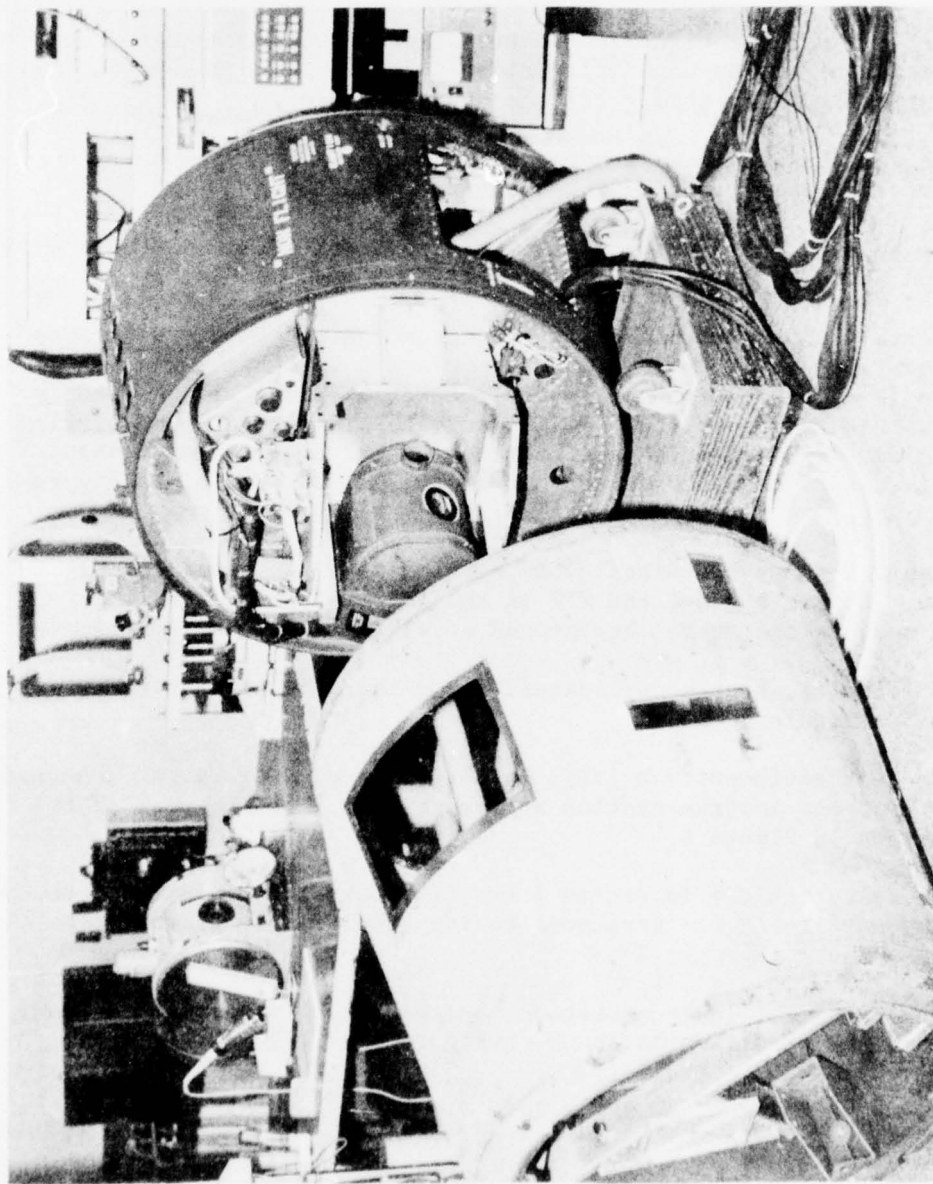


Figure 2. IMU rotated in mounting fixture, optical port exposed.

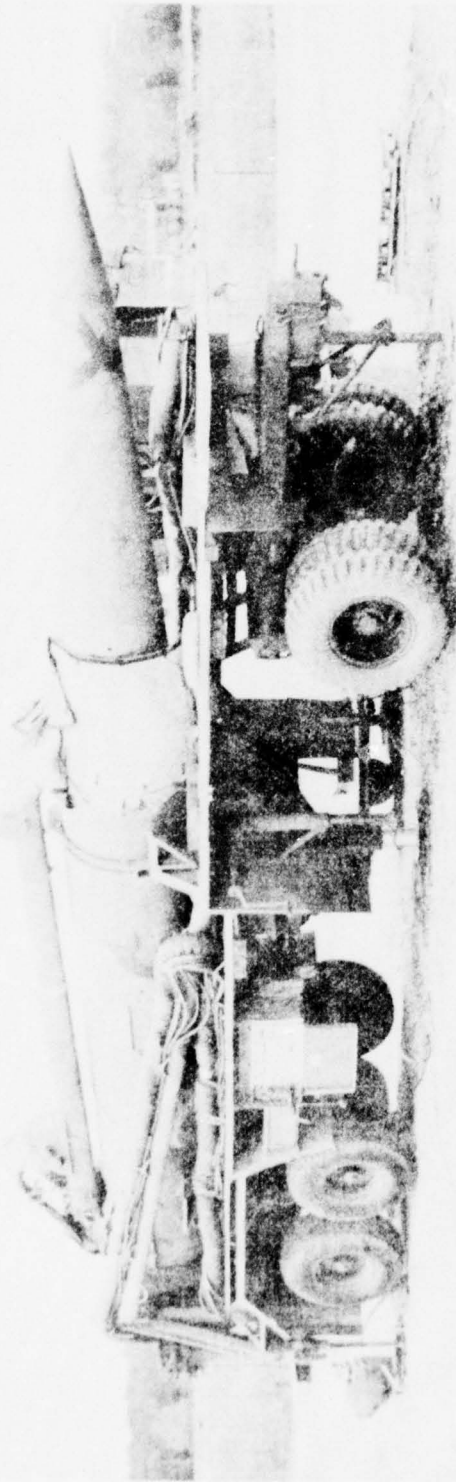


Figure 3. EL-mounted missile system ready for test.

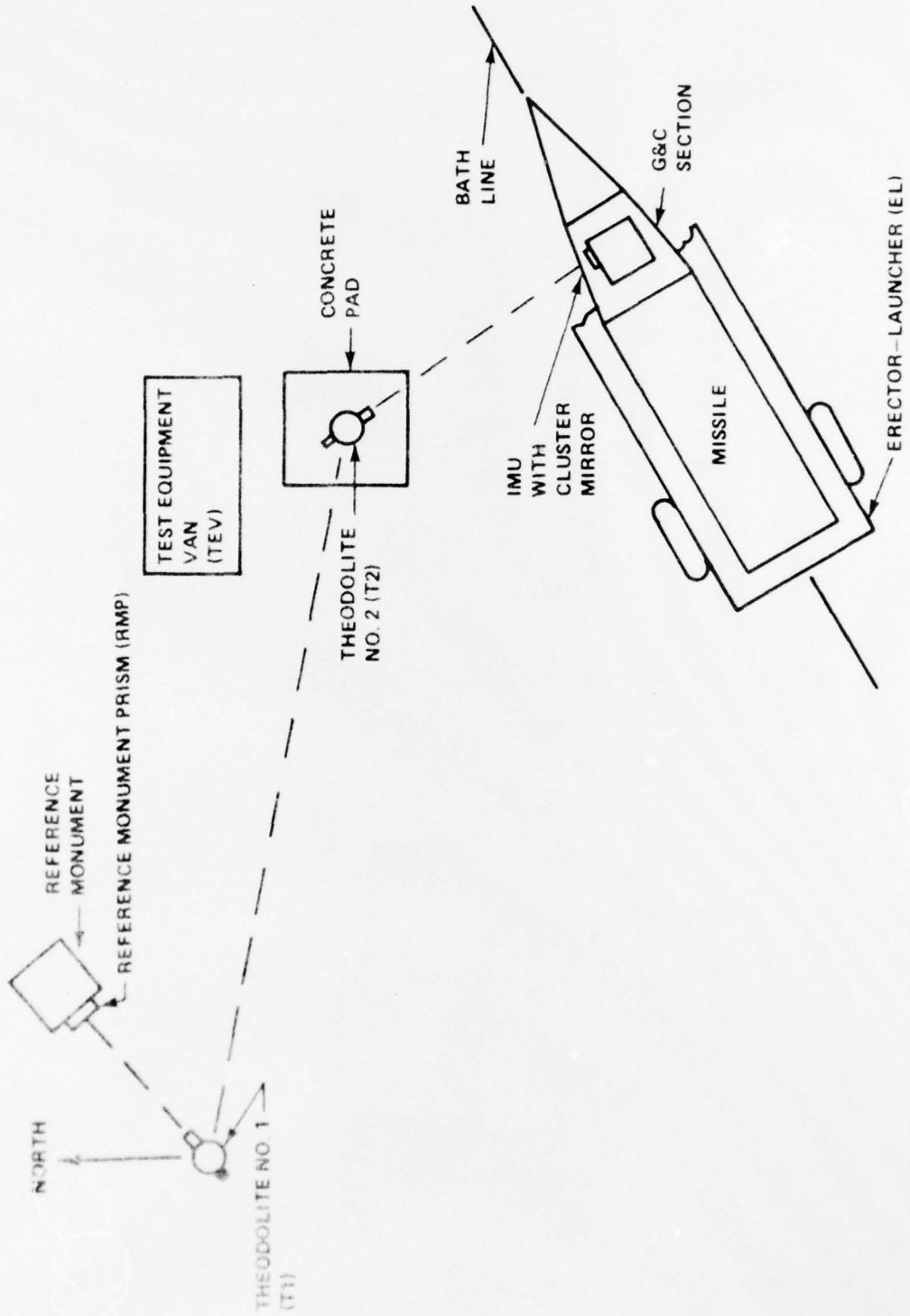


Figure 4. MOD shop area typical test setup.

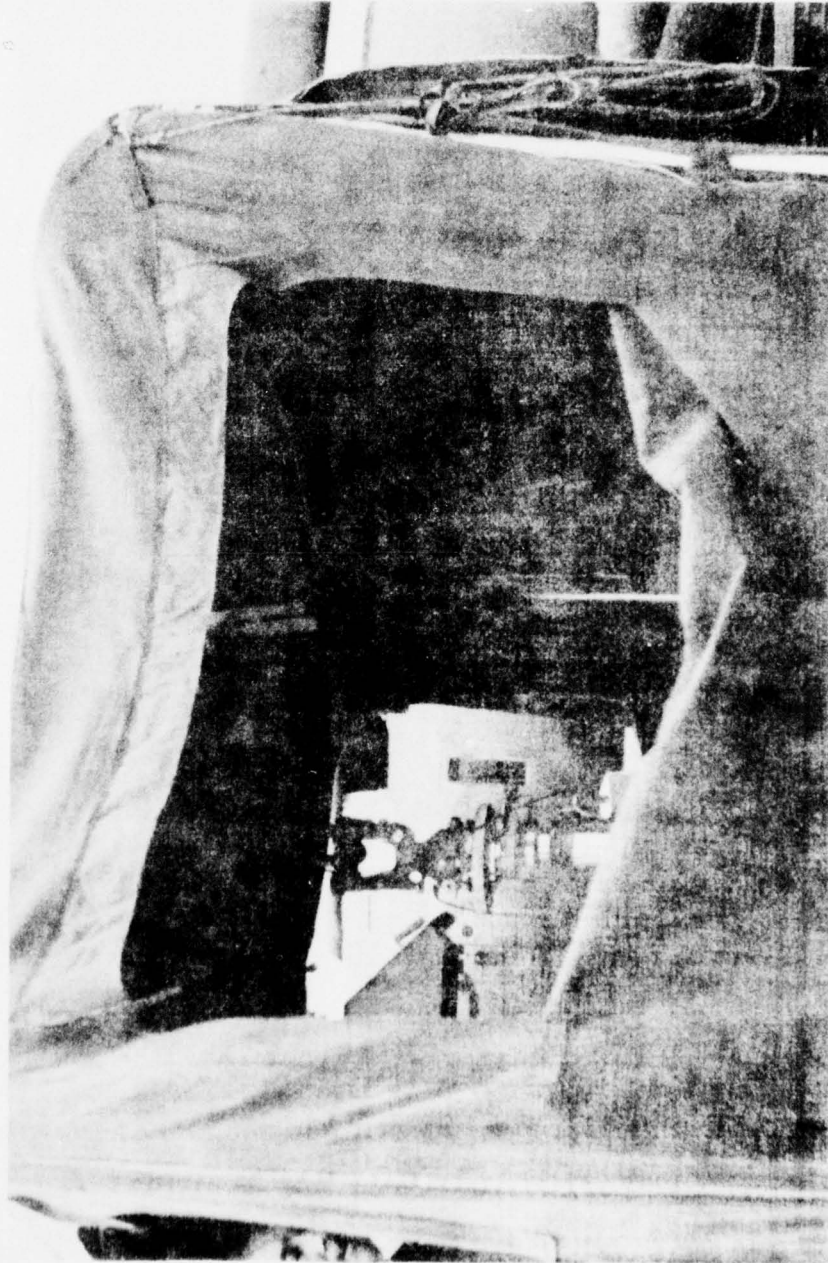


Figure 5. Missile G&C section viewed from T2 position.



Figure 6. Reference monument prism and nose of missile viewed from T1 area.



Figure 7. Field test setup.

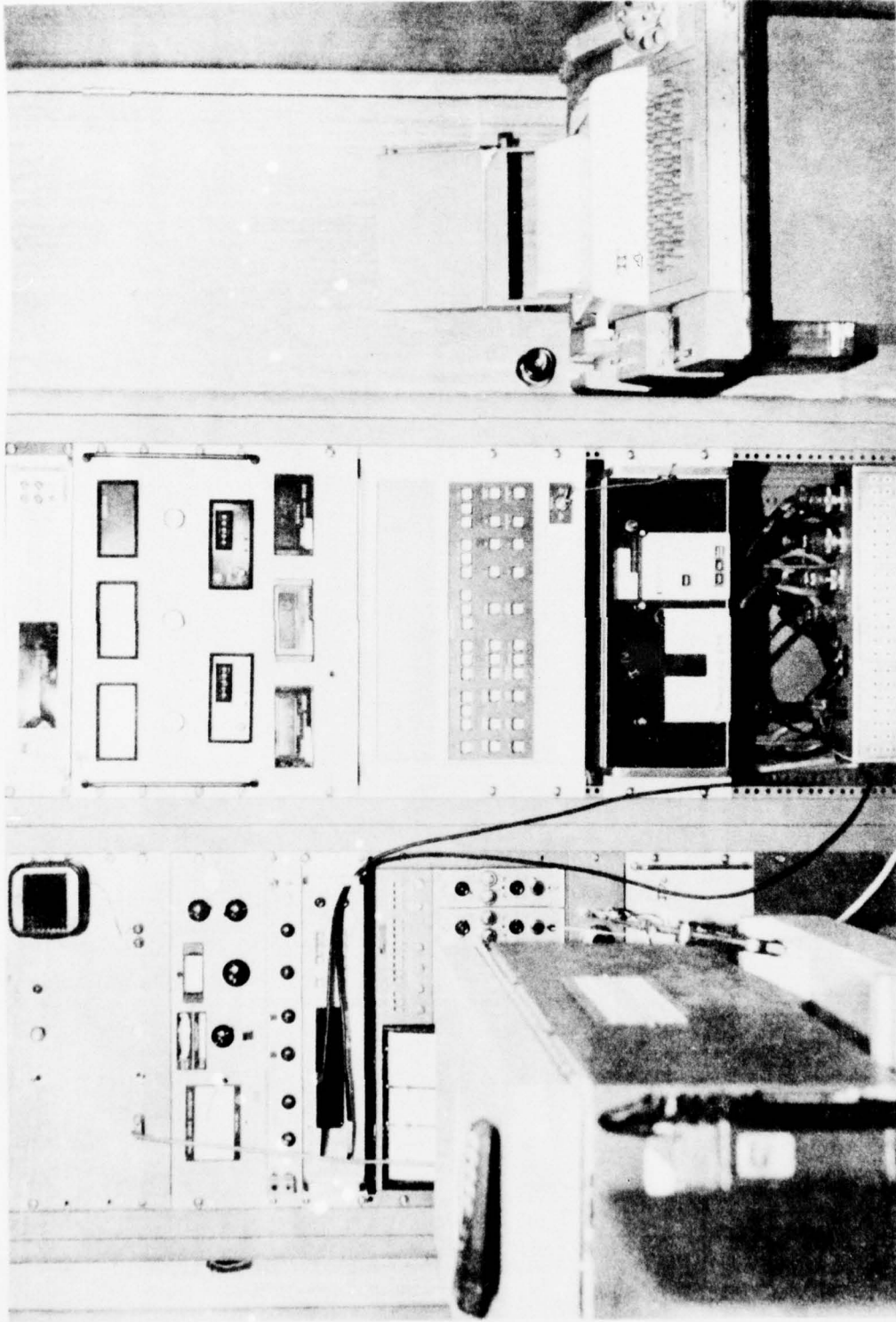


Figure 8. Interior of test equipment van.

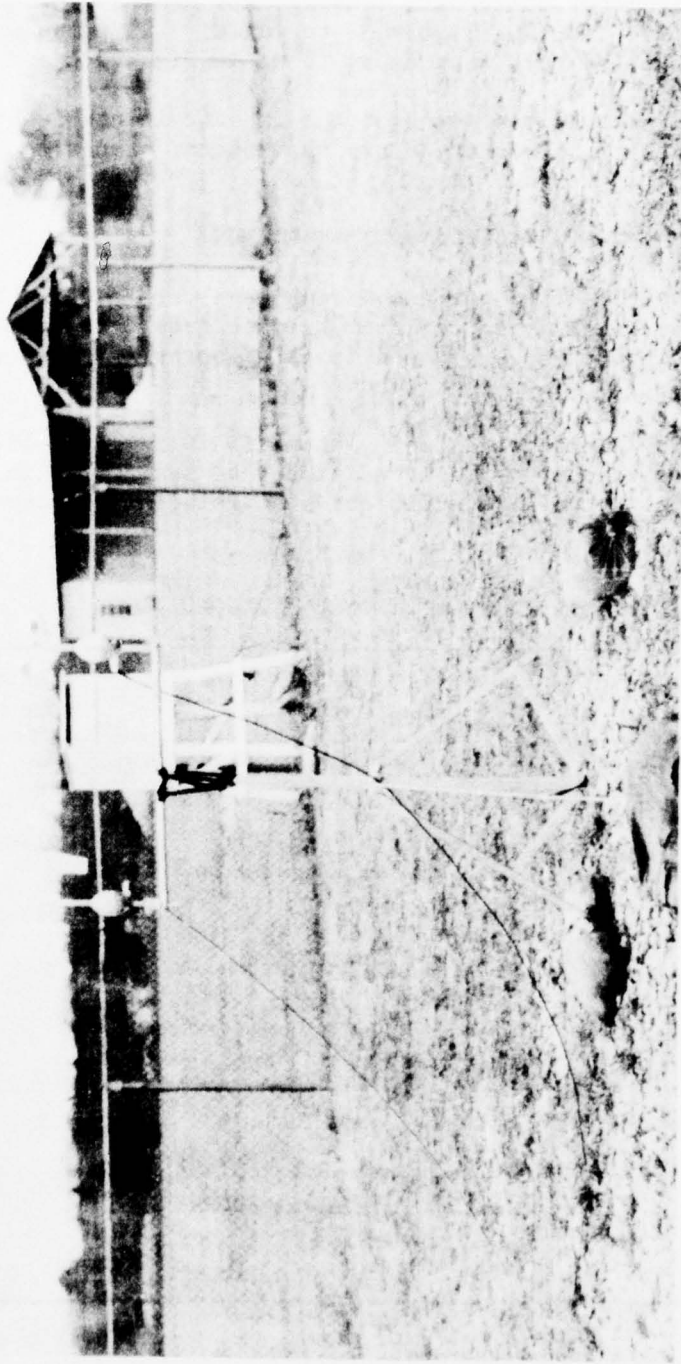


Figure 9. Meteorological instrumentation equipment.

Environmental disturbances imparted to the IMU case were monitored by an accelerometer triad with sensing axes nominally along the roll (X), pitch (Y), and yaw (Z) axes of the unit. The triad was mounted to the top of the IMU test fixture as shown in Figures 1 and 2.

Temperature was monitored at the IMU air inlet and at the accelerometer triad with a pair of quartz thermometer probes.

IV. TEST OPERATIONS AND CONDITIONS

A total of 64 gyrocompassing runs were made at 8 different headings approximately 45° apart. Azimuth data were taken optically using the same procedure as used in the laboratory. The detailed test procedure is given in Appendix A.

Testing was performed during the 2 to 14 December 1976 time period. The prevailing environmental conditions are summarized in Table 1. Corresponding laboratory conditions are included for comparison purposes.

TABLE 1. ENVIRONMENTAL CONDITIONS

Test Condition	Field Environment	Laboratory Environment
Soil condition	Large gravel spread over area (See Figure 7)	Isolated test pad
Weather	Sunny; partly cloudy; cloudy with light rain	Controlled environment
Temperature	29° - 67°F	Controlled at 72°F
Wind	1-13 mph, direction variable	None
Vehicular traffic	During 31 test runs	None
Vehicle idling	During 24 test runs	
Beside EL		
No vehicle operation	During 9 test runs	
IMU case orientation		
Pitch	0.4° fore axis down	0°
Roll	4.5° clockwise from aft	0°

V. TEST DATA

Optical, meteorological, and acceleration data were acquired for each of the 64 test runs. Appendix B presents a sample of raw data for each of these parameters. A heading of 180° was arbitrarily chosen as the position for which the raw data are given.

Average power spectra of accelerometer data were determined for each of the three axes monitored. A discussion of average power spectra and results from each of 8 runs at 180° heading are presented in Appendix C. Average power spectra for each of the three accelerometer channels operating in the laboratory are also presented.

Appendix D contains a summary of gyrocompass accuracy test results. Detailed data obtained from each of 8 test runs at each of 8 azimuth headings are presented along with the statistical results. The 40° and 70° headings were used rather than 45° and 90° headings, respectively, because of difficulty in positioning the EL at these headings.

The reduced data are further summarized, compiled, and plotted for comparison with pretest and post-test laboratory performance. Composite statistics are presented for the 64 pretest runs, the 64 field-test runs, and the 64 post-test runs for comparison purposes.

Pretest and post-test calibration data are also presented as part of Appendix D.

VI. DISCUSSION OF RESULTS

Figures D-1 and D-2 of Appendix D readily show the increase in RMS and average errors resulting from field-test runs over pretest and post-test runs. At a given heading, however, Figure D-3 of Appendix D shows that no great variations in standard deviations exist among the three test conditions. When the composite statistics for the field test, as shown in Table D-10 of Appendix D, are examined it is noted that if the average error had been near zero (as for pretest or post-test average error) the RMS error would approximate the one-sigma value of 66 arc sec. This is indicative of the fact that even though the standard deviation about the average at an individual heading is comparable to laboratory data, the peak error swings in the field are significantly greater. This can be visualized by drawing a horizontal axis at 40 arc sec average error on Figure D-2 of Appendix D and comparing the peak swings about this offset to those of the other two test conditions with offsets near zero. Thus, without an offset, the field RMS error would still be larger than the laboratory errors.

The exact cause of increased error in the field is undetermined; however, in the discussion that follows potential sources are examined.

It is noted from Table D-10 of Appendix D that during certain of the test runs the laboratory latitude rather than the test site latitude was mistakenly entered into the gyrocompass program. It can be shown that a reasonable approximation of azimuth error, σ_L , due to misbiasing the west gyro caused by a small incorrect latitude input is given by

$$|\sigma_L| = |\Delta\lambda \tan \lambda| \quad (1)$$

in which λ is the correct latitude and $\Delta\lambda$ is the difference between correct and incorrect latitude inputs. For the local latitude and $\Delta\lambda = 41$ arc sec

$$|\sigma_L| = |28| \text{ arc sec} \quad (2)$$

The composite field statistics of Table D-10 of Appendix D are repeated in Table 2 along with the resulting values when the correction of equation (2) is applied in both a positive and negative sense.

TABLE 2. COMPOSITE FIELD STATISTICS

Table D-10 (arc sec)	Positive Sense (arc sec)	Negative Sense (arc sec)
RMS 77	85	71
Avg 40	54	26
σ 66	66	66

The general shape of the pretest and the post-test average error curves of Figure D-3 of Appendix D suggests that the correction should be applied in the negative sense.

Another complicating factor is the non-extension of EL jacks during the same runs for which incorrect latitude setting was applied. An examination of instrumentation accelerometer data reveals that base motions were generally slightly higher when the jacks were supporting the EL; however, it is shown that measured base motions, whether the jacks were extended or not, contribute an insignificant amount of azimuth error.

It can be shown to a reasonable approximation, that gyro drift rate error ($D\epsilon$), due to base vibratory acceleration inputs of the form $G = G_{PN} \sin(N\omega_o t + \phi)$, is given by

$$D\epsilon = \frac{30\sqrt{2}}{t^3 \omega_o^2} \left(\sum_{N=1}^k \frac{G_{PN}^2}{N^4} \right)^{1/2} \text{ rad/sec} \quad (3)$$

where

$G_{PN}(g)$ = peak sinusoidal acceleration at frequency $N\omega_o$

$t(\text{sec})$ = time duration of gyro bias/fine gyrocompass sequence

$\omega_o(\text{rad/sec})$ = lowest sinusoidal base motion frequency present

$N = 1, 2, 3, \dots, k$ such that $k\omega_o$ is the highest acceleration frequency of interest.

An examination of accelerometer average power spectra (180° heading) in Figures D-3 through D-26 of Appendix D shows the variation of the square of peak acceleration input as a function of frequency. Equation (3) indicates that gyro drift rate due to high frequency inputs is insignificant. This, along with the fact that IMU vibration isolators start attenuating case inputs at 40 to 50 hertz, sets the highest frequency of interest at

$$k\omega_o = 2\pi f = 2\pi(50) = 100\pi \text{ rad/sec} \quad (4)$$

Determination of the lowest frequency present is more difficult because uncompensable DC amplifier offset tended to swamp out amplitudes at other frequencies. To obtain reasonable scaling, the spectrum plots were started at 0.5 hertz. Except for the DC component, very little amplitude was noted below 0.5 hertz and for analytical purposes a low frequency of this value was chosen. This gives

$$\omega_o = 2\pi f = 2\pi(0.5) = \pi \text{ rad/sec} \quad (5)$$

and from Equation (4)

$$k = 100 \quad (6)$$

The maximum peak acceleration as determined by the average power spectrum analysis in either the X or Y channel never exceeded 2×10^{-3} g's for any of the 64 test runs.

An extreme worst case condition can be analyzed by assuming that this peak value was present over the total frequency range from 0.5 to 50 hertz. Under this assumption equation (3) can be written as

$$D_{\epsilon} = \frac{30 \sqrt{2} G_{PN}}{t^3 \omega_o^2} \left(\sum_{N=1}^k \frac{1}{N^4} \right)^{1/2} \text{ rad/sec} \quad (7)$$

where

$$G_{PN} = 2 \times 10^{-3} \text{ g}$$

$$t = 240 \text{ sec}$$

$$\omega_o = \pi \text{ rad sec}$$

$$k = 100 \text{ .}$$

By actual computation

$$\sum_{N=1}^{100} \frac{1}{N^4} = 1.082323 \quad (8)$$

so that the square root of the term is taken as unity.

With this approximation and with the values shown substituted into Equation (7)

$$D_{\epsilon} = 6.22 \times 10^{-10} \text{ rad/sec} = 1.28 \times 10^{-4} \text{ deg/hr} \text{ .} \quad (9)$$

Making the assumption that the X and Y gyro error drift rates are equal at both the 0° and 90° positions, a composite drift rate, $D_{\epsilon T}$, is given by

$$D_{\epsilon T}^2 = D_{\epsilon x}^2 (0^\circ) + D_{\epsilon y}^2 (0^\circ) + D_{\epsilon x}^2 (90^\circ) + D_{\epsilon y}^2 (90^\circ) \quad (10)$$

$$D_{\epsilon T}^2 = 4 D_{\epsilon}^2 \quad (11)$$

$$D_{\epsilon T} = 2 D_{\epsilon} \text{ .} \quad (12)$$

The ratio of the composite drift error of equation (12) and local horizontal component of earth's rate ($\Omega \cos \lambda$) gives azimuth error, σ_G , as indicated:

$$\sigma_G = \frac{2 D \epsilon}{\Omega \cos \lambda} = 2.07 \times 10^{-5} \text{ rad} = 4.28 \text{ arc sec} \quad . \quad (13)$$

This is a negligible error even though extreme worst case conditions were assumed. Vehicular traffic and ambient winds therefore apparently contributed an insignificant amount to the errors shown in Table D-10, Appendix D.

Another error source could be possible inaccuracy in the accuracy of line-of-sight heading to the prism which was used as a reference for all test runs.

The line-of-sight heading was established by measuring the angle relative to Polaris. The heading was verified by a gyrocompass which was carefully calibrated in the laboratory, before and after the verification run, at the heading determined by theodolite readings on Polaris. Verification results differed from the original heading by 11 arc seconds and the uncertainty in the reference heading is judged to be in no greater error than this amount.

Operator error is always a possible error source. A review of the raw optical data, however, indicates repeatability comparable to that obtained in laboratory measurements. The fact that the optical measurement equipment was subjected to essentially the same environmental conditions as the test specimen, however, cannot be overlooked.

Re-setup of the system, as described in Appendix D at 225° heading which gave results very similar to those obtained the previous day, gives added confidence that the test setup and measurement operations were performed properly.

The fact that the IMU case was rotated approximately 4.5° about the roll axis and 0.4° about the pitch axis should theoretically cause no azimuth error. A speculation is, however, that some measurement error may have accrued because the optical line-of-sight to the IMU cluster mirror was not perpendicular to the glass in the optical access post.

Pretest and post-test calibration runs as shown in Tables D-11 and D-12, Appendix D, indicate that no unusual parameter changes occurred during the field-test period. This is further evidenced by pretest and post-test gyrocompass performance.

VII. CONCLUSIONS AND RECOMMENDATION

This test has provided the first PERSHING PII IMU gyrocompass accuracy data outside the laboratory. Although RMS and average errors increased by significant amounts, no catastrophic performance breakdown was experienced. Repeatability at each heading did not deviate significantly from laboratory performance.

The most readily identifiable error source which, if corrected, significantly decreases the composite average error and slightly decreases the composite RMS error is the incorrect latitude input for four of the headings. The data in the third column of Table 2, which is corrected in the negative sense, are believed to be the proper representation of system performance.

Little, if any, of the error can be attributed to base motions caused by either vehicular traffic or ambient winds.

Other measurement errors such as operator, reference, and possibly optical glass errors contribute to the system error to some degree but cannot fully account for the rather large swings about the average error.

A significant finding is that the error from the first run in the morning from a cold start differs substantially from the succeeding runs. This phenomenon occurred when the first run was made after only a 9-minute system warm-up as required by the IMU specification. The error does not appear to belong to the succeeding population of errors and is most likely connected with IMU thermal characteristics. The phenomenon can be observed in Tables D-1 through D-8, Appendix D, by noting unusual error values and the accompanying remarks.

It is recommended that this phenomenon be carefully monitored during up-coming tests to be performed with PII hardware by the system contractor.

Use of IMU EM S/N 001 is recommended for the full-scale test for data comparison, particularly in the area of average errors as a function of heading.

It is recognized that the foregoing test results are by no means conclusive; however, the indications are that errors grow when the system is operated outside a benign laboratory environment. This is sufficient reason for non-relaxation of current performance specifications.

Appendix A. TEST PROCEDURE

A. Equipment List

The following equipment is required for performance of the outdoor gyrocompass test:

- 1) Pla missile
- 2) Erector-launcher
- 3) G&C section and shroud modified to accept PII IMU and mounting fixture and to provide access for routing cables, cooling air hose and for manual rotation of IMU case.
- 4) PII IMU
- 5) PII IMU mounting fixture
- 6) PII IMU test equipment
- 7) Cable set, 40 ft long
- 8) Shop vacuum for cooling air
- 9) Magnetic compass, or equivalent, for obtaining best available true heading (BATH)
- 10) Theodolite, 3 each
- 11) Anemometer
- 12) Accelerometer triad for instrumentation
- 13) Thermometer
- 14) Test equipment van
- 15) Tent or umbrella shelters for theodolites
- 16) Multichannel chart recorder
- 17) Multichannel tape recorder

B. Pretest Activities

Prior to start of outdoor testing, a full checkout of the system will be performed in the laboratory.

The IMU mounting fixture will be equipped with an accelerometer triad for measurement of vibrational disturbances, nominally along the three principal axes of the IMU. A quartz thermometer probe will be installed in the IMU cooling air inlet and the accelerometer triad mounting block.

The IMU and mounting fixture will be installed in the G&C section and its weight and center of gravity will be adjusted to approximate P_{1a} values.

Test equipment will be connected to the IMU, through the long (40 ft) cable set and pretest gyrocompass runs will be made very similar to those to be made outdoors, to determine if use of long cables affects gyrocompass performance. Accelerometer triad and thermometer instrumentation will be checked at this time.

The IMU will then be removed from the G&C section and reinstalled on the laboratory test table. A final pretest calibration run will be made, using the long cables to determine if use of long cables produces any significant effect on IMU calibration results.

Pretest activities in the Mod Shop area will involve the laying off of eight lines in the vicinity of the concrete pad at nominal azimuth headings of 0° , 45° , 90° , 135° , 180° , 225° , 270° , and 315° . This will be accomplished by use of a magnetic compass or equivalent device to provide a BATH. The EL will be parked, in turn, with its longitudinal axis nominally along a line to provide gyrocompass data at each of the previously mentioned nominal headings. Combined accuracy of the line layout and EL parking operations will be held within the range of approximately $\pm 5^\circ$.

Following these activities, the G&C section will be taken to the Mod Shop and installed on the missile. The complete system will then be set up outdoors in the typical configuration shown in Figure A-1.

C. Operational Procedure

The procedure for performing gyrocompass tests is outlined as follows:

- 1) Park EL nominally along 0° line in such a manner that the G&C section optical access window can be viewed by T2.
- 2) Connect IMU test cables to test set in TEV, connect accelerometer triad, thermometer and anemometer to test instrumentation equipment, and connect IMU cooling vacuum hose.
- 3) Set up T1 and T2; acquire RMP with T1 and IMU optical port with T2.
- 4) Turn on all power to the TEV and allow instrumentation (accelerometers, thermometer electronics, recording equipment, etc.) to warm up at least 30 minutes.

5) Turn on IMU power and vacuum source and proceed into a preliminary gyrocompass run using laboratory operating procedure set forth in Singer, Kearfott Division (SKD) document number E100F547E110, Revision E. Check for proper operation of accelerometer triad, thermometer, anemometer and recording equipment.

6) When "ALIGN HOLD" event is reached (as printed out by the teletype) remove bolts holding test fixture rotatable member in place and rotate IMU case through approximately 103°. Pin fixture at this point with dowel pin.

7) Acquire IMU cluster mirror with T2. T2 is now positioned such that gyrocompass runs for record can be performed at a nominal heading of 0°.

8) Rotate IMU case to original position (fore axis nominally along missile longitudinal fore axis) and secure with bolts.

9) Set up recording equipment for runs for record (set zeros, scale factors, etc.)

10) Commence gyrocompass run using laboratory operating procedure set forth in SKD document number E100F547E110, Revision E. Start heavy vehicle traffic in vicinity of EL.

11) Record the following parameters starting at the beginning of the gyrocompass run.

a) Air inlet temperature
b) Wind speed and direction
c) Accelerometer triad outputs (chart and tape recorders). Voice annotate tape recording, with date, heading, run number, start of run, end of run, etc.

d) Other remarks such as rapid change in temperature, wind gusts, and other unusual occurrences.

12) Near the end of the gyrocompass run, set up T1 and T2 so that a minimum amount of releveling and other adjustments are required at "ALIGN HOLD".

13) When "ALIGN HOLD" event is reached, stop vehicle traffic, and carefully rotate IMU case through 103° as in step 6. The operator performing this manual task should avoid imparting disturbances to the missile body.

14) Repeat step 11 at the end ("ALIGN HOLD") of gyrocompass run.

15) At "ALIGN HOLD", immediately commence taking optical data by sighting on the IMU cluster mirror with T2, and by sighting on RMP with T1.

- 16) Complete optical measurements by collimating T1 and T2.
- 17) Repeat steps 8 through 16 for a total of eight runs.

The procedure outlined previously is to be repeated at each 45° nominal heading increment of the EL and missile, and will likely entail movement of the TEV for each heading.

D. Data Acquisition

Gyrocompass accuracy data will be acquired using T1, T2, RMP, and the IMU CM. The measurement diagram is shown in Figure A-2 in which the following definitions apply:

- 1) R1 = T1 horizontal scale reading when sighting from T1 to RMP
- 2) R2 = T1 horizontal scale reading when sighting from T1 to T2
- 3) R3 = T2 horizontal scale reading when sighting from T2 to T1
- 4) R4 = T2 horizontal scale reading when sighting from T2 to CM

Using Figure A-2 and the foregoing definitions, the following angles are known or can be calculated as indicated:

- 1) A = Known angle between North and line-of-sight (LOS) to RMP
- 2) $B = R_2 - R_1$
- 3) $C = R_3 - R_4$
- 4) $D = A + B$
- 5) $\bar{D} = 180^\circ - D$
- 6) E = LOS heading to CM
 $E = 180^\circ - C + D$
- 7) γ = Known angle between LOS to CM and X accelerometer input axis
- 8) $\bar{\gamma} = 180^\circ - \gamma$
- 9) α_0 = Azimuth heading of X accelerometer input axis (the required angle)
 $\alpha_0 = E - \bar{\gamma}$

Optical readings R1, R2, R3, and R4 will each be calculated as the average of a minimum of two sets of forward and reverse measurements made with the applicable theodolite.

The measurement diagram of Figure A-3 applies when the missile interferes with the LOS between T1 and T2.

Entries necessary for calculation of α_o will be made on attached Data Sheet No. 1.

Data Sheet No. 2 will be used when the missile interferes with the LOS between T1 and T2.

Accelerometer triad data will be acquired using a chart recorder for quick-look purposes and will also be tape recorded for off-line processing.

Temperature and wind data will be recorded during each gyrocompass run as well as any unusual occurrences during a test.

At the end of each gyrocompass run a computed value of azimuth heading, α , is printed out by the teletype. North channel drift rate (DN), west channel drift rate (DW), and azimuth resolver readout (RSV) are also printed out. These parameters along with α_o as computed on Data Sheet No. 1 or Data Sheet No. 2 will be entered on attached Data Sheet No. 3. Other pertinent data will be entered as indicated at the top of Data Sheet No. 3.

E. Data Reduction

With reference to Data Sheet No. 3, the error in a gyrocompass run is computed as

$$\epsilon_o = \alpha - \alpha_o \text{ (arc sec)}$$

and will be entered in the indicated column.

The root mean square (RMS), average (AVG), and standard deviation (σ) of the errors determined in the series of eight runs at a particular heading will be calculated in the conventional manner:

$$\text{RMS} = \left(\frac{\sum_{i=1}^N \epsilon_{oi}^2}{N} \right)^{1/2}$$

$$AVG = \frac{\sum_{i=1}^N \epsilon_{oi}}{N}$$

$$\sigma = \left(\frac{\sum_{i=1}^N (\epsilon_{oi} - AVG)^2}{N - 1} \right)^{1/2}$$

N = Number of runs = 8

The results will be entered on Data Sheet No. 3.

Tape recorded accelerometer triad data will be processed off-line to determine the average power spectra of environmental disturbances coupled to the IMU mounting fixture and case.

F. Post-Test Activities

At the completion of outdoor gyrocompass testing the IMU will be returned to the laboratory test setup and a calibration run will be made.

Eight gyrocompass runs will be made at each heading for which tests were performed outdoors:

Pretest data, outdoor data, and post-test data will be compiled on attached Data Sheet No. 4. Data Sheet No. 4 will be used to analyze pretest and post-test data versus outdoor data to determine if significant differences exist. Plots will be made showing RMS, AVG, and standard deviation of error values versus heading for each of three test conditions.

Pretest and post-test calibration data will also be examined.

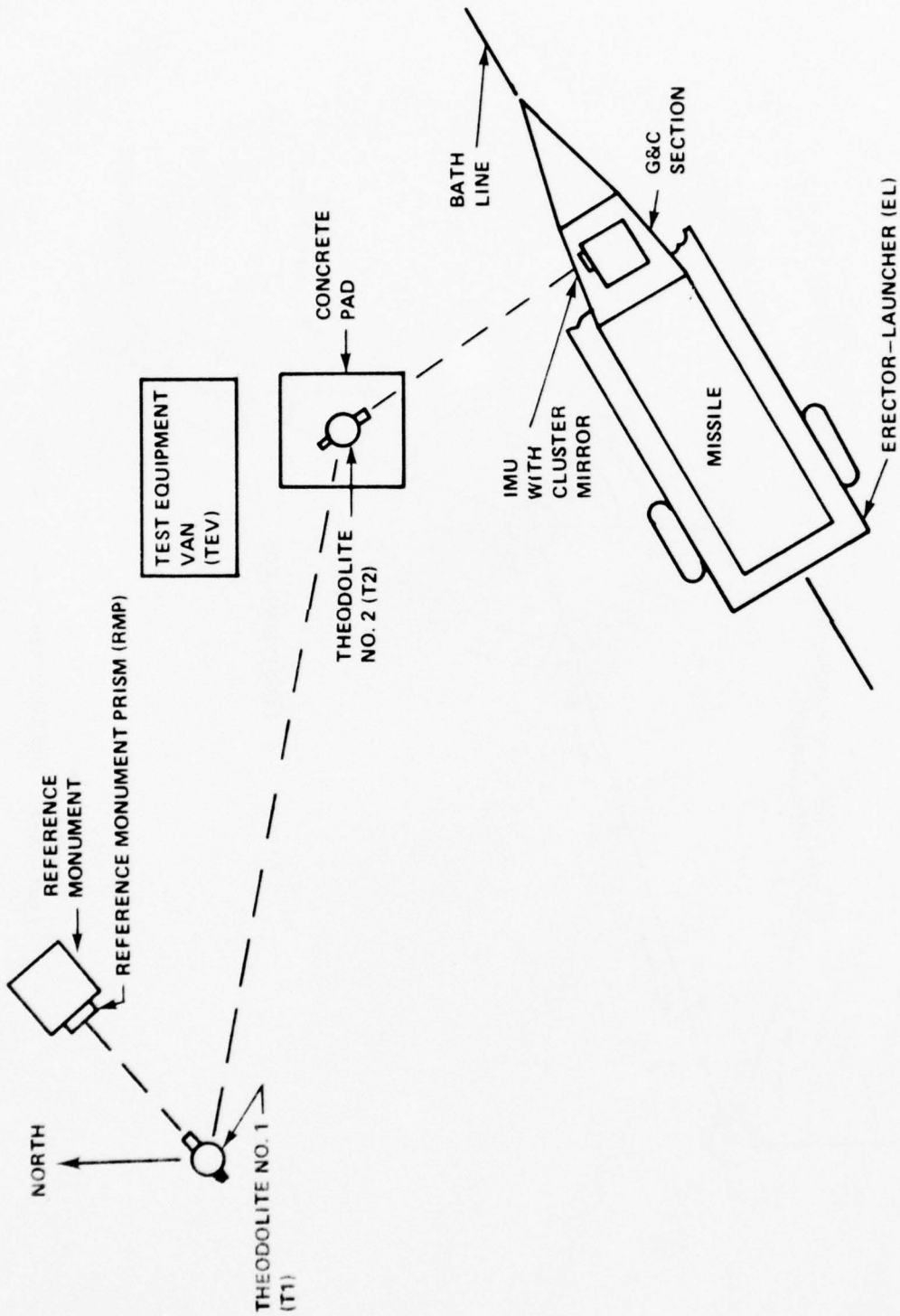


Figure A-1. Mod Shop area typical test setup.

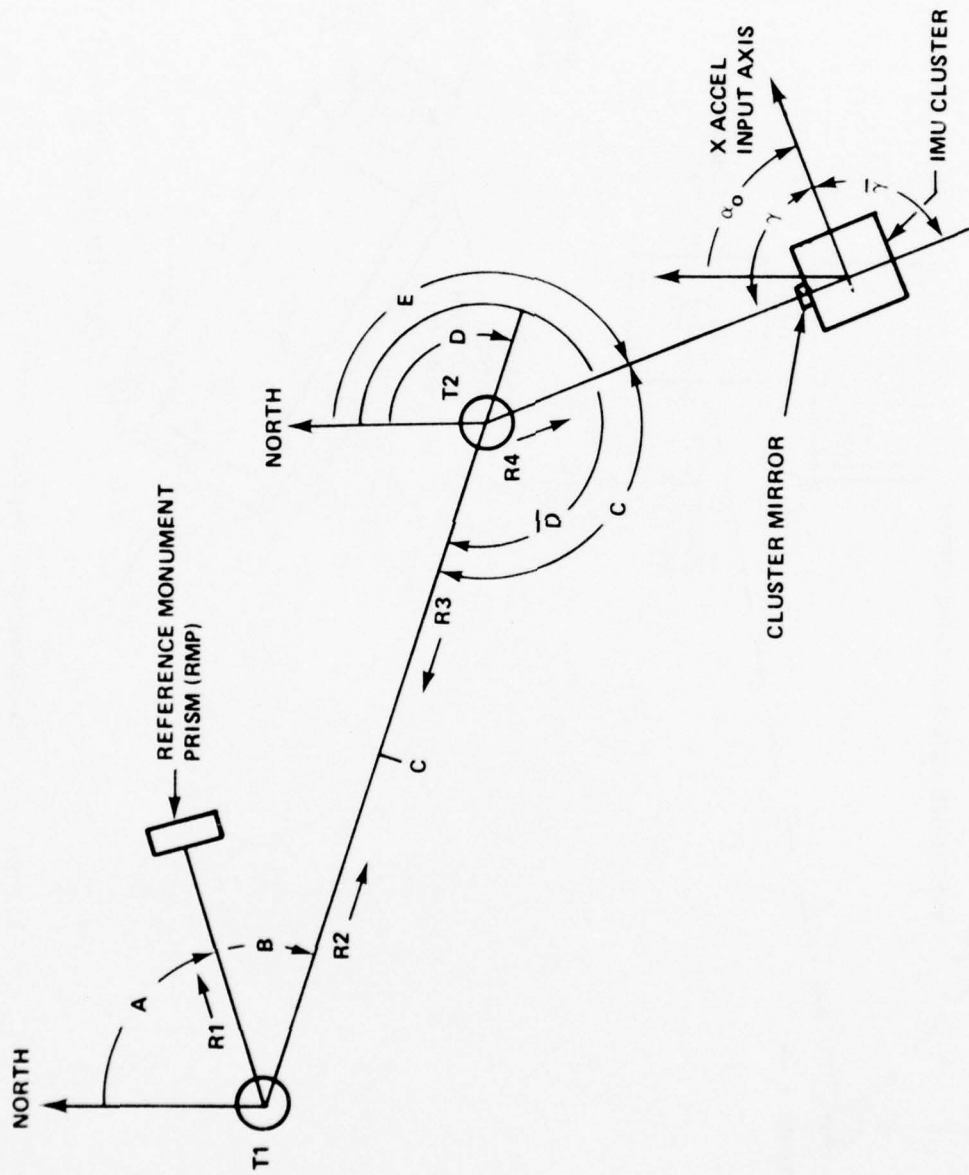


Figure A-2. Optical measurement diagram.

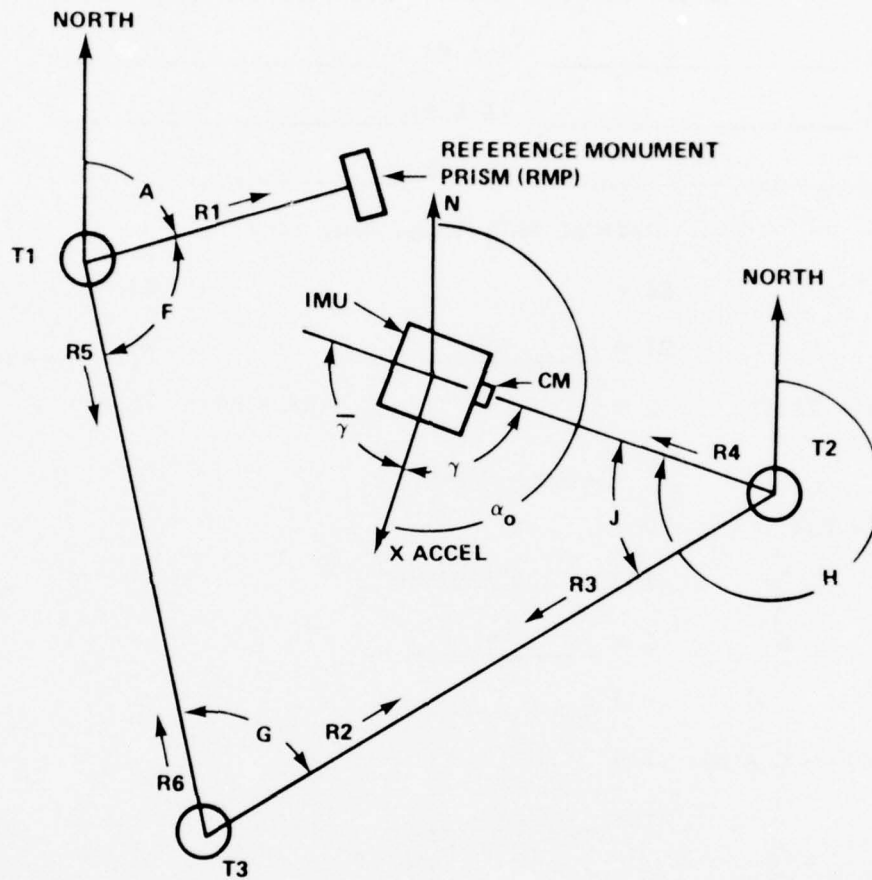


Figure A-3. Optical measurement diagram when missile interferes with LOS between T1 and T2.

DATA SHEET No. 1

PII IMU MISSILE-MOUNTED GYROCOMPASS TEST

Heading: _____ Run No.: _____

IMU S/N: _____ T1 S/N: _____

Date: _____ T2 S/N: _____

OPTICAL DATA (deg, min, sec)

R2 = _____ R3 = _____

R1 = _____ R4 = _____

(B = R2 - R1): B = _____ (C = R3 - R4): C = _____

A = _____

(D = A + B): D = _____

180° = 179° 59' 60"

C = _____

D = _____

(E = 180° - C + D): E = _____

$\bar{\gamma}$ = _____

($\alpha_0 = E - \bar{\gamma}$): $\alpha_0 =$ _____

TEMPERATURE AND WIND DATA

Temperature (°F)

	Accel Triad	IMU Air Inlet	Wind Speed/Direction (mph/deg)
Start:	_____	_____	Start: _____
End:	_____	_____	End: _____

DATA SHEET NO. 2

PII IMU MISSILE-MOUNTED GYROCOMPASS TEST

Heading: _____ Run No.: _____

IMU S/N: _____ T1 S/N: _____

Date: _____ T2 S/N: _____

T3 S/N: _____

OPTICAL DATA (deg, min, sec)

R5 = _____ A = _____

R1 = _____ F = _____

(F = R5 - R1): F = _____ G = _____

R2 = _____ J = _____

R6 = _____ (H = A + F + G + J): H = _____

(G = R2 - R6): G = _____ $\bar{\gamma}$ = _____

R4 = _____ ($\alpha_o = H - \bar{\gamma}$): α_o = _____

R3 = _____ α = _____

(J = R4 - R3): J = _____ α_o = _____

$\epsilon_o = (\alpha - \alpha_o)$: ϵ_o = _____

TEMPERATURE AND WIND DATA

Temperature (°F)

Accel
Triad

IMU Air
Inlet

Wind Speed/Direction (mph/deg)

Start: _____ Start: _____

End: _____ End: _____

DATA SHEET NO. 3

P11 IMU MISSILE-MOUNTED GYROCOMPASS FIELD TEST

IMU S/N: _____
 Date: _____
 Heading: _____
 Weather: _____

Remarks Legend: (1) Temperature (°F) Range
 (2) Wind speed (mph), and direction (deg) range
 (3) Other

Run No.	α (deg, min, sec)	α_o (deg, min, sec)	α_o (arc sec)	ϵ_o (arc sec)	DN(°/hr)	DW(°/hr)	RSV (deg, min, sec)	Remarks
1								
2								
3								
4								
5								
6								
7								
8								

RMS
 AVG
 σ

DATA SHEET NO. 4

PII IMU GYROCOMPASS FIELD TEST RESULTS

IMU S/N 001: COMPILATION OF PRETEST, FIELD TEST AND POST-TEST DATA

Heading (deg)	Statistics for 8 Runs	Pretest Error (arc sec)	Field Test Error (arc sec)	Post-Test Error (arc sec)
0	RMS AVG σ			
45	RMS AVG σ			
90	RMS AVG σ			
135	RMS AVG σ			
180	RMS AVG σ			
225	RMS AVG σ			
270	RMS AVG σ			
315	RMS AVG σ			
Composite Statistics for 64 runs for Each Test Condi- tion	RMS AVG σ			

Appendix B. RAW DATA SAMPLE

The following raw data were taken at a nominal missile heading of 180°F. At this heading, the missile blocked the line-of-sight between T1 and T2 requiring the use of an auxiliary theodolite, T3.

Raw optical data (theodolite readings) corresponding to the requirements (minimum of two sets of forward and reverse measurements) of Appendix A, Test Procedure are presented in Table B-1. Tables B-2 through B-9 present results of raw data reduction using the optical measurement diagram of Figure A-3, Appendix A. Temperature and wind data are also shown in Tables B-2 through B-9.

Detailed meteorological data are shown in Table B-10 at 1-minute intervals during each of the 8 gyrocompass tests at this heading.

Samples of accelerometer output data as recorded with a multichannel chart recorder for each of the 8 runs are shown in Figures B-1 through B-8. All recordings were made with a chart speed of 100 mm/sec and a scale factor of 100 μ V/mm. The accelerometer scale factor is 0.4 μ g/mm so that the chart recorder scale factor in terms of acceleration is 400 μ g/mm.

Channel 4 of the recorder was not used.

TABLE B-1. THEODOLITE READINGS

Date: 14 Dec 76 Heading: 180°

Run No.	R1: T1 to prism		R2: T3 to T2		R3: T2 to T3		R4: T2 to CM		R5: T1 to T3		R6: T3 to T1	
	Fwd	Rev	Fwd	Rev	Fwd	Rev	Fwd	Rev	Fwd	Rev	Fwd	Rev
1	097 48 02 277 48 00		044 47 31 224 47 29		000 00 55 180 00 43		104 31 46 284 31 34		138 23 42 318 23 41		001 01 33 181 01 36	
	03 47 59		33 34		51 44		40 29		44 50		001 01 35 181 01 37	
	AVG: 097 48 01		044 47 32		000 00 48		104 31 37		138 23 44		001 01 35	
2	097 47 58 277 48 03		044 47 33 224 47 40		000 01 02 180 00 50		104 34 08 284 33 54		138 23 43 33 23 44		001 01 37 181 01 42	
	59 03		35 36		55 48		33 48 44		48 49		001 01 40 181 01 42	
	AVG: 097 48 01		044 47 36		000 00 54		104 33 54		138 23 47		001 01 40	
3	097 48 04 277 48 01		044 47 40 224 47 42		001 01 02 180 00 48		104 53 54 284 33 42		138 23 36 318 23 42		001 01 38 181 01 36	
	00 02		39 43		00 50		45 30		38 42		001 01 38 181 01 36	
	AVG: 097 48 02		044 47 41		000 00 55		104 33 43		138 23 40		001 01 38	
4	097 48 00 277 47 54		044 47 41 224 47 47		001 01 12 180 01 05		104 33 36 284 33 17		138 23 40 318 23 48		001 01 15 181 01 10	
	04 48 01		44 49		11 03		17 10		36 41		001 01 16 181 01 14	
	AVG: 097 48 00		044 47 45		000 01 08		104 33 20		138 23 41		001 01 14	
5	097 47 57 277 47 51		044 47 44 224 47 48		000 01 12 180 01 09		104 33 38 284 33 28		138 23 28 318 23 27		001 01 12 181 01 17	
	56 59		47 45		10 05		28 14		25 27		001 01 14 181 01 13	
	AVG: 097 47 56		044 47 46		000 01 09		104 33 27		138 23 27		001 01 14	
6	097 48 12 227 48 04		044 47 51 224 47 51		000 01 09 180 01 00		104 33 23 284 33 12		138 23 36 318 23 22		001 01 12 181 01 16	
	17 16		46 51		05 55		09 32 53		35 37		001 01 11 181 01 13	
	AVG: 097 48 12		044 47 50		000 01 02		104 33 09		138 23 25		001 01 13	
7	097 48 13 227 48 12		044 47 51 224 47 58		000 01 14 180 01 08		104 32 55 284 32 41		138 23 30 318 23 33		001 01 13 181 01 15	
	16 15		56 56		13 11		43 28		31 32		001 01 10 181 01 15	
	AVG: 097 48 14		044 47 55		000 01 12		104 32 42		138 23 32		001 01 13	
8	097 48 12 227 48 08		044 48 01 224 48 05		000 01 24 180 01 16		104 32 20 284 32 11		138 23 39 318 23 41		001 01 11 181 01 05	
	15 14		47 59 00		20 14		07 31 55		39 42		001 01 10 181 01 04	
	AVG: 097 48 12		044 48 01		000 01 18		104 32 08		138 23 40		001 01 08	

Note: Entries are in deg, min, sec.

TABLE B-2. PII IMU MISSILE-MOUNTED GYROCOMPASS TEST,
HEADING 180°, RUN NO. 1

IMU S/N: 001 T1 S/N: 119678
 Date: 14 Dec 76 T2 S/N: 55939
 T3 S/N: 116699

OPTICAL DATA (deg, min, sec)

R5 = 137 83 44	A = 094 33 18
R1 = <u>097 48 01</u>	F = 040 35 43
(F = R5 - R1): F = 040 35 43	G = 043 45 57
R2 = 044 46 92	J = <u>104 30 43</u>
R6 = <u>001 01 35</u>	(H = A + F + G + J): H = 283 25 41
(G = R2 - R6): G = 043 45 57	$\bar{\gamma} = \underline{102 02 19}$
R4 = 104 30 91	($\alpha_o = H - \bar{\gamma}$): $\alpha_o = 181 23 22$
R3 = <u>000 00 48</u>	$\alpha = 181 24 28$
(J = R4 - R3): J = 104 30 43	$\alpha_o = \underline{181 23 22}$
	($\epsilon_o = \alpha - \alpha_o$): $\epsilon_o = 000 01 06$
	$\epsilon_o = 66 \text{ arc sec}$

TEMPERATURE AND WIND DATA

Temperature (°F)		Wind Speed/Direction (mph/deg)
Accel Triad	IMU Air Inlet	
Start: <u>39</u>	<u>39</u>	Start: <u>5/130</u>
End: <u>42</u>	<u>41</u>	End: <u>5/110</u>

TABLE B-3. PII IMU MISSILE-MOUNTED GYROCOMPASS TEST
HEADING 180°, RUN NO. 2

IMU S/N: 001 T1 S/N: 119678
Date: 14 Dec 76 T2 S/N: 55939
T3 S/N: 116699

OPTICAL DATA (deg, min, sec)

R5 = 137 83 47	A = 094 33 18
R1 = <u>097 48 01</u>	F = 040 35 46
(F = R5 - R1): F = 040 35 46	G = 043 45 56
R2 = 044 46 96	J = <u>104 33 00</u>
R6 = <u>001 01 40</u>	(H = A + F + G + J): H = 283 27 60
(G = R2 - R6): G = 043 45 56	$\bar{\gamma} = \underline{102 02 19}$
R4 = 104 33 54	($\alpha_o = H - \bar{\gamma}$): $\alpha_o = 181 25 41$
R3 = <u>000 00 54</u>	$\alpha = 181 26 76$
(J = R4 - R3): J = 104 33 00	$\alpha_o = \underline{181 25 41}$
	($\epsilon_o = \alpha - \alpha_o$): $\epsilon_o = 000 01 35$
	$\epsilon_o = 95 \text{ arc sec}$

TEMPERATURE AND WIND DATA

Temperature (°F)

Accel Triad	IMU Air Inlet	Wind Speed/Direction (mph/deg)
Start: <u>48</u>	<u>46</u>	Start: <u>8/130</u>
End: <u>50</u>	<u>48</u>	End: <u>4/120</u>

TABLE B-4. PII IMU MISSILE-MOUNTED GYROCOMPASS TEST,
HEADING 180°, RUN NO. 3

IMU S/N: 601 T1 S/N: 119678

Date: 14 Dec 76 T2 S/N: 55939

T3 S/N: 116699

OPTICAL DATA (deg, min, sec)

R5 = 137 83 40		A = 094 33 18
R1 = <u>097 48 02</u>		F = 040 35 38
(F = R5 - R1): F = 040 35 38		G = 043 46 03
R2 = 044 47 41		J = <u>104 32 48</u>
R6 = <u>001 01 38</u>	(H = A + F + G + J):	H = 283 27 47
(G = R2 - R6): G = 043 46 03		$\bar{\gamma} = \underline{102 02 19}$
R4 = 104 32 103	($\alpha_o = H - \bar{\gamma}$):	$\alpha_o = 181 25 28$
R3 = <u>000 00 55</u>		$\alpha = 181 25 85$
(J = R4 - R3): J = 104 32 48		$\alpha_o = \underline{181 25 28}$
	($\epsilon_o = \alpha - \alpha_o$):	$\epsilon_o = 000 00 57$
		$\epsilon_o = 57 \text{ arc sec}$

TEMPERATURE AND WIND DATA

Temperature (°F)

Accel Triad	IMU Air Inlet	Wind Speed/Direction (mph/deg)
Start: <u>50</u>	<u>48</u>	Start: <u>6/110</u>
End: <u>55</u>	<u>52</u>	End: <u>5/130</u>

TABLE B-5. PII IMU MISSILE-MOUNTED GYROCOMPASS TEST,
HEADING 180°, RUN NO. 4

IMU S/N: 001 T1 S/N: 119678
 Date: 14 Dec 76 T2 S/N: 55939
 T3 S/N: 116699

OPTICAL DATA (deg, min, sec)

R5 = 137 83 41	A = 094 33 18
R1 = <u>097 48 00</u>	F = 040 35 41
(F = R5 - R1): F = 040 35 41	G = 043 46 31
R2 = 044 47 45	J = <u>104 32 12</u>
R6 = <u>001 01 14</u>	(H = A + F + G + J): H = 283 27 42
(G = R2 - R6): G = <u>043 46 31</u>	$\bar{\gamma} = 102 02 19$
R4 = 104 33 20	($\alpha_o = H - \bar{\gamma}$): $\alpha_o = 181 25 23$
R3 = <u>000 01 08</u>	$\alpha = 181 25 61$
(J = R4 - R3): J = 104 32 12	$\alpha_o = 181 25 23$
	$\epsilon_o = 000 00 38$
	($\epsilon_o = \alpha - \alpha_o$): $\epsilon_o = 38$ arc sec

TEMPERATURE AND WIND DATA

Temperature (°F)

Accel Triad	IMU Air Inlet	Wind Speed/Direction (mph/deg)
Start: <u>55</u>	<u>52</u>	Start: <u>3/120</u>
End: <u>56</u>	<u>52</u>	End: <u>3/090</u>

TABLE B-6. PII IMU MISSILE-MOUNTED GYROCOMPASS TEST,
HEADING 180°, RUN NO. 5

IMU S/N: 001 T1 S/N: 119678
 Date: 14 Dec 76 T2 S/N: 55939
 T3 S/N: 116699

OPTICAL DATA (deg, min, sec)

R5 = 137 82 87	A = 094 33 18
R1 = <u>097 47 56</u>	F = 040 35 31
(F = R5 - R1): F = 040 35 31	G = 043 46 32
R2 = 044 47 46	J = <u>104 32 18</u>
R6 = <u>001 01 14</u>	(H = A + F + G + J): H = 283 27 39
(G = R2 - R6): G = 043 46 32	$\bar{\gamma} = \underline{102 02 19}$
R4 = 104 33 27	($\alpha_o = H - \bar{\gamma}$): $\alpha_o = 181 25 20$
R3 = <u>000 01 09</u>	$\alpha = 181 25 10$
(J = R4 - R3): J = 104 32 18	$\alpha_o = \underline{181 25 20}$
	$\epsilon_o = 000 00 10$
	($\epsilon_o = \alpha - \alpha_o$): $\epsilon_o = -10$ arc sec

TEMPERATURE AND WIND DATA

Temperature (°F)

Accel Triad	IMU Air Inlet	Wind Speed/Direction (mph/deg)
Start: <u>56</u>	<u>53</u>	Start: <u>6/120</u>
End: <u>57</u>	<u>54</u>	End: <u>6/120</u>

TABLE B-7. PII IMU MISSILE-MOUNTED GYROCOMPASS TEST,
HEADING 180°, RUN NO. 6

IMU S/N: 001 T1 S/N: 119678
 Date: 14 Dec 1976 T2 S/N: 55939
 T3 S/N: 116699

OPTICAL DATA (deg, min, sec)

R5 = 137 83 35 A = 094 33 18
 R1 = 097 48 12 F = 040 35 23
 (F = R5 - R1): F = 040 35 23 G = 043 46 37
 R2 = 044 47 50 J = 104 32 07
 R6 = 001 01 13 (H = A + F + G + J): H = 283 26 85
 (G = R2 - R6): G = 043 46 37 $\bar{\gamma} = \underline{102 02 19}$
 R4 = 104 33 09 ($\alpha_o = H - \bar{\gamma}$): $\alpha_o = 181 24 66$
 R3 = 000 01 02 $\alpha = 181 25 63$
 (J = R4 - R3): J = 104 32 07 $\alpha_o = \underline{181 25 06}$
 ($\epsilon_o = \alpha - \alpha_o$): $\epsilon_o = 000 00 57$
 $\epsilon_o = 57 \text{ arc sec}$

TEMPERATURE AND WIND DATA

Temperature (°F)

Accel Triad	IMU Air Inlet	Wind Speed/Direction (mph/deg)
Start: <u>58</u>	<u>55</u>	Start: <u>4/120</u>
End: <u>59</u>	<u>55</u>	End: <u>3/150</u>

TABLE B-8. PII IMU MISSILE-MOUNTED GYROCOMPASS TEST,
HEADING 180°, RUN NO. 7

IMU S/N: 001 T1 S/N: 119678
 Date: 19 Dec 1976 T2 S/N: 55939
 T3 S/N: 116699

OPTICAL DATA (deg, min, sec)

R5 = 137 83 32		A = 094 33 18
R1 = <u>097 48 14</u>		F = 040 35 18
(F = R5 - R1): F = 040 35 18		G = 043 46 42
R2 = 044 47 55		J = <u>104 31 30</u>
R6 = <u>001 01 13</u>	(H = A + F + G + J):	H = 283 26 48
(G = R2 - R6): G = 043 46 42		$\bar{\gamma} = \underline{102 02 19}$
R4 = 104 32 42	($\alpha_o = H - \bar{\gamma}$):	$\alpha_o = 181 24 29$
R3 = <u>000 01 12</u>		$\alpha = 181 24 87$
(J = R4 - R3): J = 104 31 30		$\alpha_o = \underline{181 24 29}$
	$\epsilon_o = (\alpha - \alpha_o)$:	$\epsilon_o = 000 00 58$
		$\epsilon_o = 58 \text{ arc sec}$

Temperature and Wind Data

Temperature (°F)

Accel Triad	IMU Air Inlet	Wind Speed/Direction (mph/deg)
Start: <u>59</u>	<u>56</u>	Start: <u>4/120</u>
End: <u>59</u>	<u>56</u>	End: <u>5/120</u>

TABLE B-9. PII IMU MISSILE-MOUNTED GYROCOMPASS TEST,
HEADING 180°, RUN NO. 8

IMU S/N: 001 T1 S/N: 119678
 Date: 19 Dec 1976 T2 S/N: 55939
 T3 S/N: 116699

Optical Data (deg, min, sec)

R5 = 137 83 40 A = 094 33 18
 R1 = 097 48 12 F = 040 35 28
 (F = R5 - R1): F = 040 35 28 G = 043 46 53
 R2 = 044 47 61 J = 104 30 50
 R6 = 001 01 08 (H = A + F + G + J): H = 283 26 29
 (G = R2 - R6): G = 043 46 53 $\bar{\gamma} = \underline{102 02 19}$
 R4 = 104 31 68 ($\alpha_o = H - \bar{\gamma}$): $\alpha_o = 181 24 10$
 R3 = 000 01 18 $\alpha = 181 25 34$
 (J = R4 - R3): J = 104 30 50 $\alpha_o = \underline{181 24 10}$
 ($\epsilon_o = \alpha - \alpha_o$): $\epsilon_o = 01 24$
 $\epsilon_o = 84 \text{ arc sec}$

Temperature and Wind Data

Temperature (°F)

Accel Triad	IMU Air Inlet	Wind Speed/Direction (mph/deg)
Start: <u>59</u>	<u>56</u>	Start: <u>8/130</u>
End: <u>59</u>	<u>57</u>	End: <u>3/100</u>

TABLE B-10. METEOROLOGICAL DATA, DATE 14 DEC 1976,
HEADING 180°

Time (min)	Run No. 1	Run No. 2	Run No. 3	Run No. 4	Run No. 5	Run No. 6	Run No. 7	Run No. 8
0	5/130	8/130	6/110	3/120	6/120	4/120	4/120	8/130
1	5/110	5/120	6/120	3/120	8/110	4/120	6/130	8/140
2	5/120	3/120	5/110	3/120	7/130	3/110	5/150	7/130
3	5/120	5/120	6/120	5/120	5/110	4/120	4/150	7/150
4	3/090	5/120	5/110	3/120	7/100	6/120	3/140	5/140
5	3/120	7/110	5/130	3/120	4/090	7/130	5/120	5/130
6	4/120	7/110	5/130	5/150	3/090	8/120	4/140	5/120
7	5/100	4/110	6/110	4/110	6/100	3/130	6/130	4/110
8	6/120	6/100	7/110	4/110	4/110	5/110	6/120	5/120
9	3/100	4/120	7/120	7/110	3/120	3/120	6/120	6/120
10	3/110	9/100	4/130	4/120	2/110	7/130	4/120	5/110
11	3/110	6/100	6/140	3/120	6/120	7/120	7/130	4/110
12	3/100	5/120	4/140	5/110	4/130	7/120	5/130	7/130
13	4/100	7/130	5/120	5/120	7/120	8/130	5/100	5/120
14	4/110	3/110	4/130	4/100	6/120	4/140	5/120	4/100
15	5/110	4/120	5/130	3/090	6/120	3/150	5/120	3/100

Note: Entries are Wind Speed (mph)/Direction (deg).

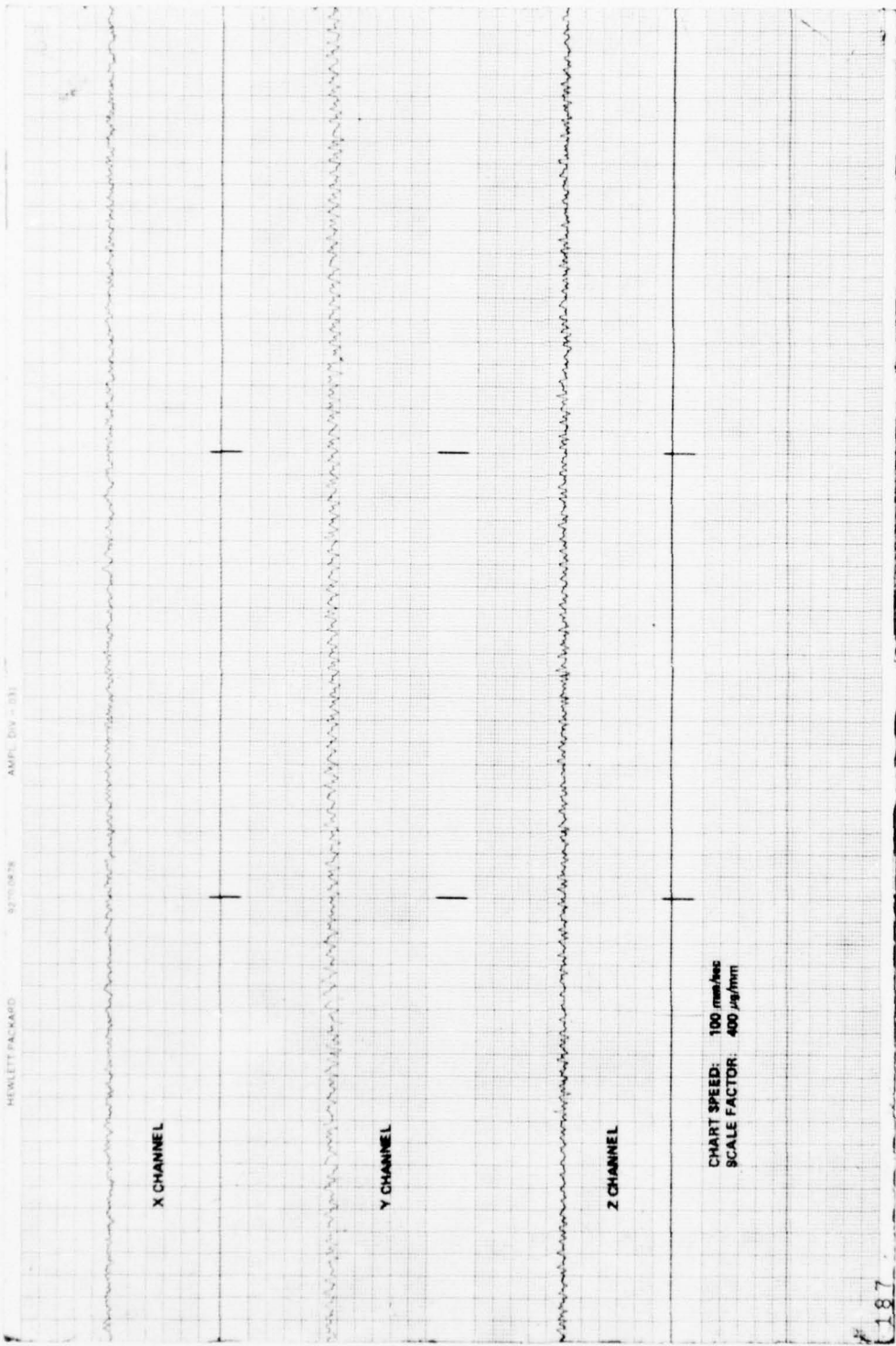


Figure B-1. Accelerometer data - 180° heading, run 1.

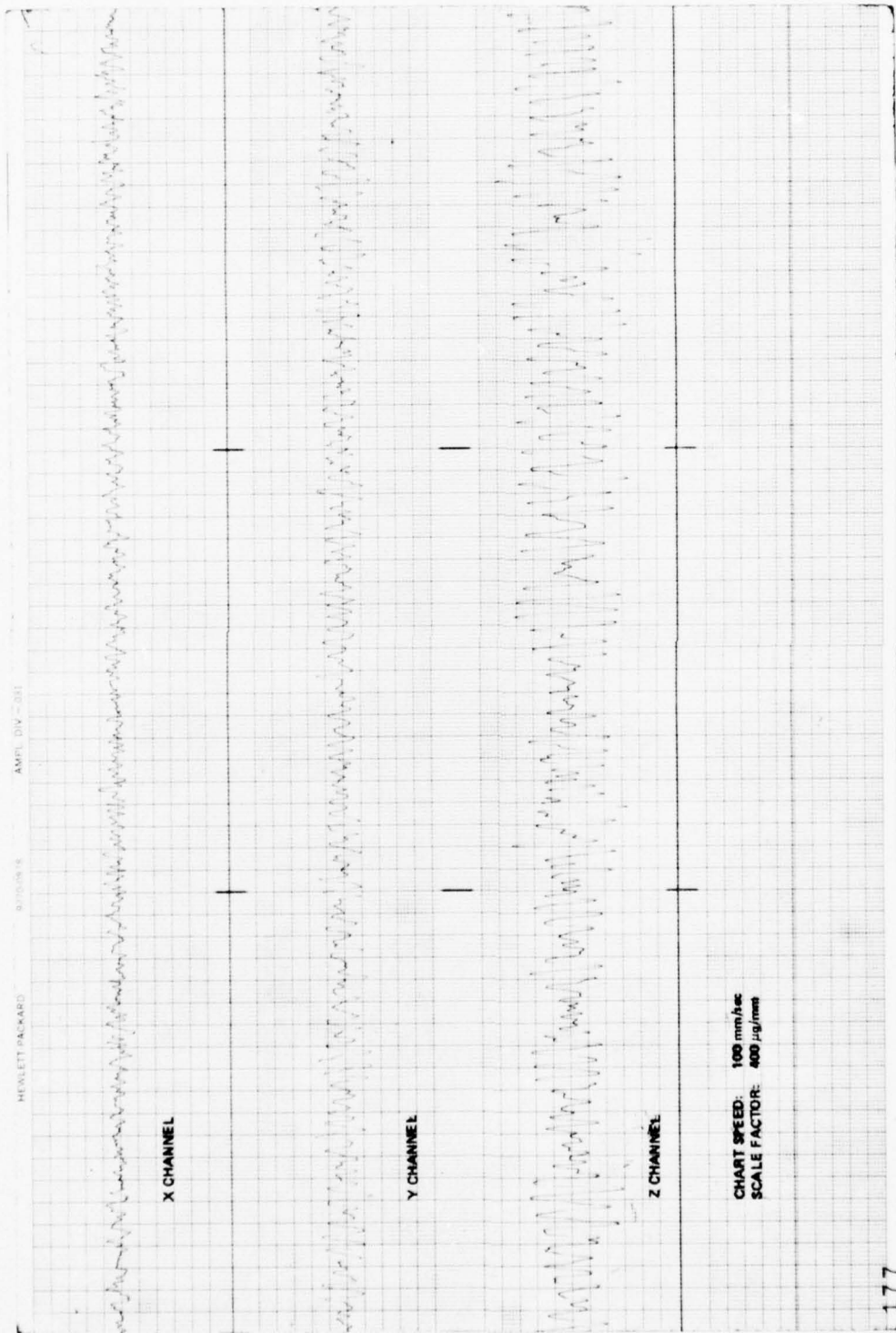


Figure B-2. Accelerometer data - 180° heading, run 2.

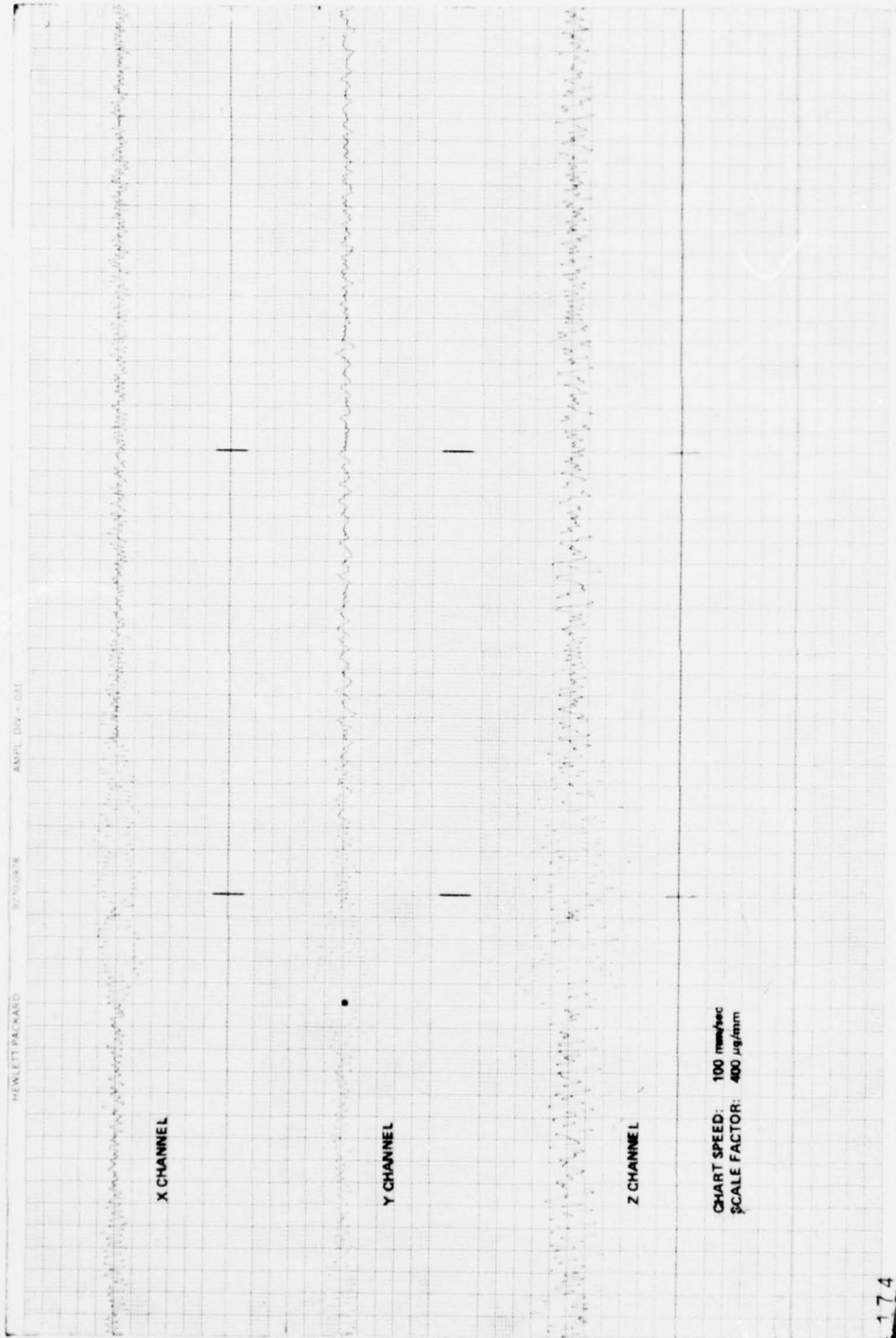


Figure B-3. Accelerometer data - 180' heading, run 3.

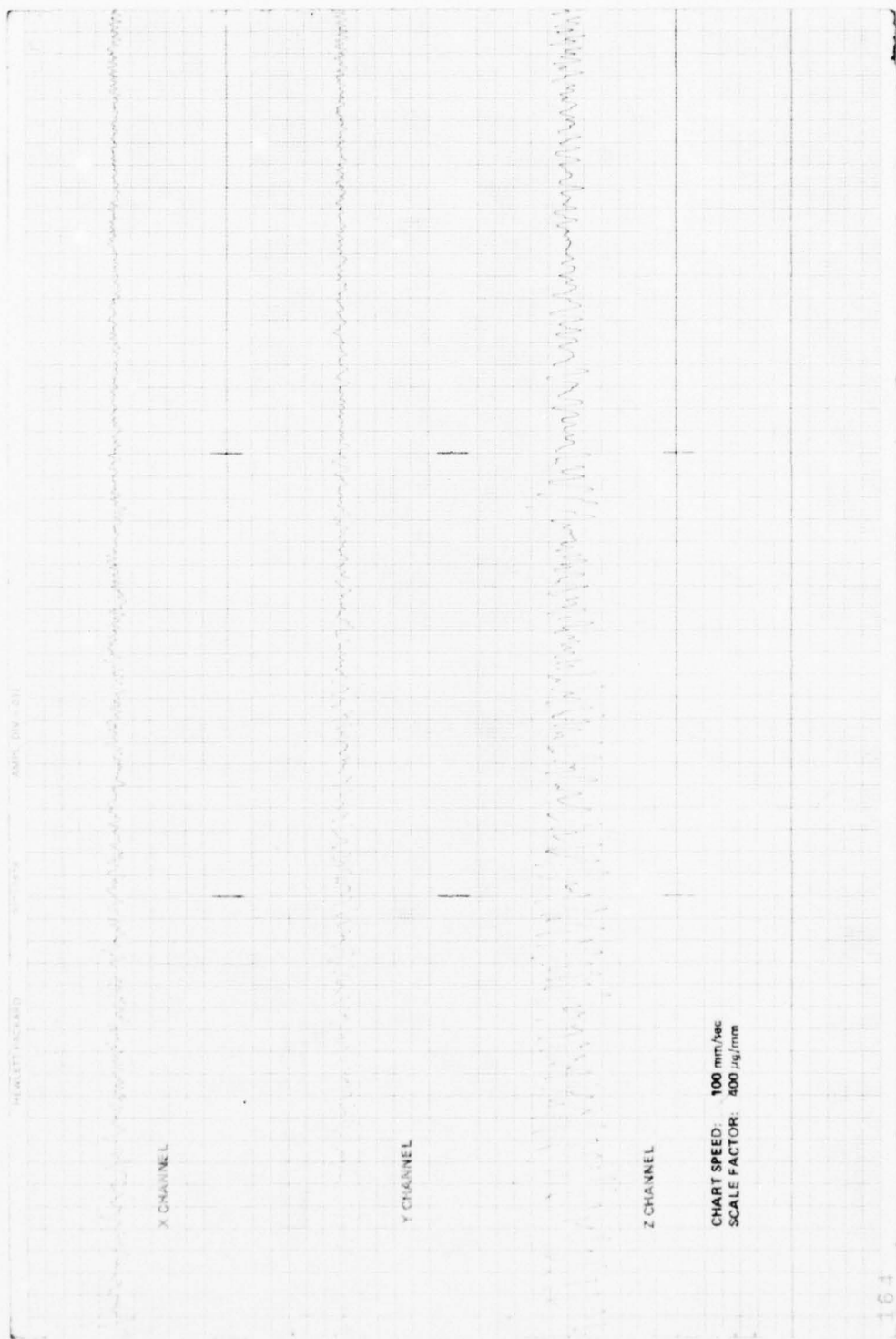


Figure B-4. Accelerometer data - 180° heading, run 4.

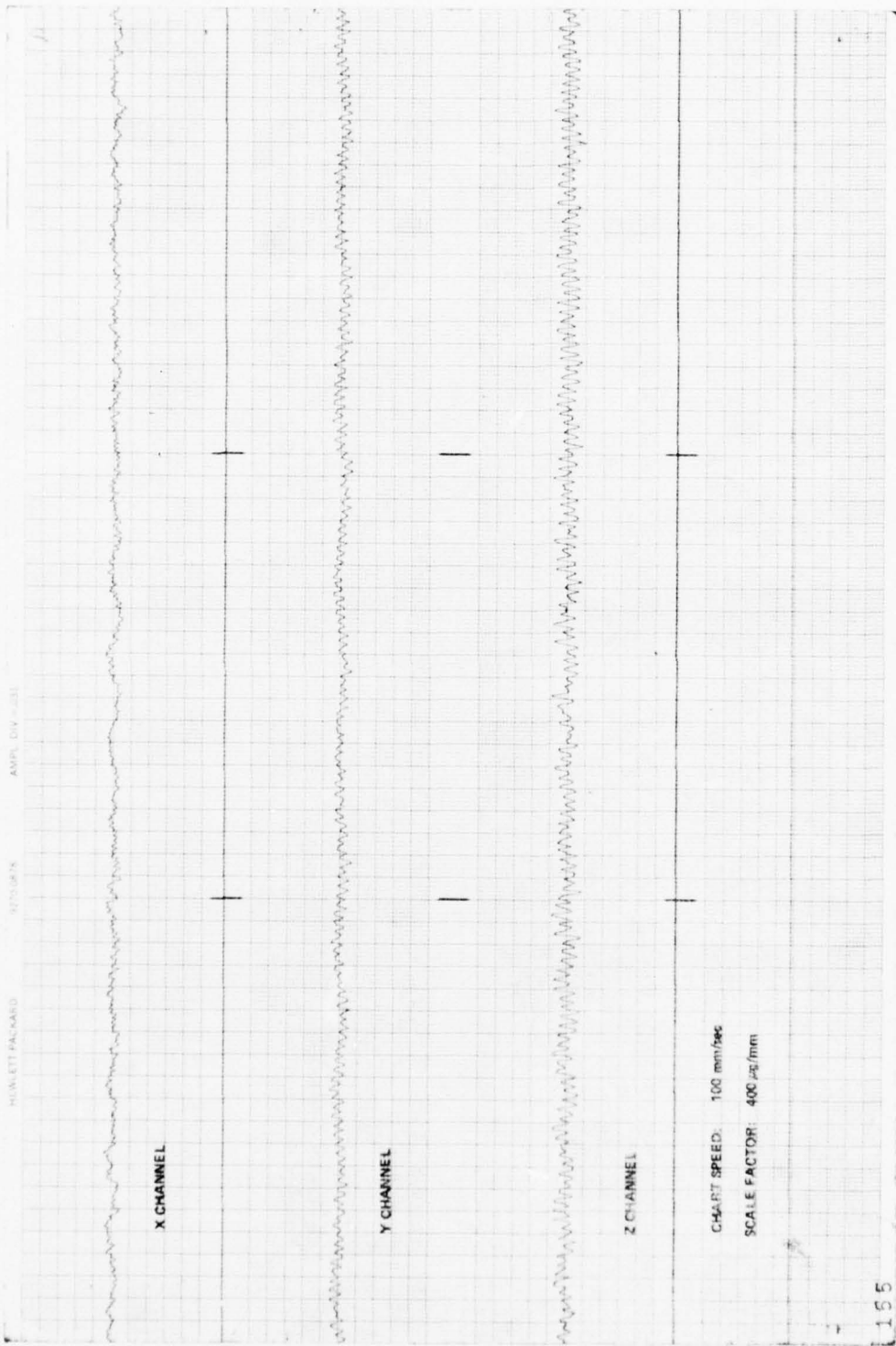


Figure B-5. Accelerometer data - 180° heading, run 5.

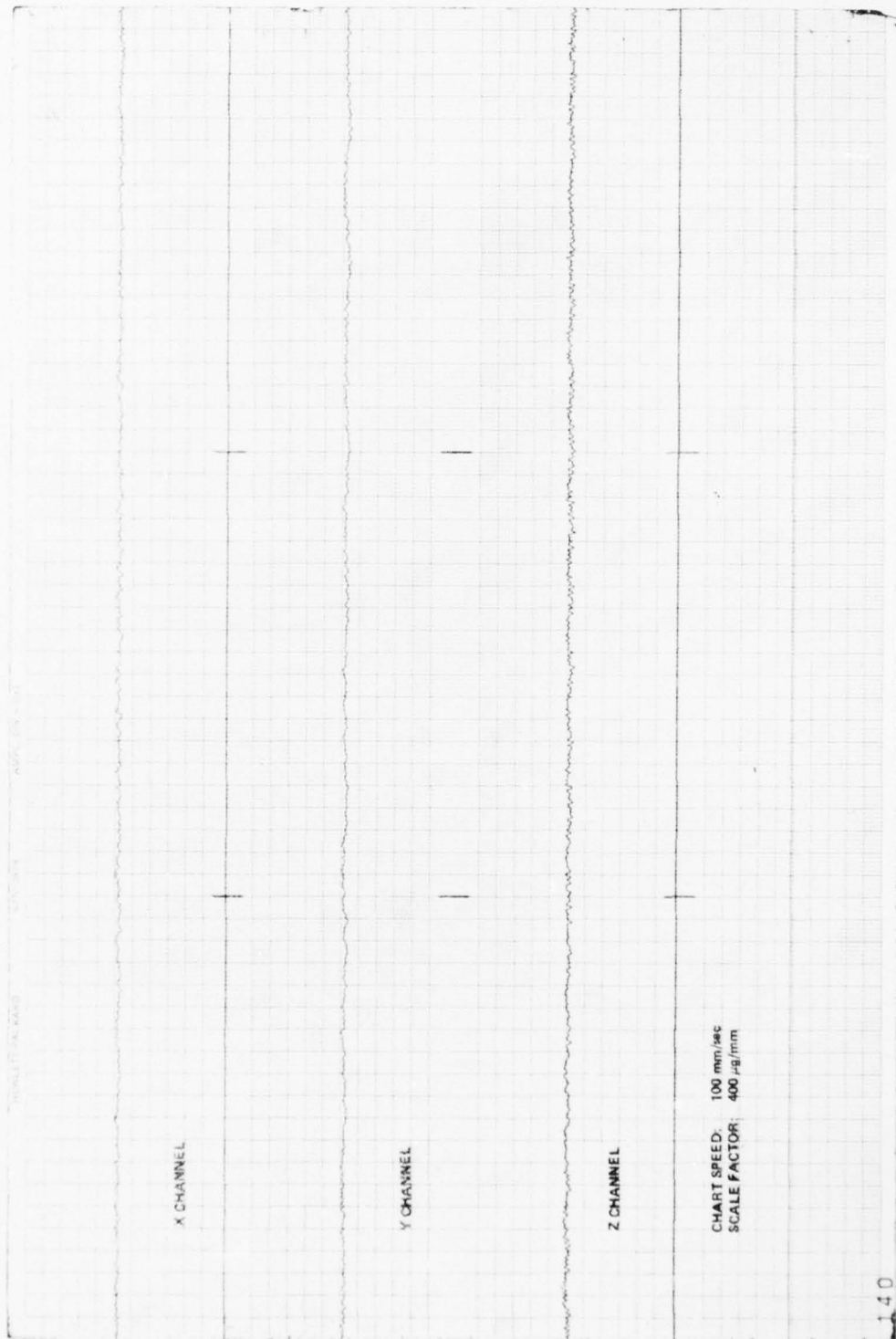


Figure B-6. Accelerometer data - 180° heading, run 6.

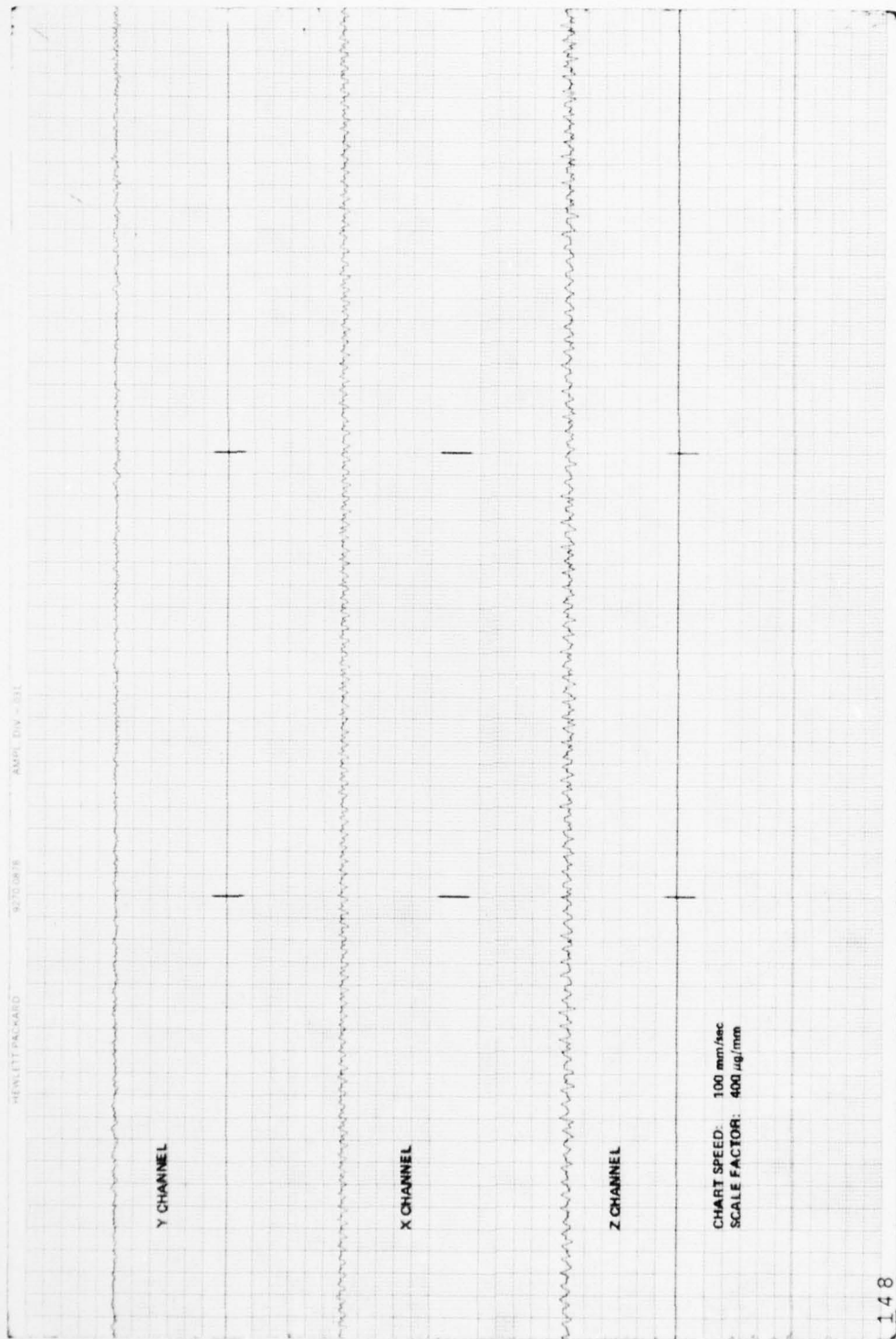


Figure B-7. Accelerometer data - 180° heading, run 7.

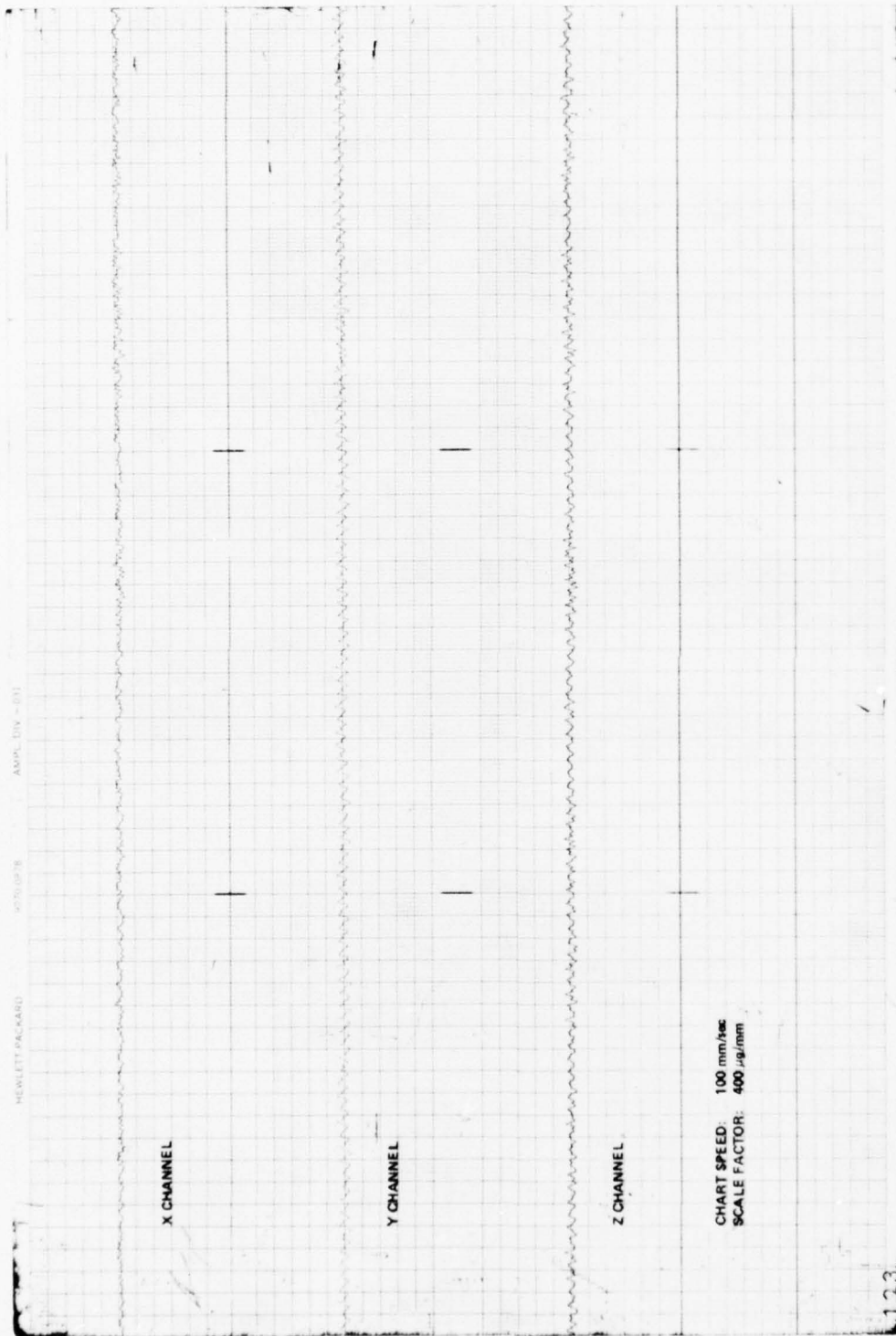


Figure B-8. Accelerometer data - 180° heading, run 8.

Appendix C. AVERAGE POWER SPECTRA OF ACCELEROMETER DATA

An accelerometer triad was used to monitor translational disturbances imparted to the IMU case. Accelerometer data were recorded with a multi-channel chart recorder, the preamplifiers of which were used to input data to the multi-channel tape recorder.

Chart recordings of only a few seconds duration were made for quick-look purposes. Tape recordings were made for the full 4-minute duration of Sequence 4 (90° position of IMU) and the full 4-minute duration of Sequence 7 (0° position of IMU) in the gyrocompass program.

Sequence 4 is the period during which IMU data are being acquired and processed by the computer for biasing the west gyro. During Sequence 7, data acquisition and processing is repeated for fine gyrocompassing. Since the IMU's accelerometers (not to be confused with the instrumentation accelerometers under discussion) are the principal sensors for performing the gyro bias and fine gyrocompass functions, any sensed extraneous accelerations due to base motions induced by whatever means are potential sources of azimuth error. This is particularly true if extraneous accelerations are sensed during Sequences 4 and 7, hence the choice of these sequences for recording purposes.

Tape recordings of each of the three accelerometer channels were made for all 64 test runs. The recordings were played back, off-line, into a digital Fourier analyzer capable of computing the average power spectrum of an arbitrary voltage signal and outputting the spectrum to a digital plotter for obtaining a hard copy of the result.

A block diagram of the complete instrumentation system is shown in Figure C-1.

The Fourier analyzer operates on the time domain signal, $V_3(t)$, as shown in Figure C-1 (one channel at a time) to obtain the Fourier transform, and subsequently computes the power spectrum. The Fourier analyzer output is scaled to give a spectral strength of $V_3^2(f)/4$ to signals of various frequencies that may be present in the input. The voltage axis of the digital plot, however, is labeled V^2 so that

$$V_3^2(f)/4 = V^2 \quad . \quad (C-1)$$

With reference to Figure C-1, the time domain input, $V_3(t)$, in terms of acceleration is given by

$$V_3(t) = K_t K K_a G(t) \quad (C-2)$$

where

K_t = Tape recorder scale factor (V/V)

K = Chart recorder preamplifier low frequency scale factor (V/V)

K_a = Accelerometer scale factor (V/g)

$G(t)$ = Input acceleration (g).

The corresponding frequency domain expression for Equation (C-3) is

$$V_3(f) = K_t K K_a G(f) \quad (C-3)$$

Substitution of Equation (C-3) into Equation (C-10) yields

$$(K_t K K_a)^2 G^2(f) = 4V^2 \quad (C-4)$$

or

$$G^2(f) = 4V^2 (K_t K K_a)^{-2} \quad (C-5)$$

so that the acceleration spectrum is directly related to the plotted voltage spectrum by the scale factor, $4 (K_t K K_a)^{-2}$.

The peak value of a sine wave function of acceleration of frequency f that may be a component of the input signal, is determined by taking the square root of Equation (C-5):

$$G(f) = 2V (K_t K K_a)^{-1} \quad (C-6)$$

where V^2 in Equation (C-5) is read directly from the plotted spectrum.

Nominal scale factor values for the system of Figure C-1 and Equation (C-5) are:

$$K_t = 1 \text{ V/V}$$

$$K = 100 \text{ V/V (low frequency)}$$

$$K_a = 2.5 \text{ V/g.}$$

Frequency response of the system is limited by the chart recorder preamplifier and the frequency response curves in Figure C-2 should be used to more accurately specify this scale factor.

With K , as read from Figure C-2, and the values mentioned previously for K_t and K_a substituted into Equation (C-5), the result is

$$G^2(f) = 0.64 V^2/K^2 \quad (C-7)$$

as indicated on the average power spectrum plots shown in Figure C-3 through C-26. These plots are the results from each accelerometer channel for the eight test runs made at a heading of 180° .

The peak value of an acceleration sinusoid corresponding to Equation (C-7) is

$$G(f) = 0.8 V/K \quad (C-8)$$

with an error of approximately 7% of reading due mainly to gain and linearity errors of the tape recorder, chart recorder, and accelerometers.

The plots shown in Figures C-3 through C-26 were obtained by analyzing 30 data samples (15 from Sequence 4 and 15 from Sequence 7) each of 4.096 seconds duration. Thus, approximately 1 minute (61.44 seconds) of data from each of the two 4-minute sequences were analyzed and averaged to produce the plots. During a data processing run, the Fourier analyzer accepts data for 4.096 seconds, computes the transform and power spectrum, sums and stores the result in approximately 8 seconds and repeats these operations a total of 30 times. The final, summed power spectrum is divided by 30 to obtain an average value.

The plots shown in Figure C-3 through C-26 are good representations of the frequencies and average strengths of disturbances present at the IMU case. It should be noted, however, that slightly different average strengths would be computed if the data were analyzed beginning at a different starting point on the tape. To completely analyze a full 4-minute sequence the data would have to be replayed three times with successive starting times delayed by 4.096 seconds from the previous starting time.

The technique used is a compromise to provide representative data without complex synchronization equipment and the additional time required to make two more playback runs.

The raw data sample in Appendix B should be consulted for the prevailing environmental stimuli during the eight test runs at a heading of 180° .

For reference purposes, the average power spectra for laboratory operation of the instrumentation accelerometers mounted on the IMU test fixture with the IMU running are presented in Figures C-27 through C-29. A value of $K = 100$ was used in the annotation of G^2 as a function of V^2 .

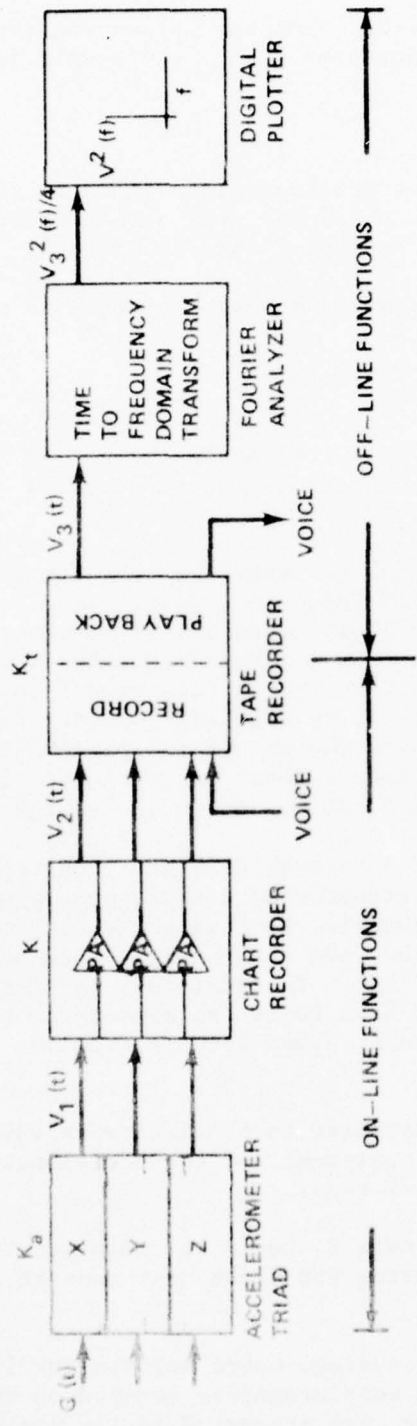


Figure C-1. Instrumentation accelerometer data acquisition and processing block diagram.

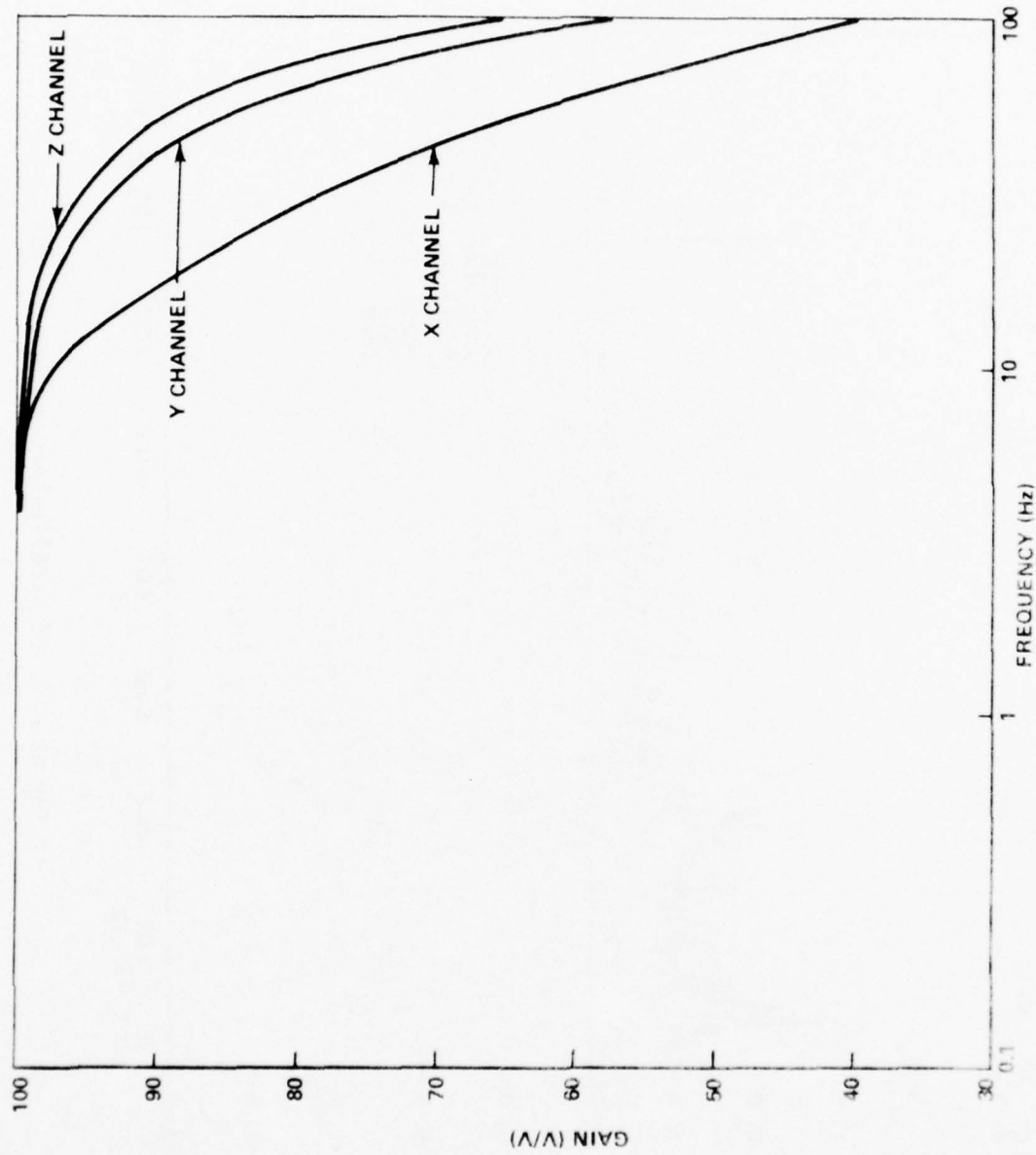


Figure C-2. Preamplifier frequency response.

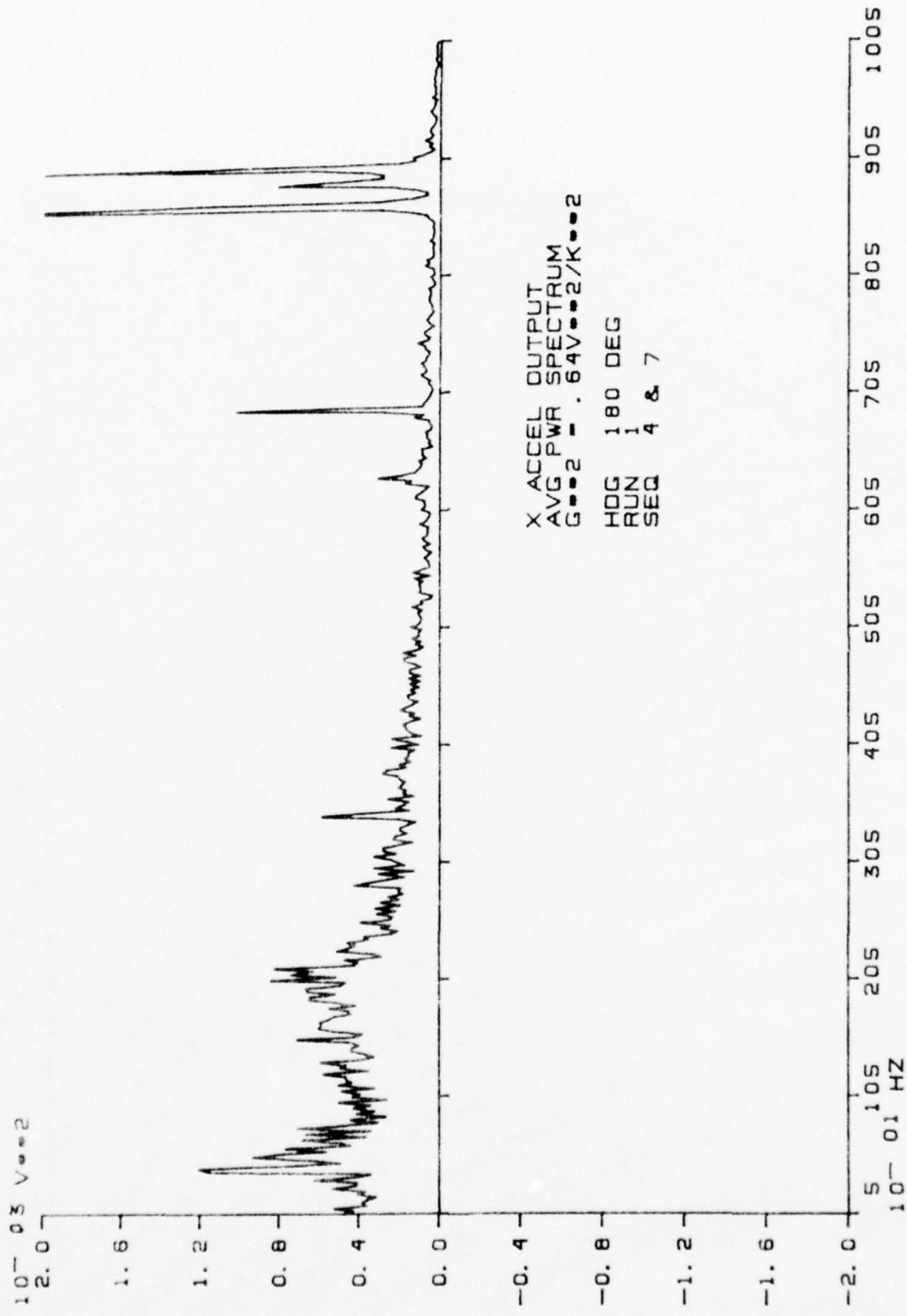


Figure C-3. X acceleration output for run 1.

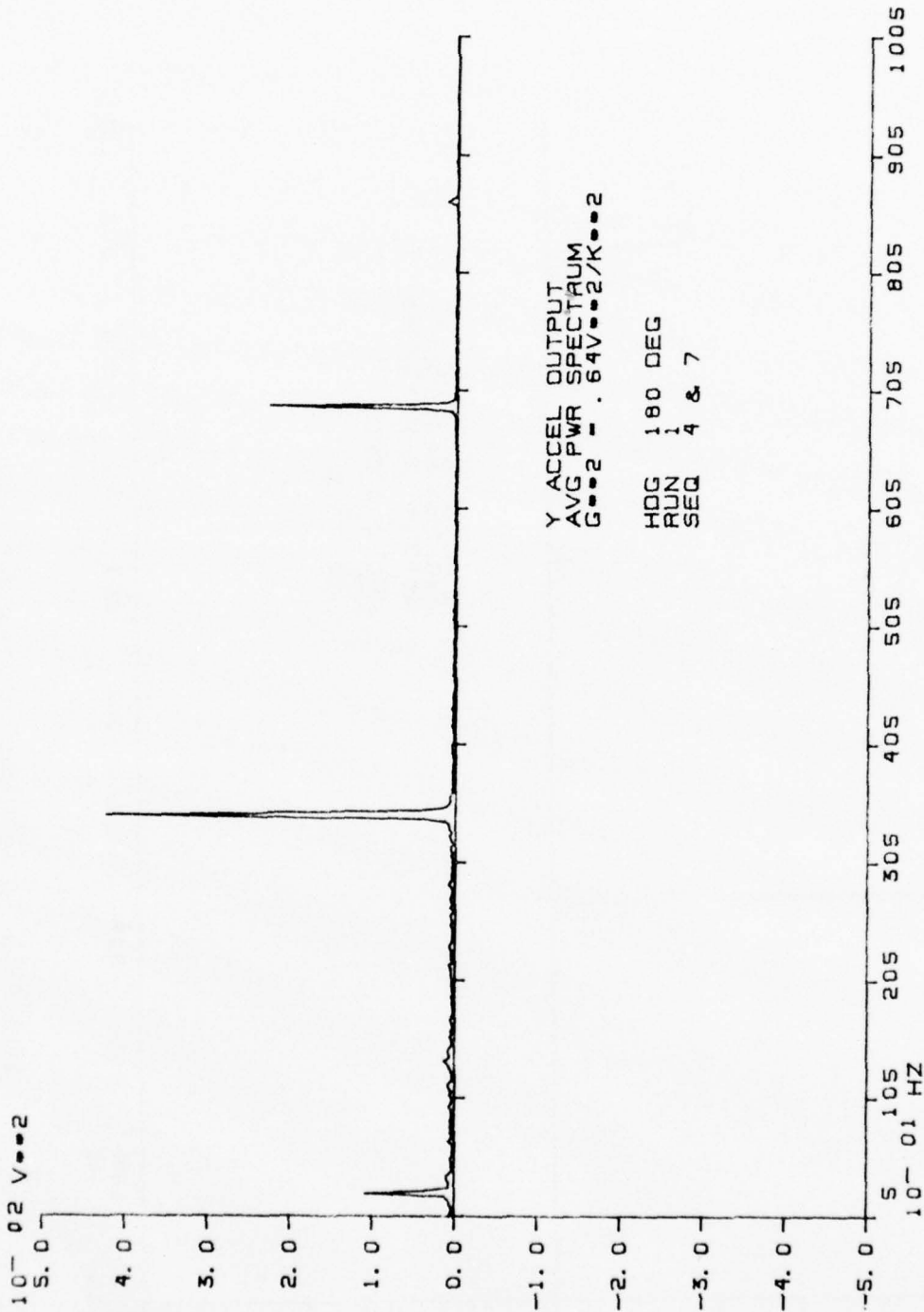


Figure C-4. Y acceleration output for run 1.

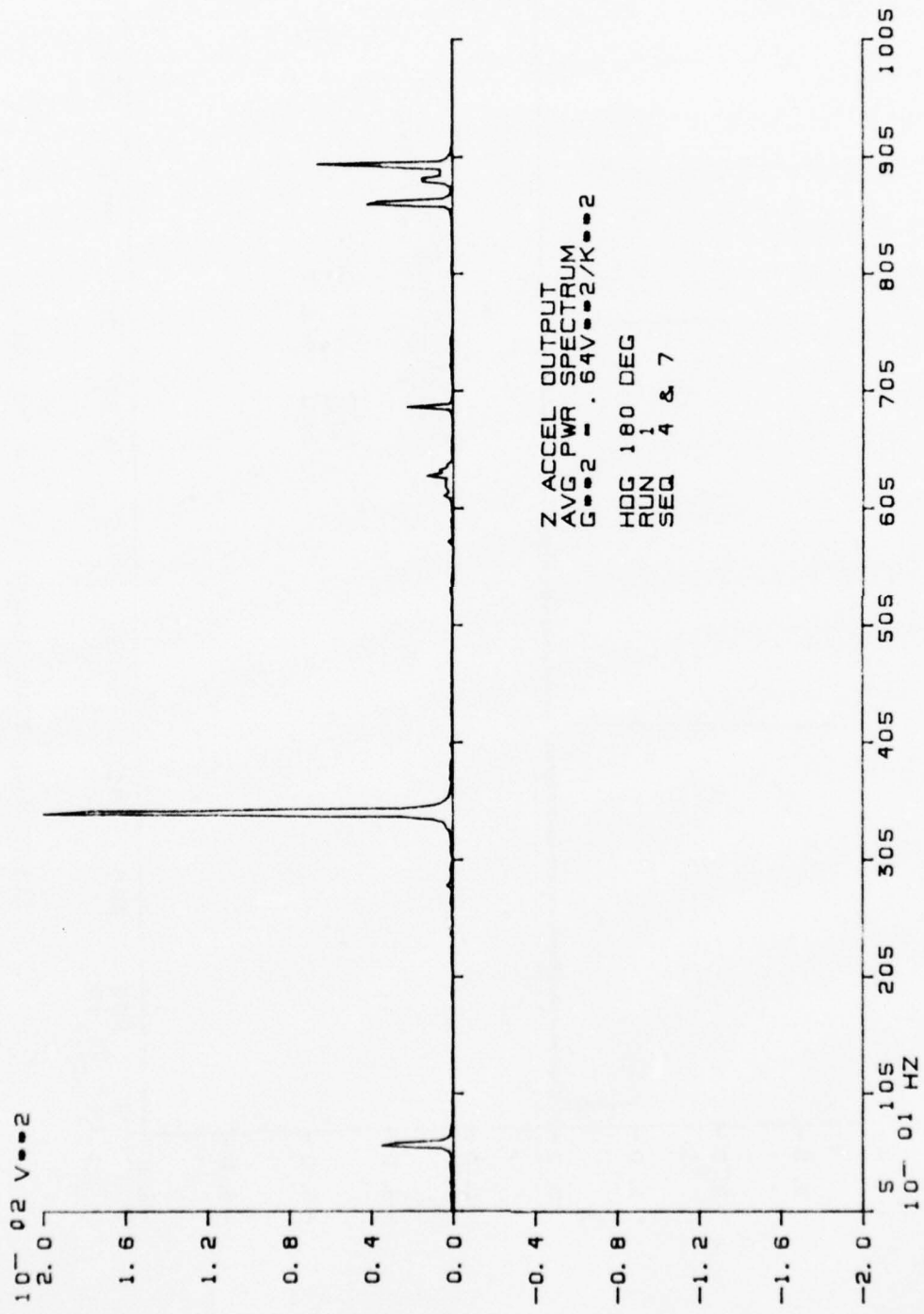


Figure C-5. Z acceleration output for run 1.

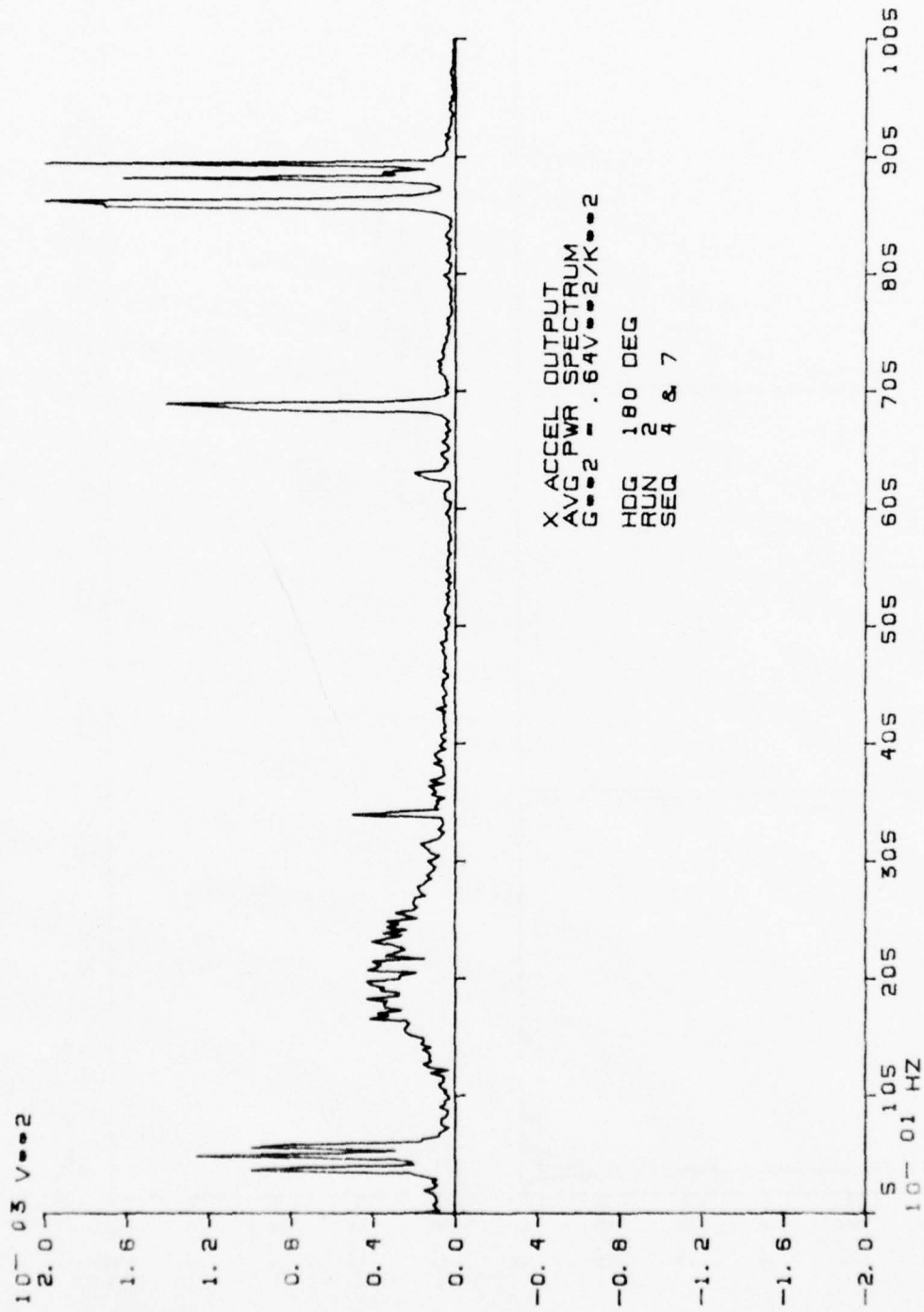


Figure C-6. X acceleration output for run 2.

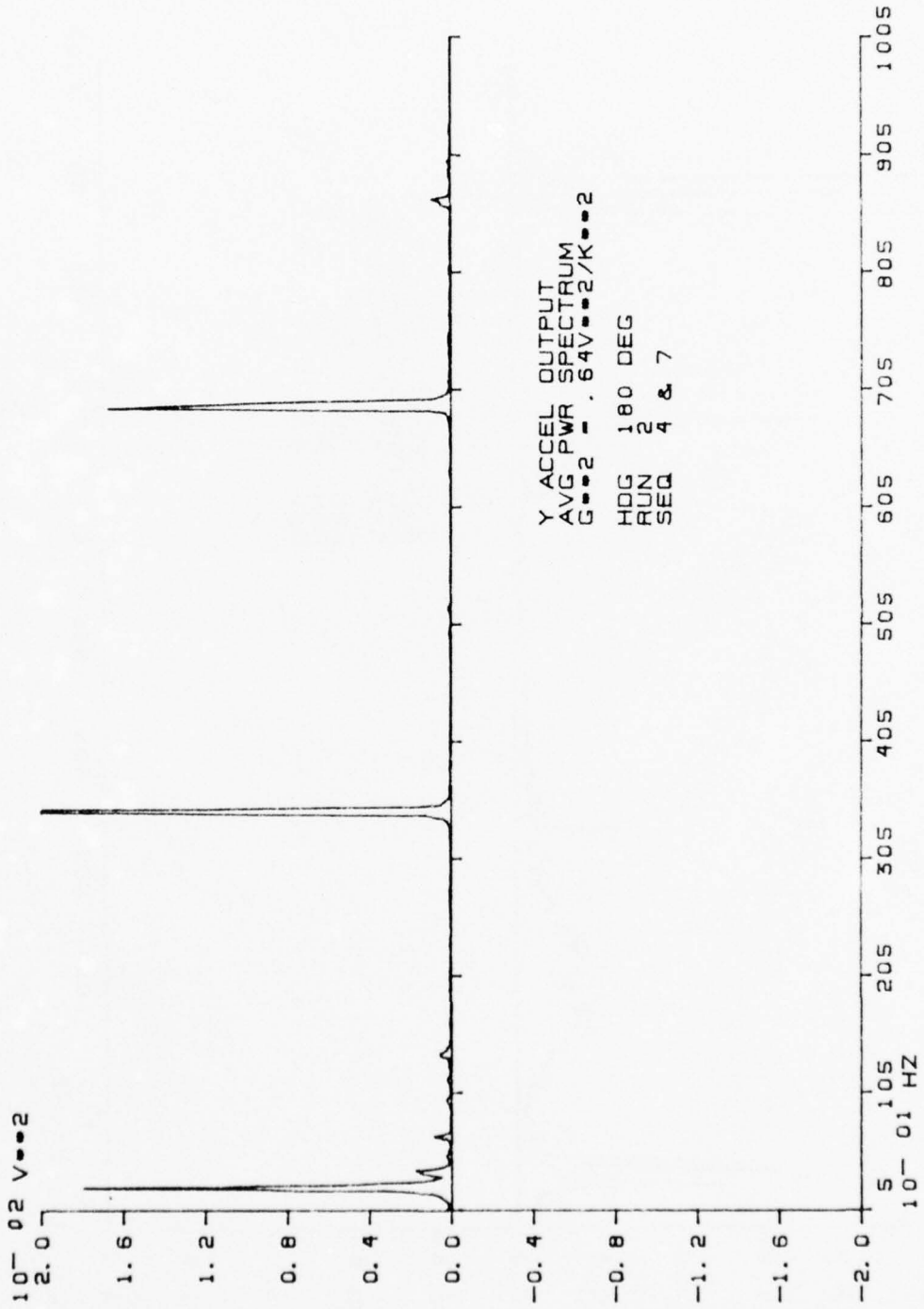


Figure C-7. Y acceleration output for run 2.

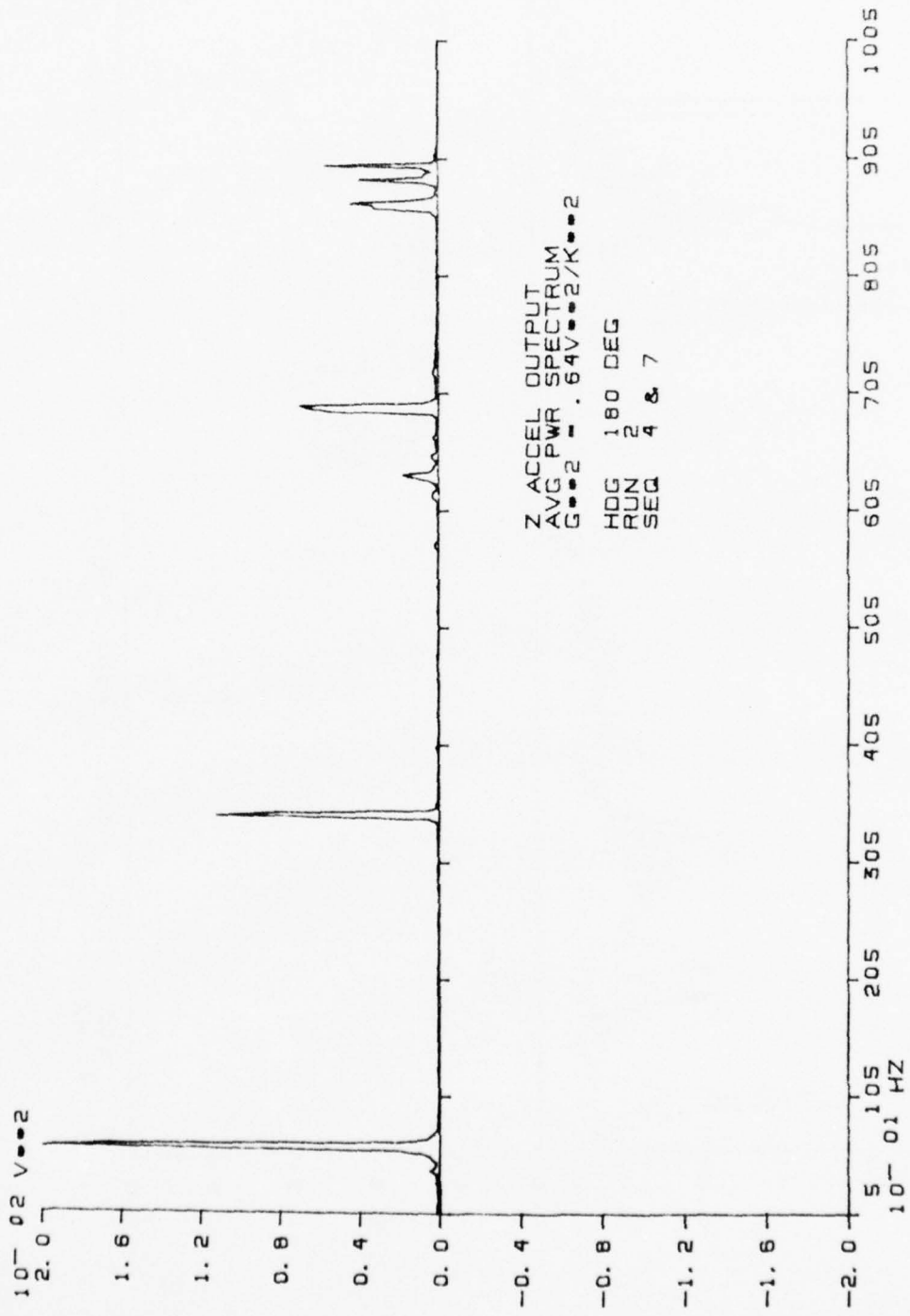


Figure C-8. Z acceleration output for run 2.

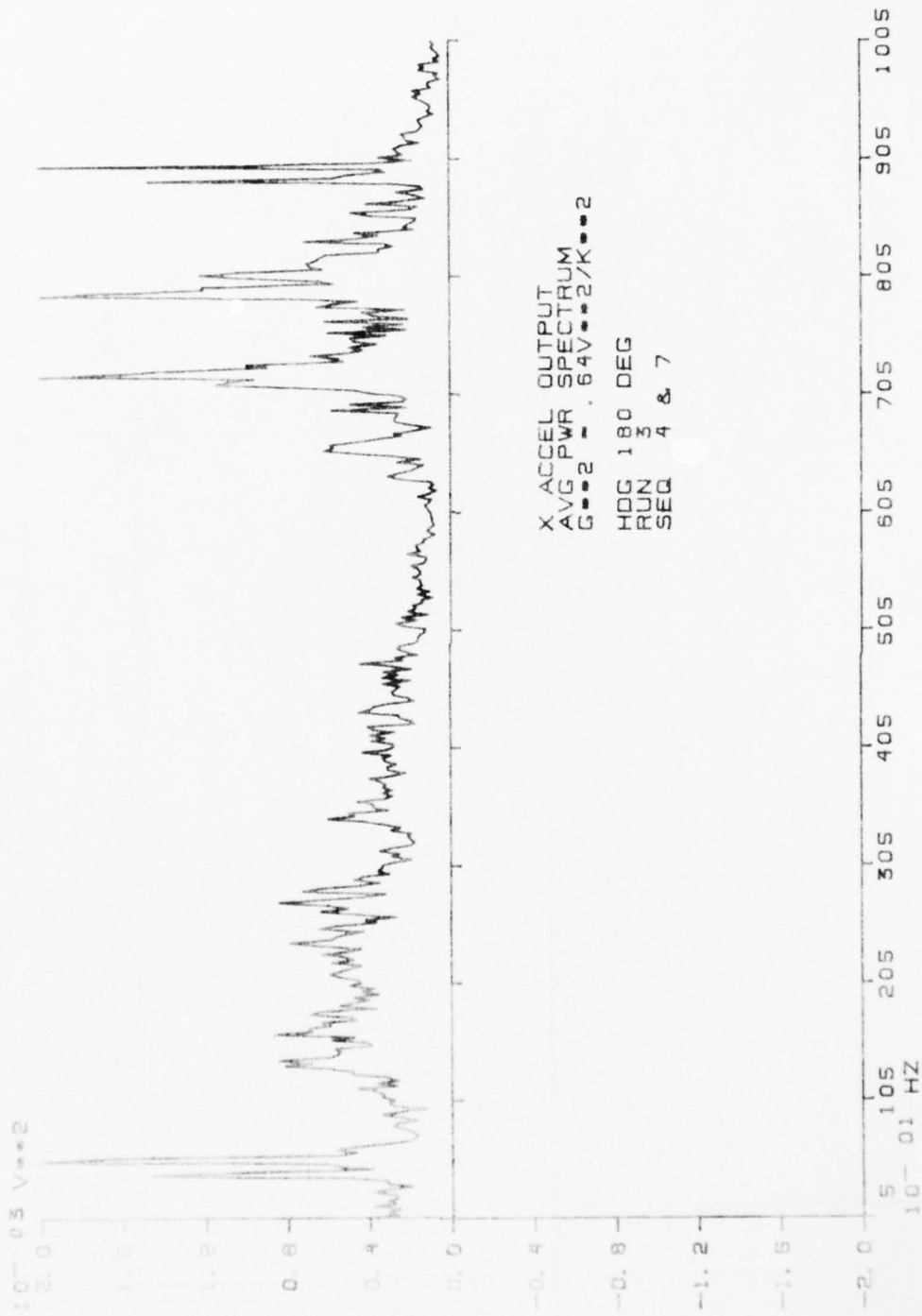


Figure C-9. X acceleration output for run 3.

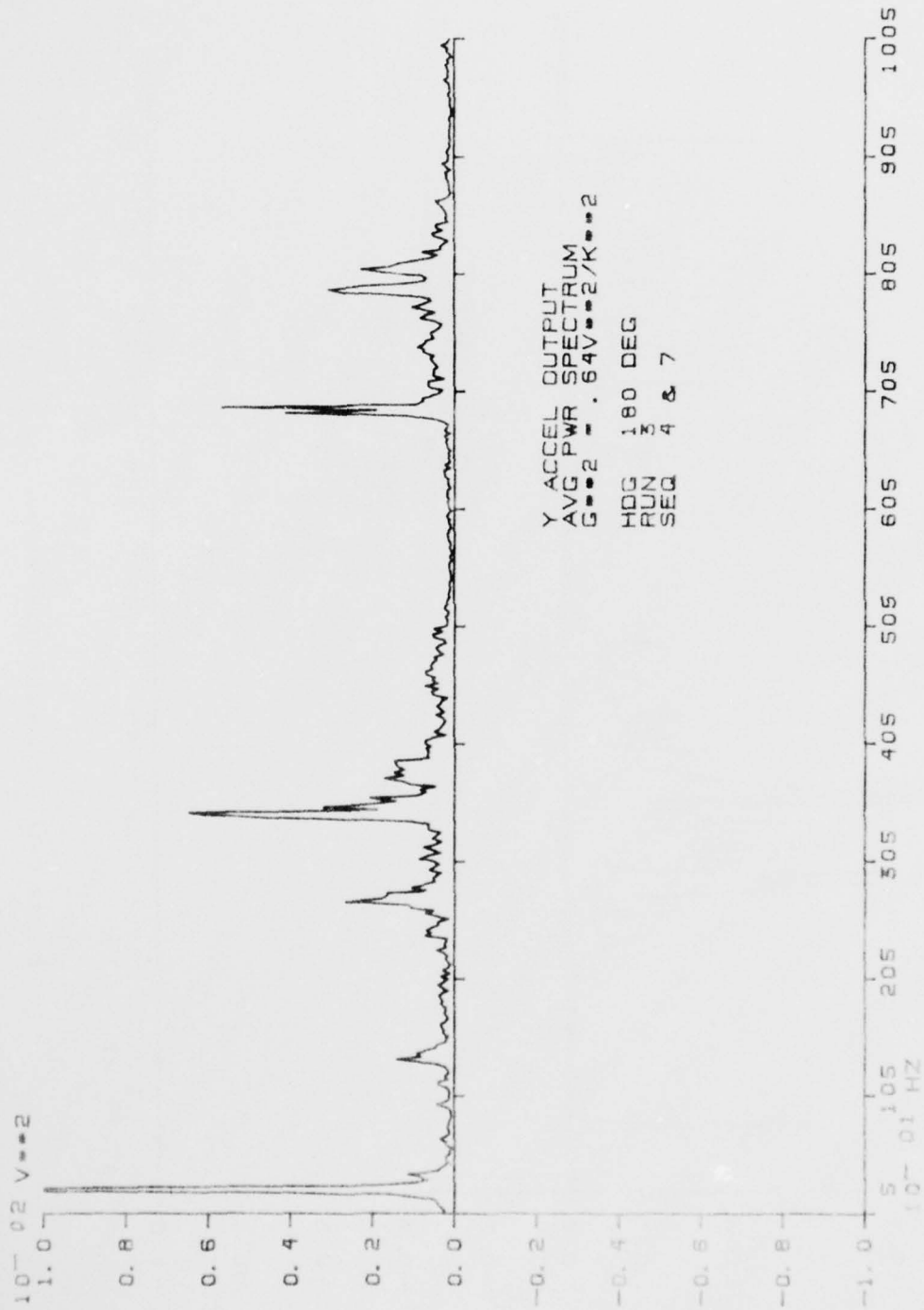


Figure C-10. Y acceleration output for run 3.

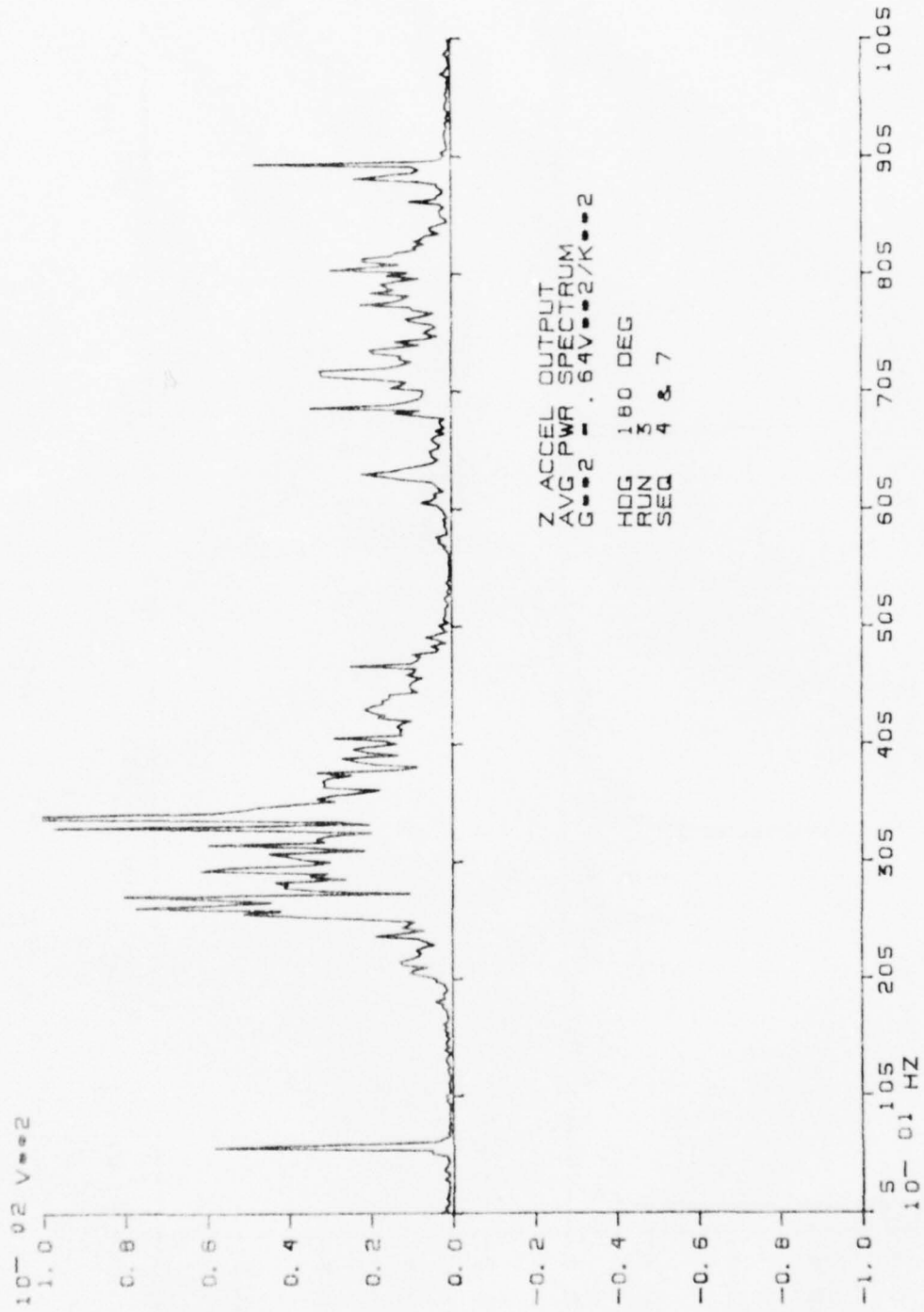


Figure C-11. Z acceleration output for run 3.

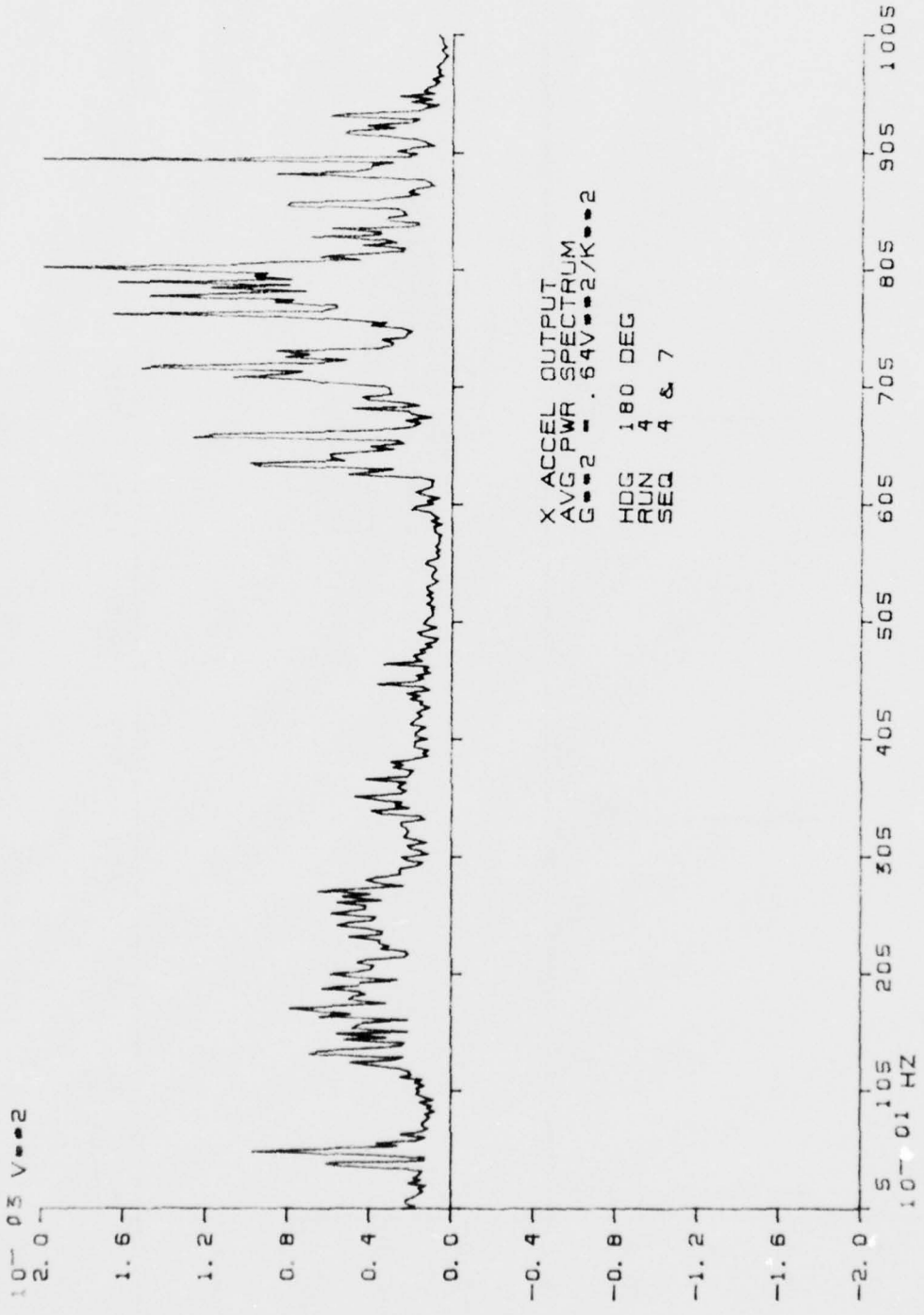


Figure C-12. X acceleration output for run 4.

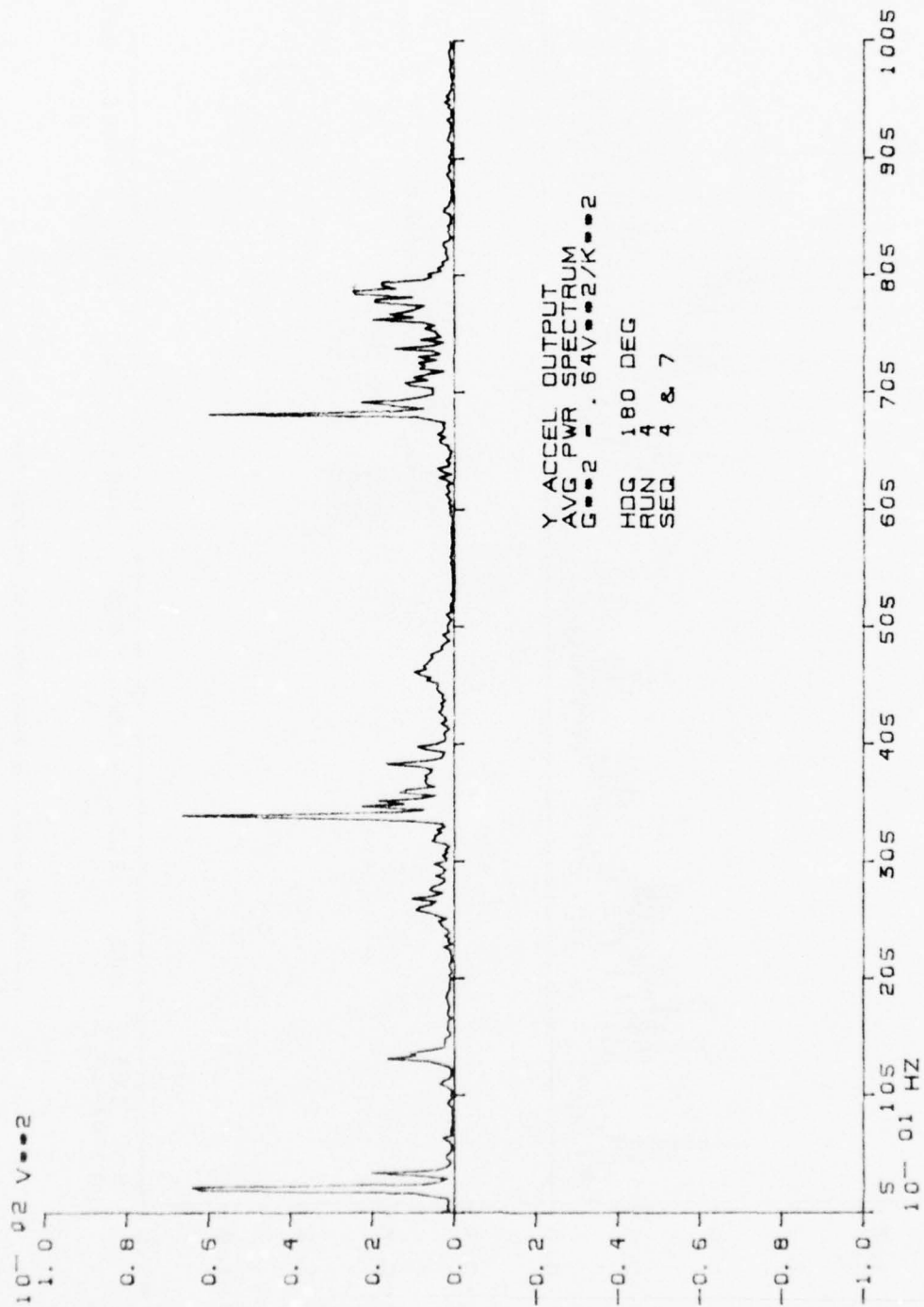


Figure C-13. Y acceleration output for run 4.

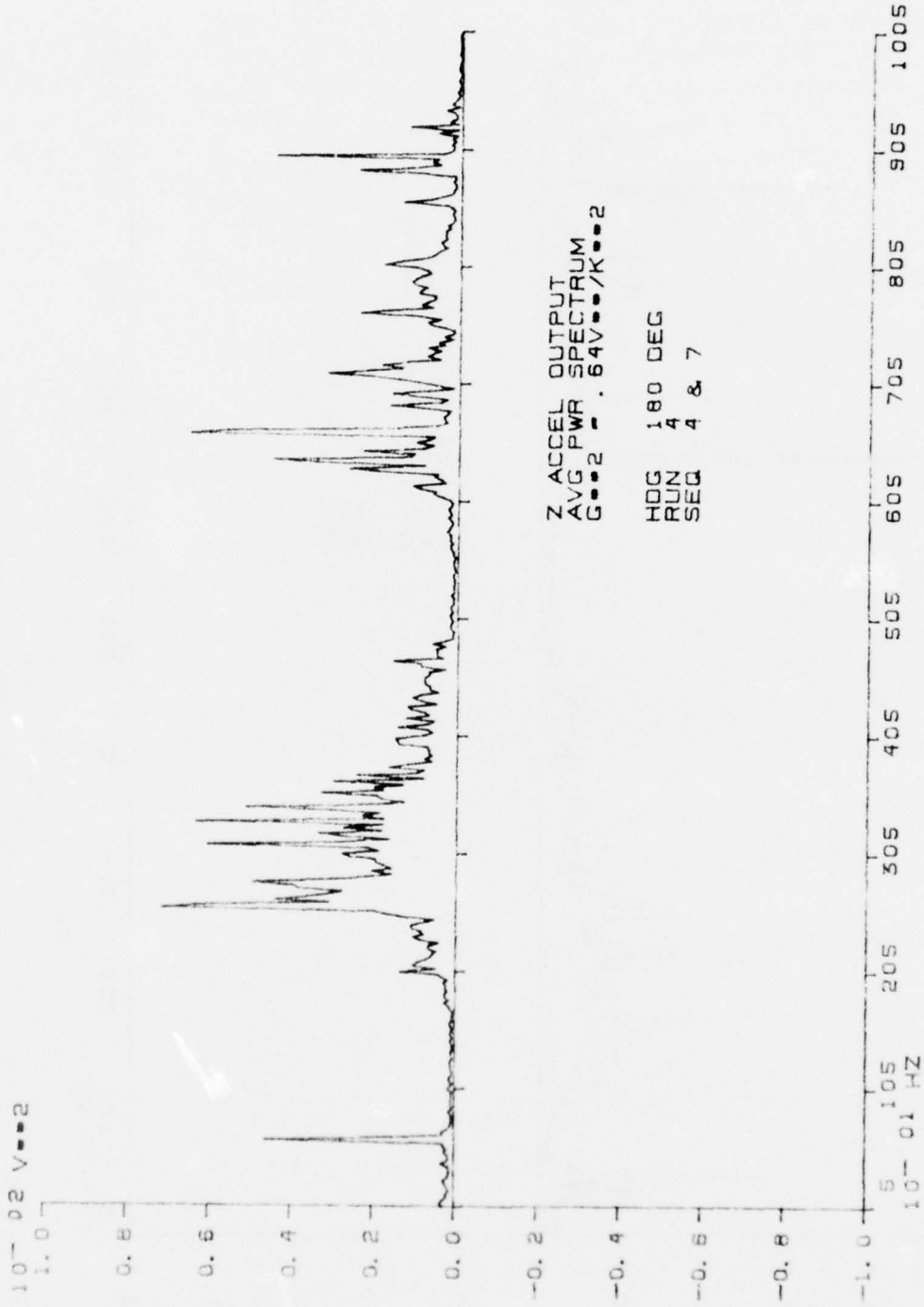


Figure C-14. Z acceleration output for run 4.

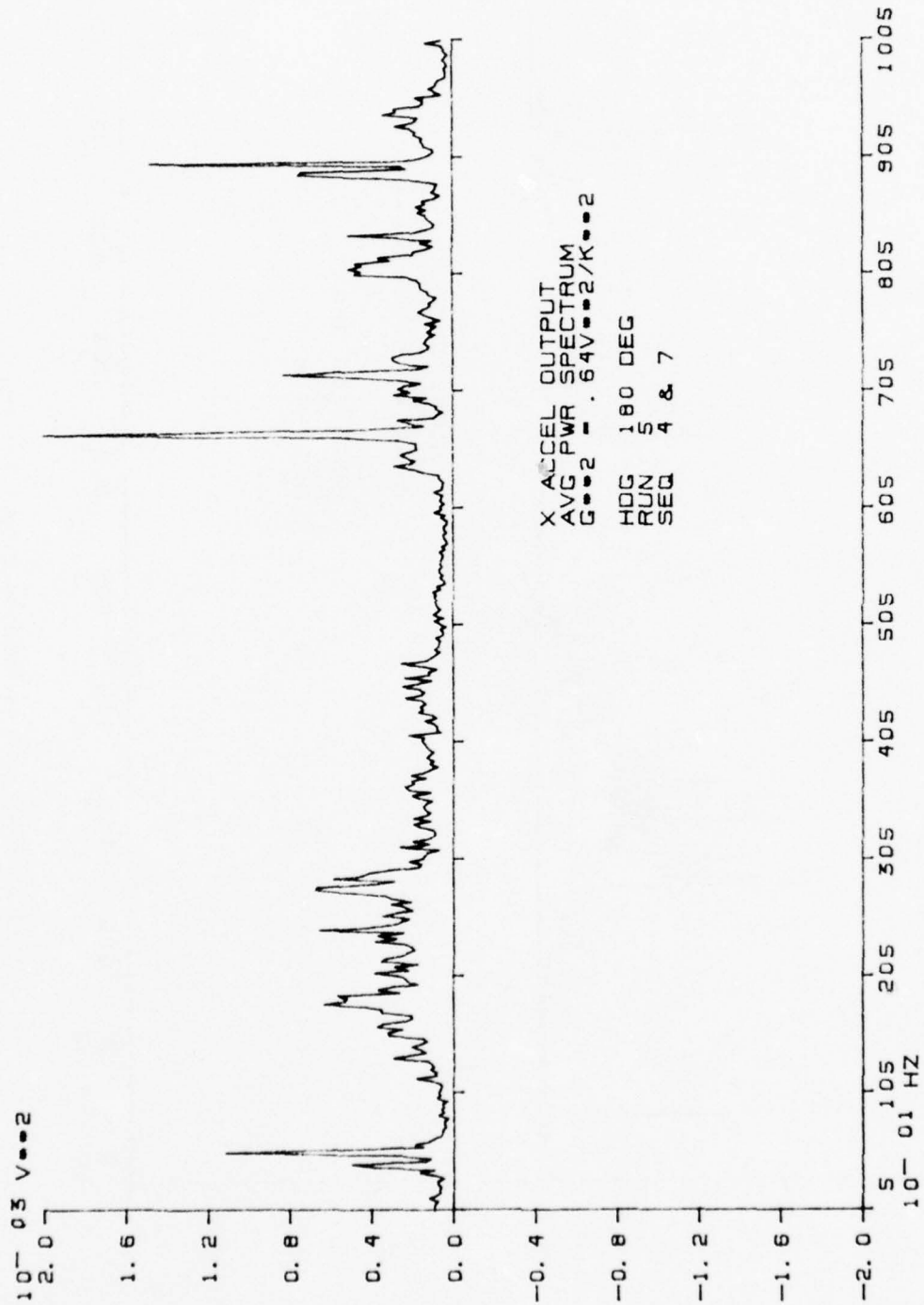


Figure C-15. X acceleration output for run 5.

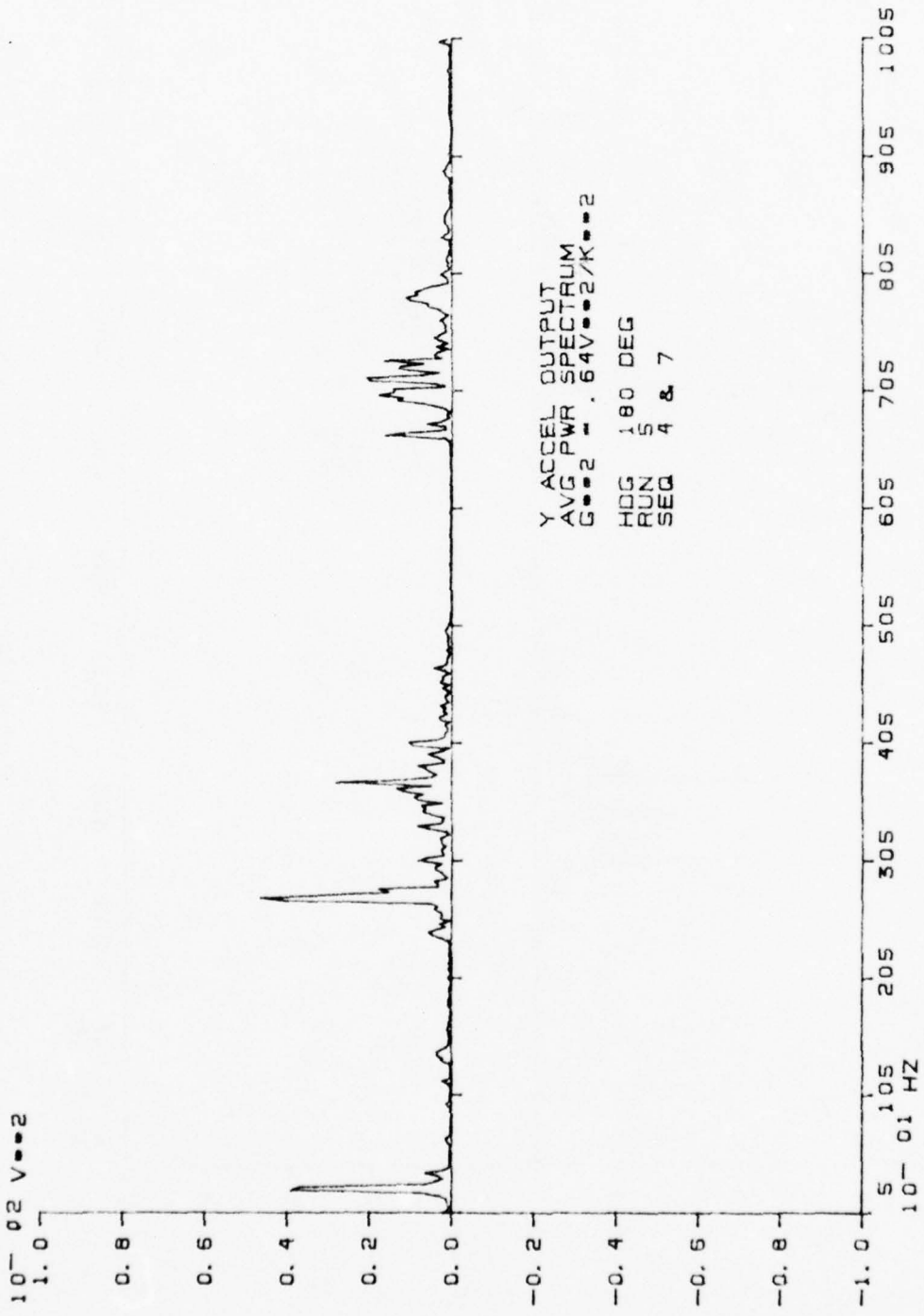


Figure C-16. Y acceleration output for run 5.

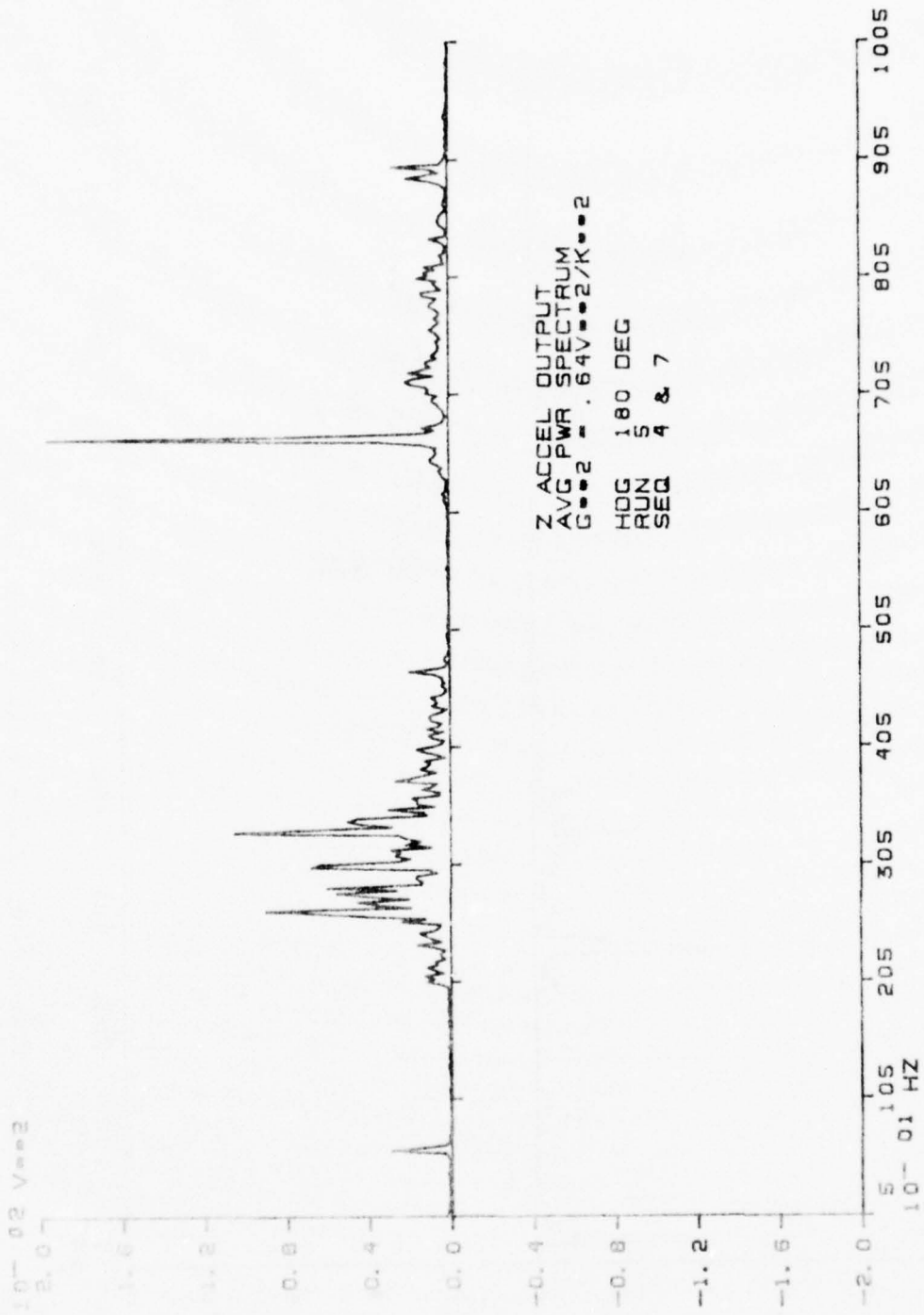


Figure C-17. Z acceleration output for run 5.

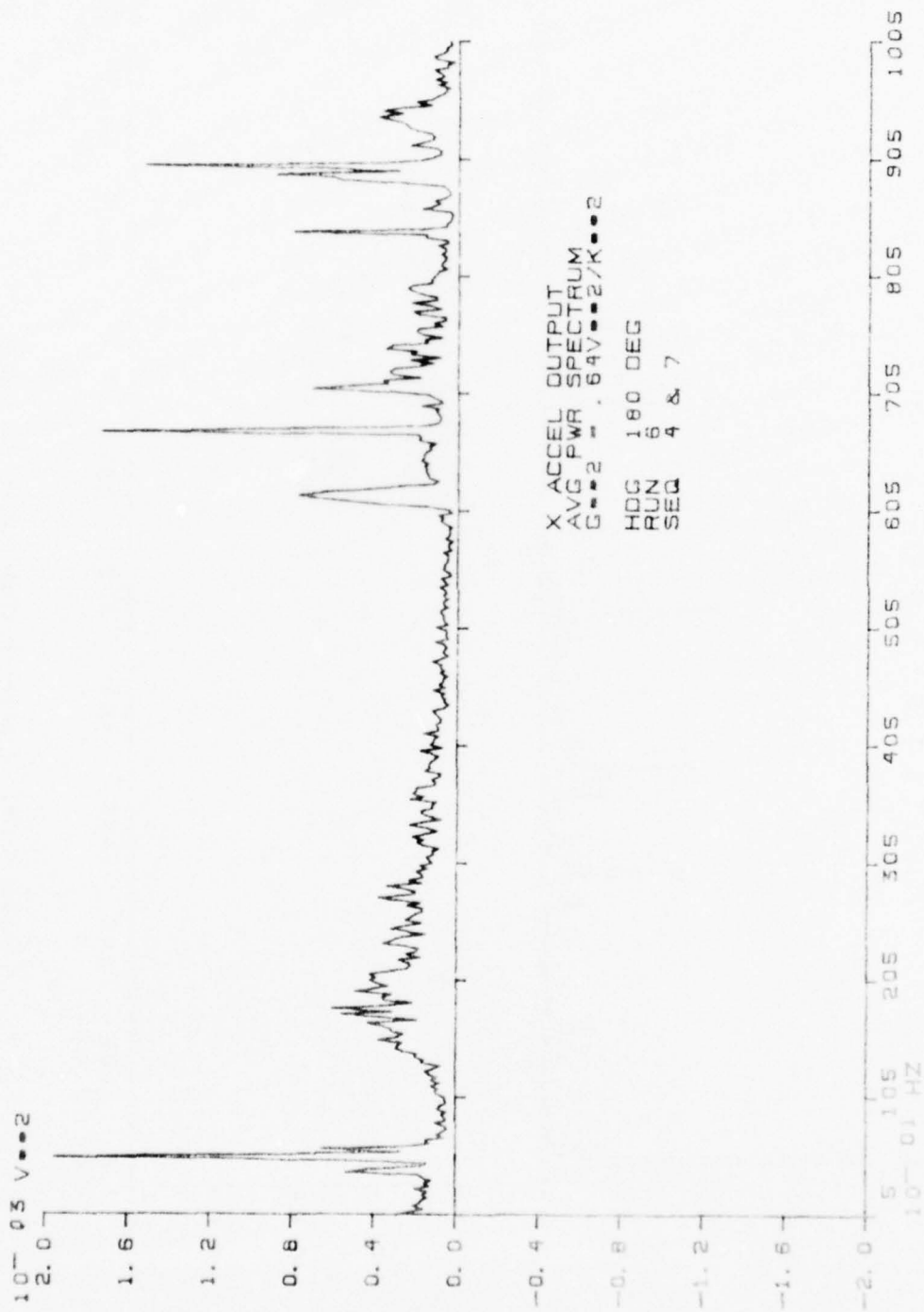


Figure C-18, X acceleration output for run 6.

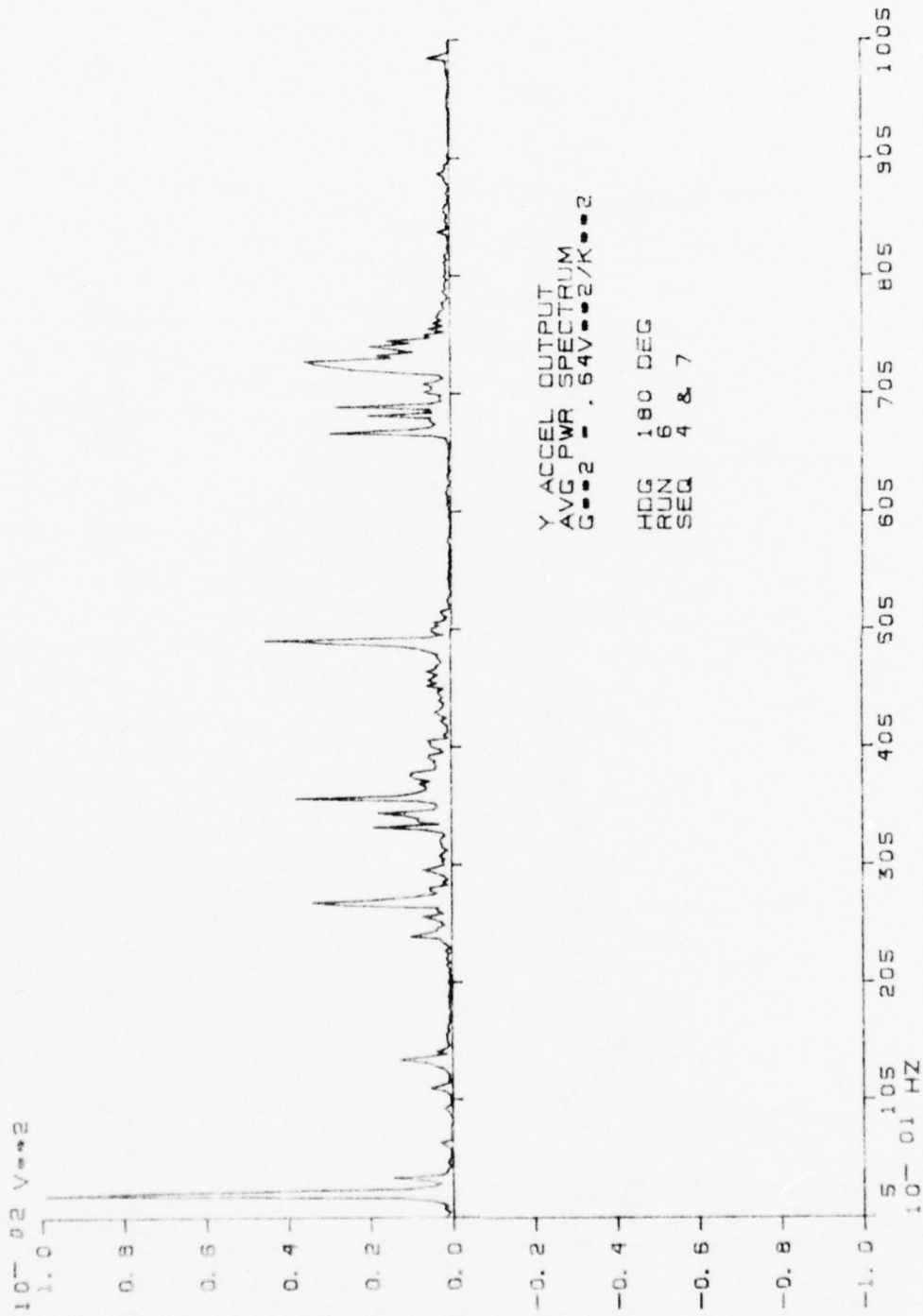


Figure C-19. Y acceleration output for run 6.

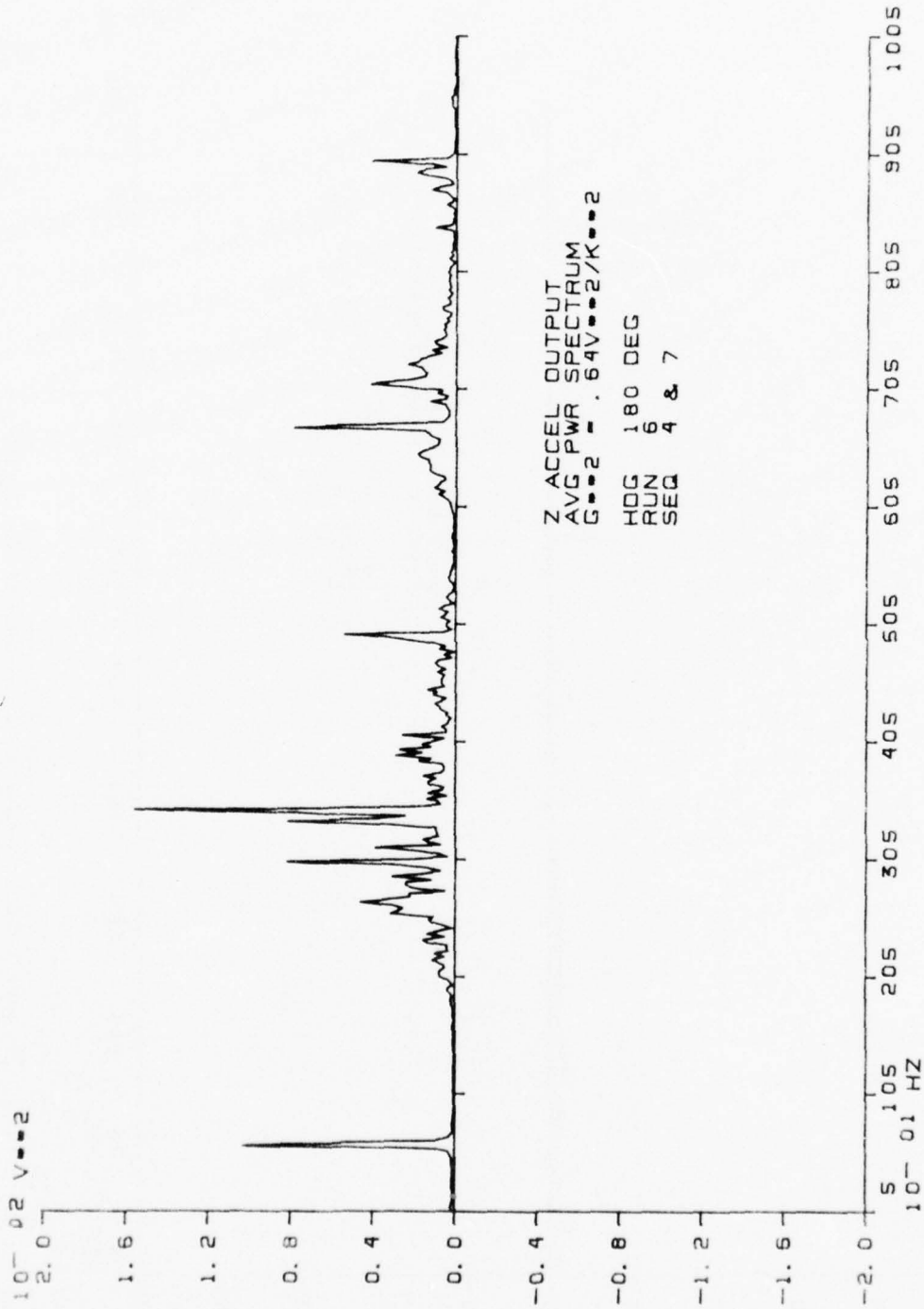


Figure C-20. Z acceleration output for run 6.

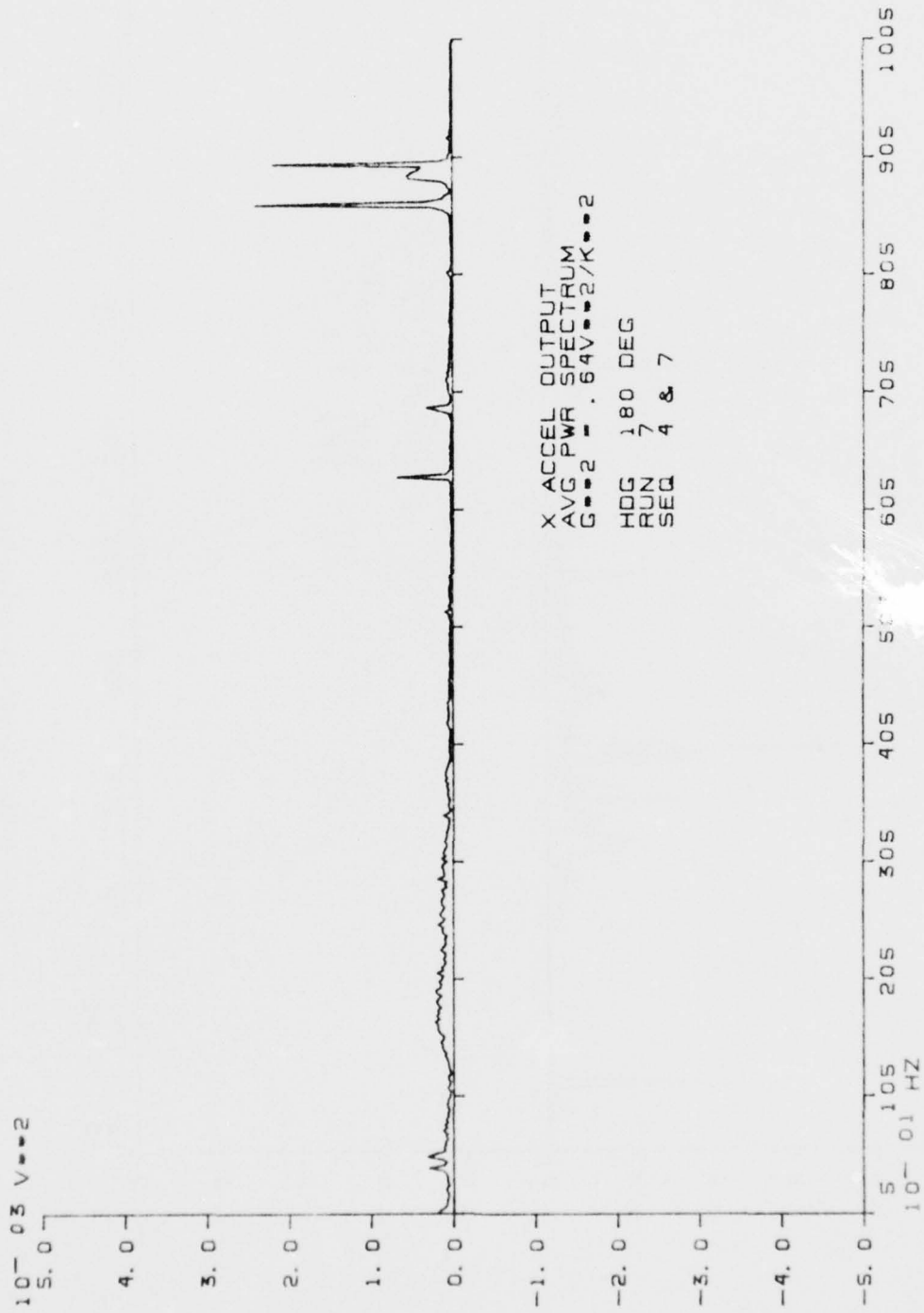


Figure C-21. X acceleration output for run 7.

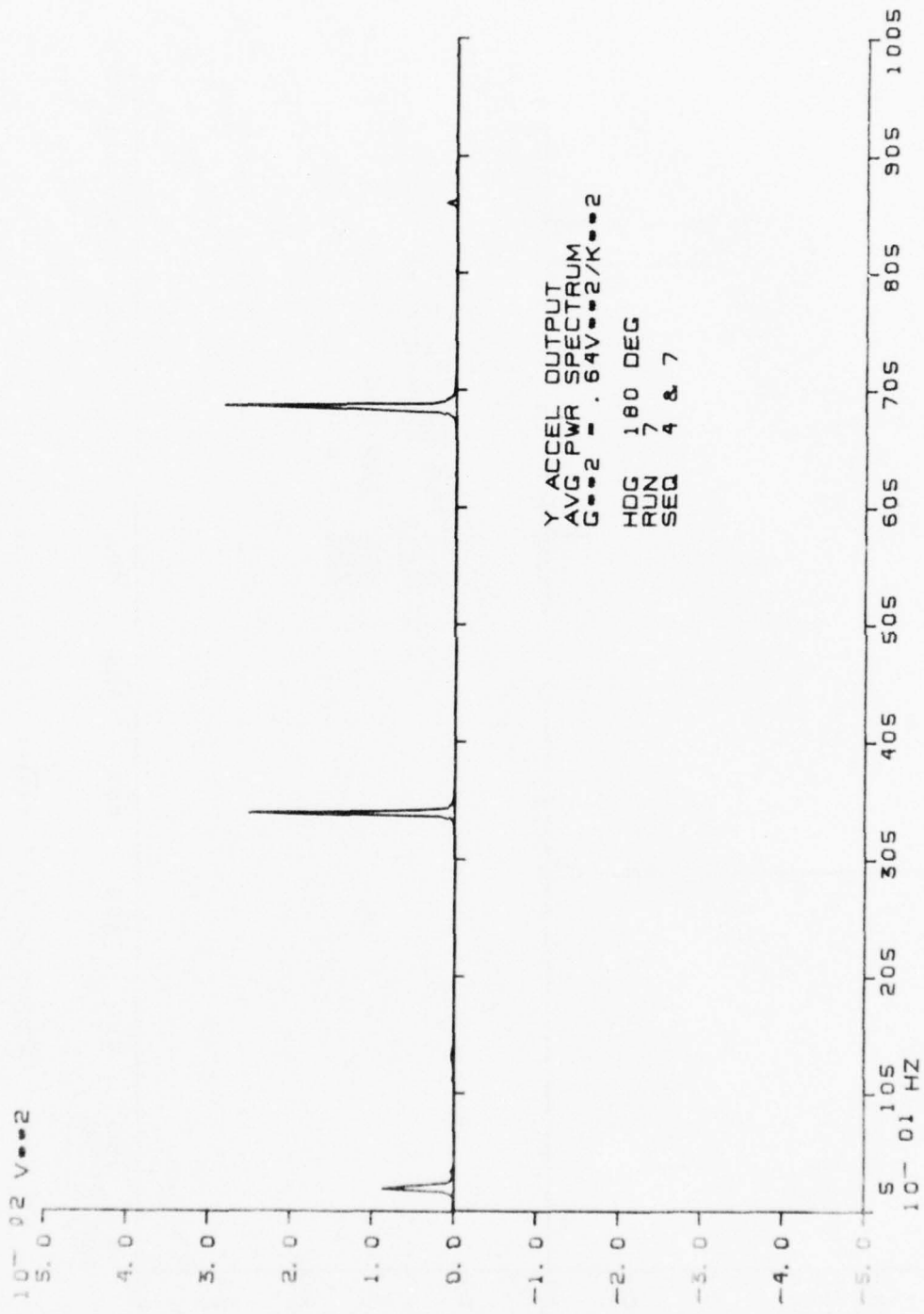


Figure C-22. Y acceleration output for run 7.

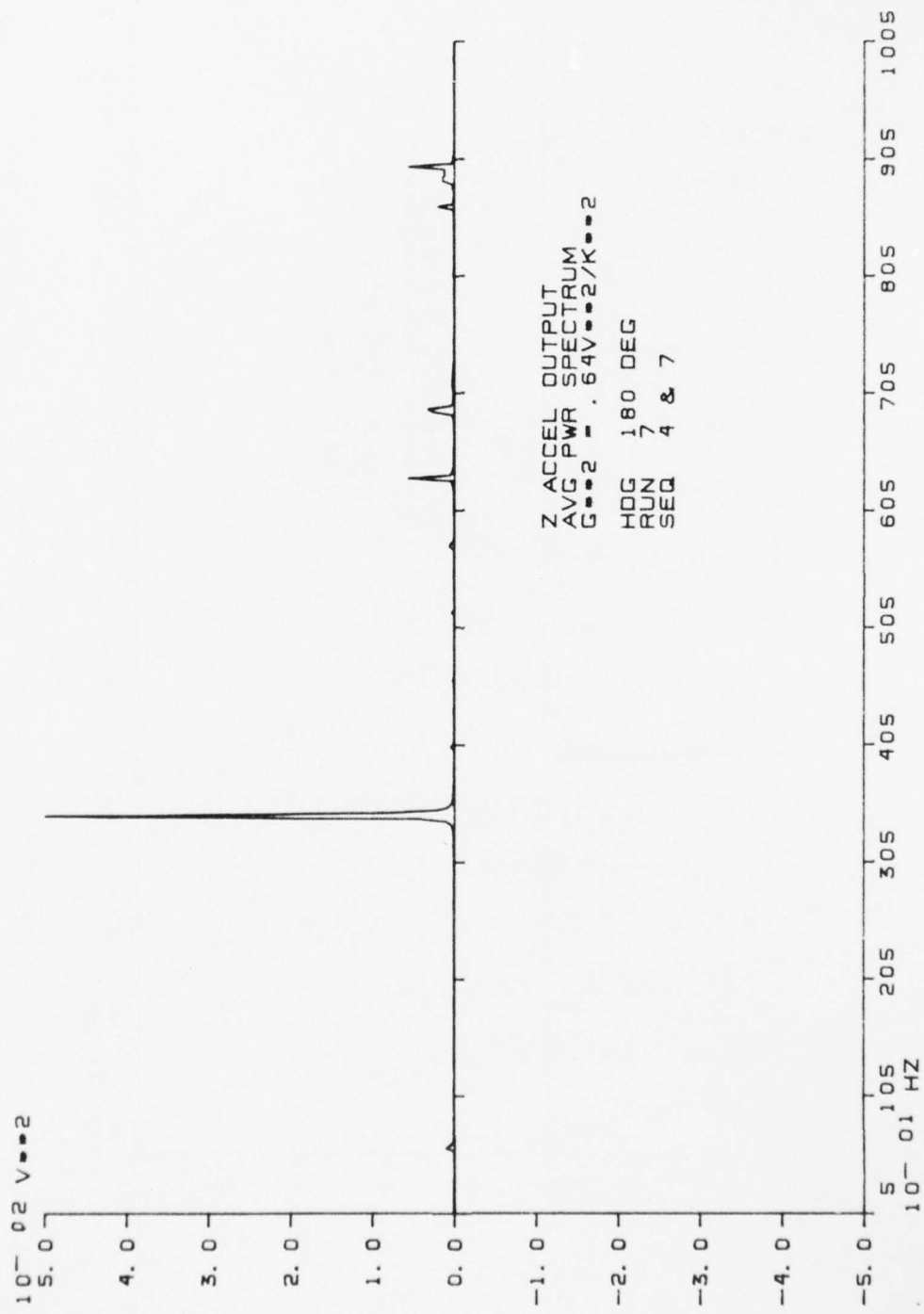


Figure C-23. Z acceleration output for run 7.

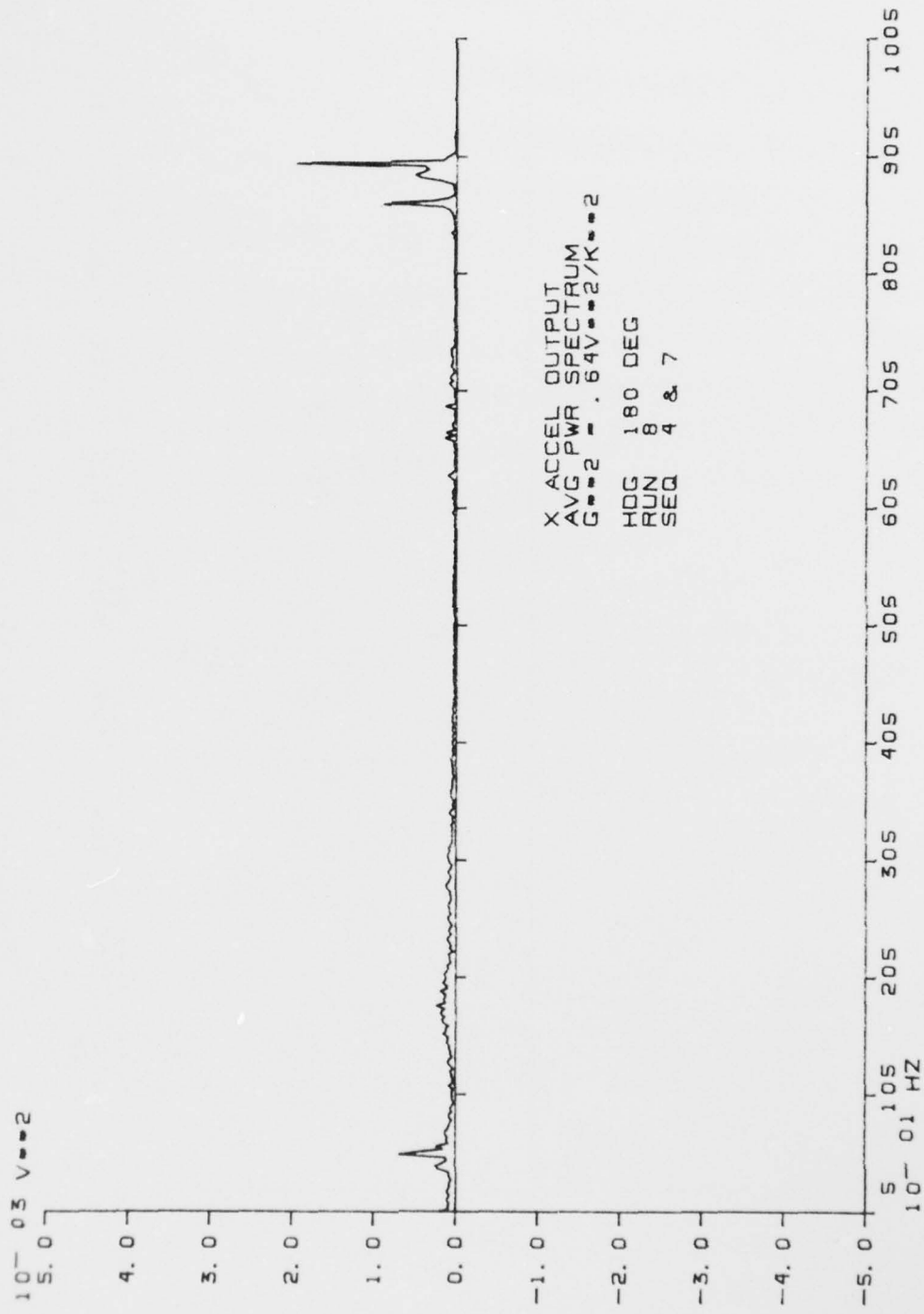


Figure C-24, X acceleration output for run 8.

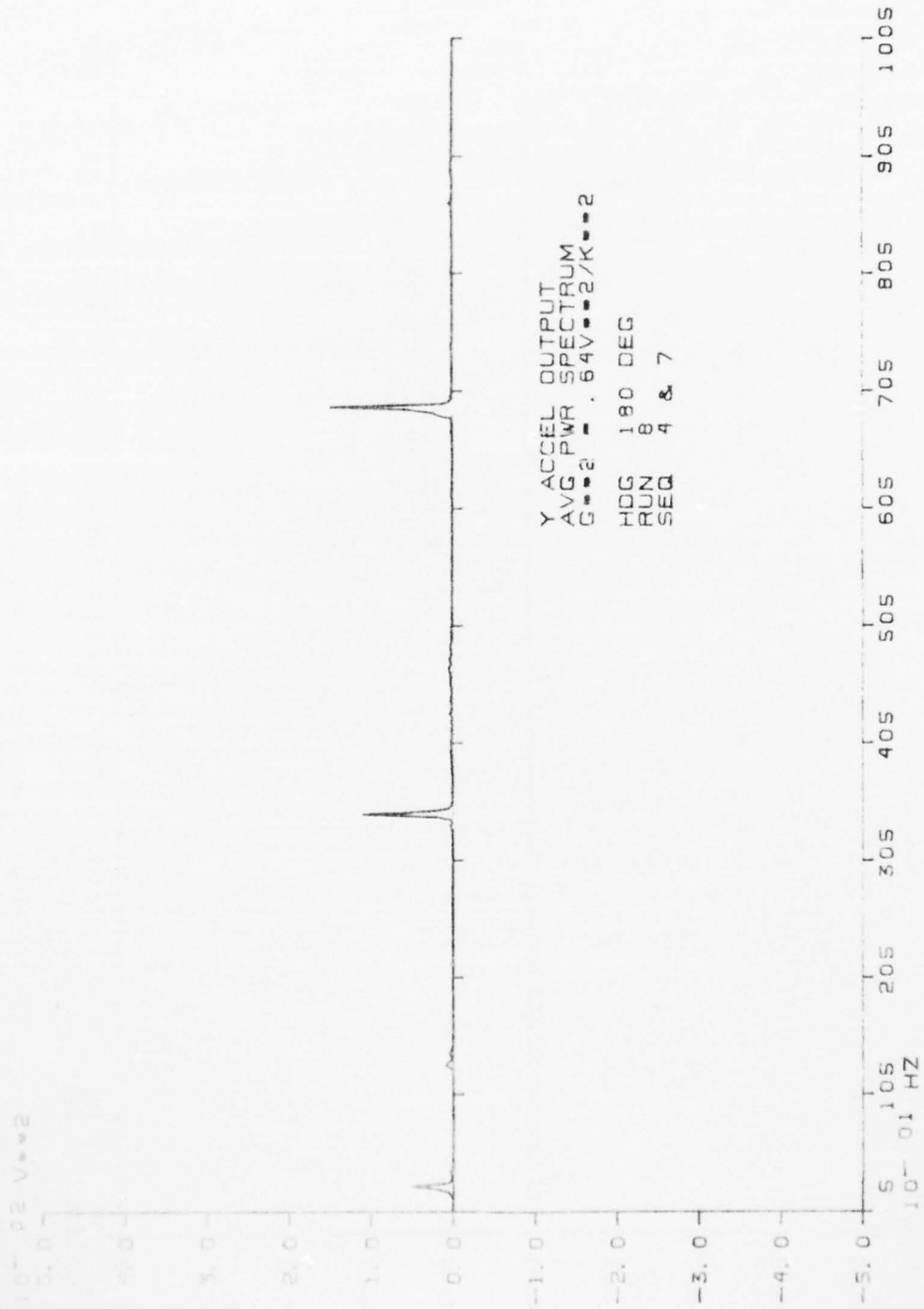


Figure C-25. Y acceleration output for run 8.

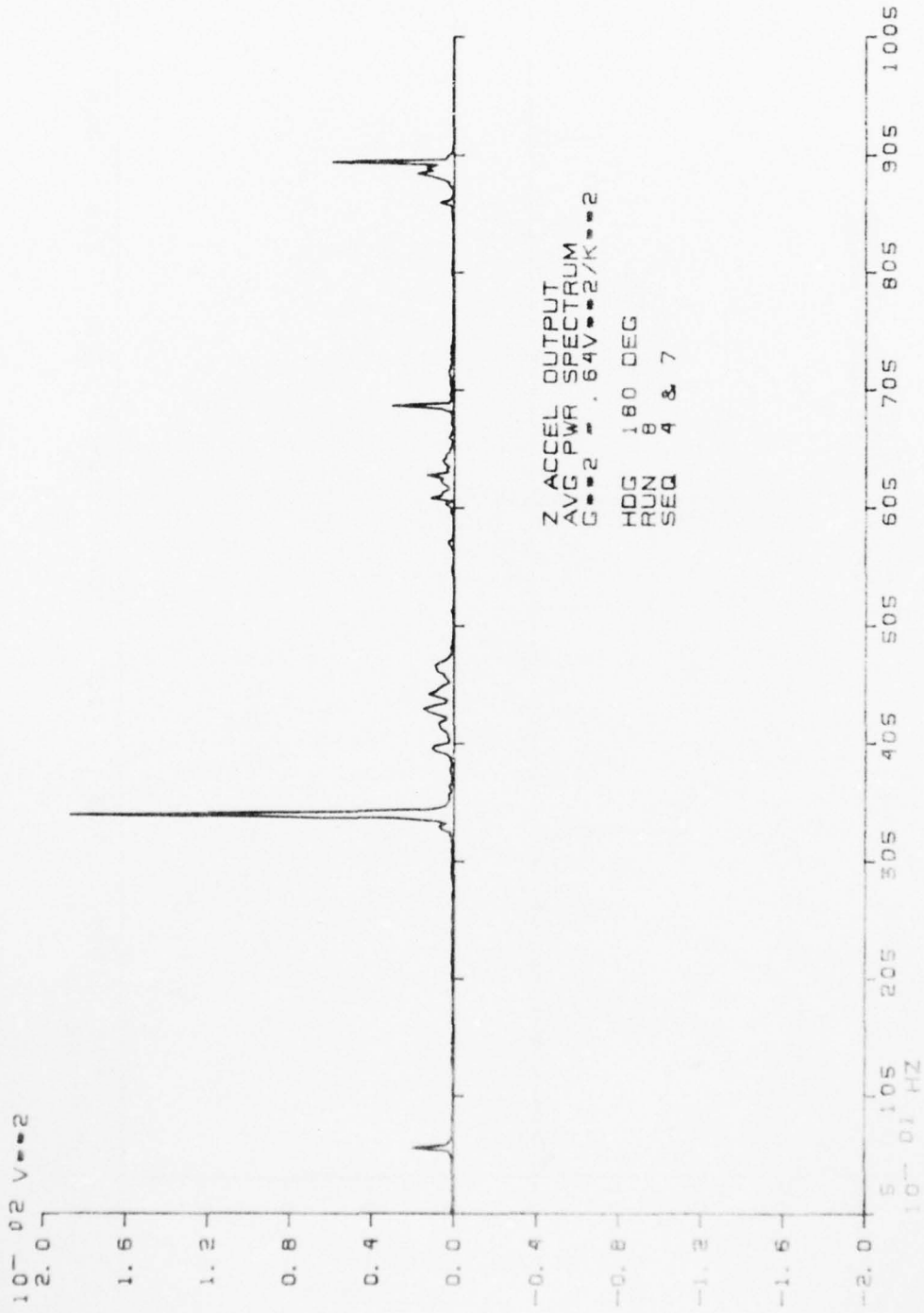


Figure C-26. Z acceleration output for run 8.

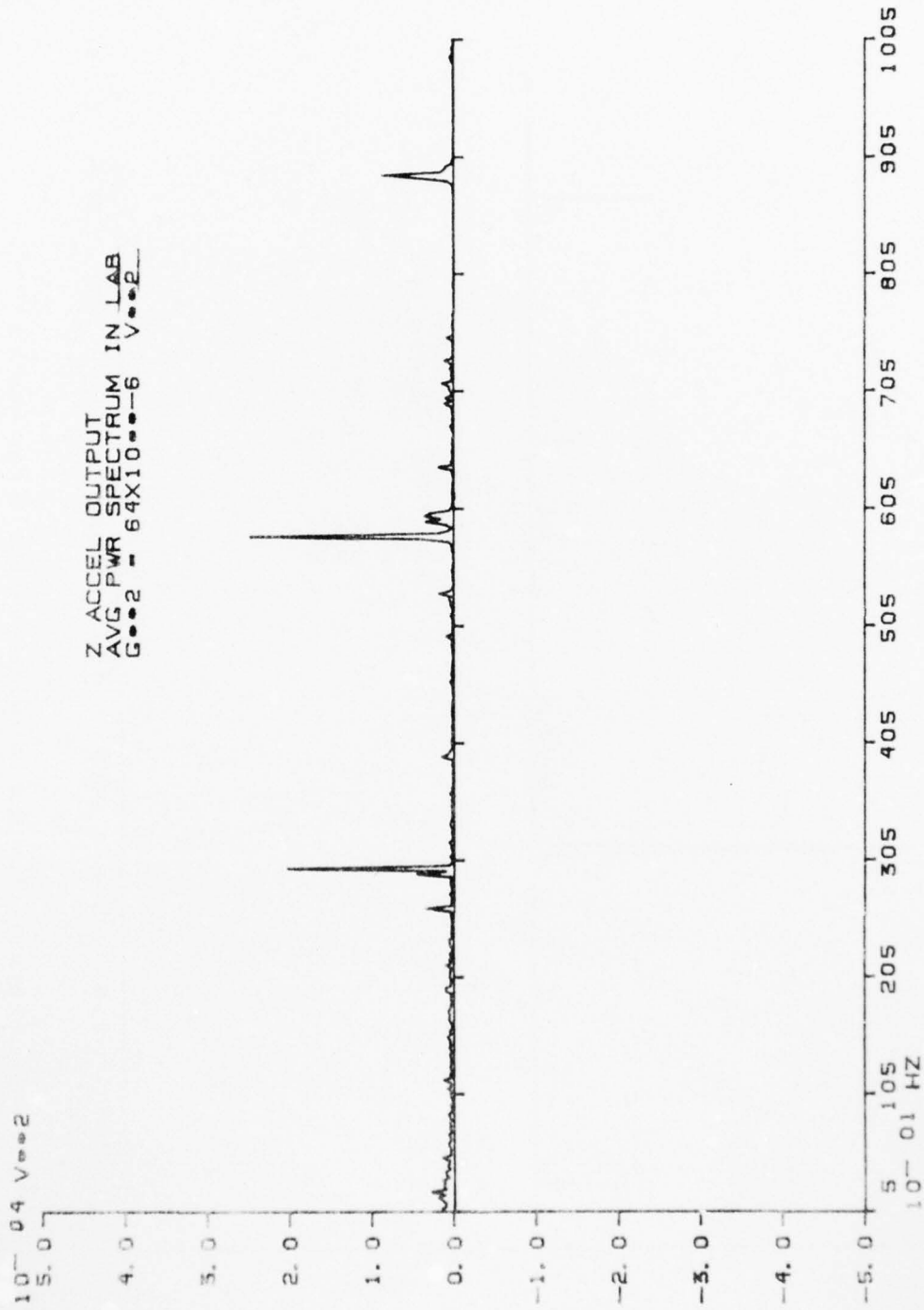


Figure C-27. Z acceleration output for laboratory operation.

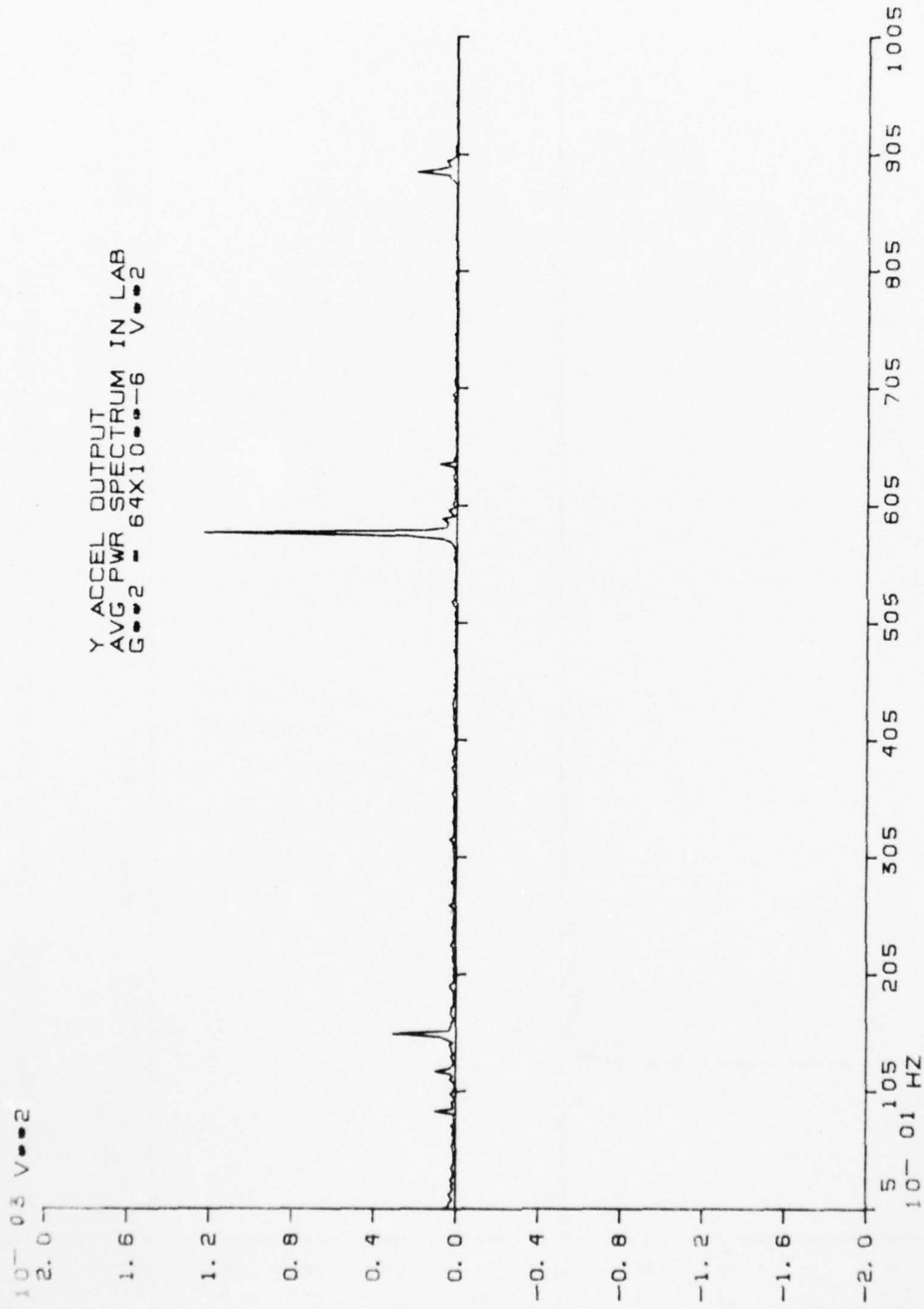


Figure C-28. Y acceleration output for laboratory operation.

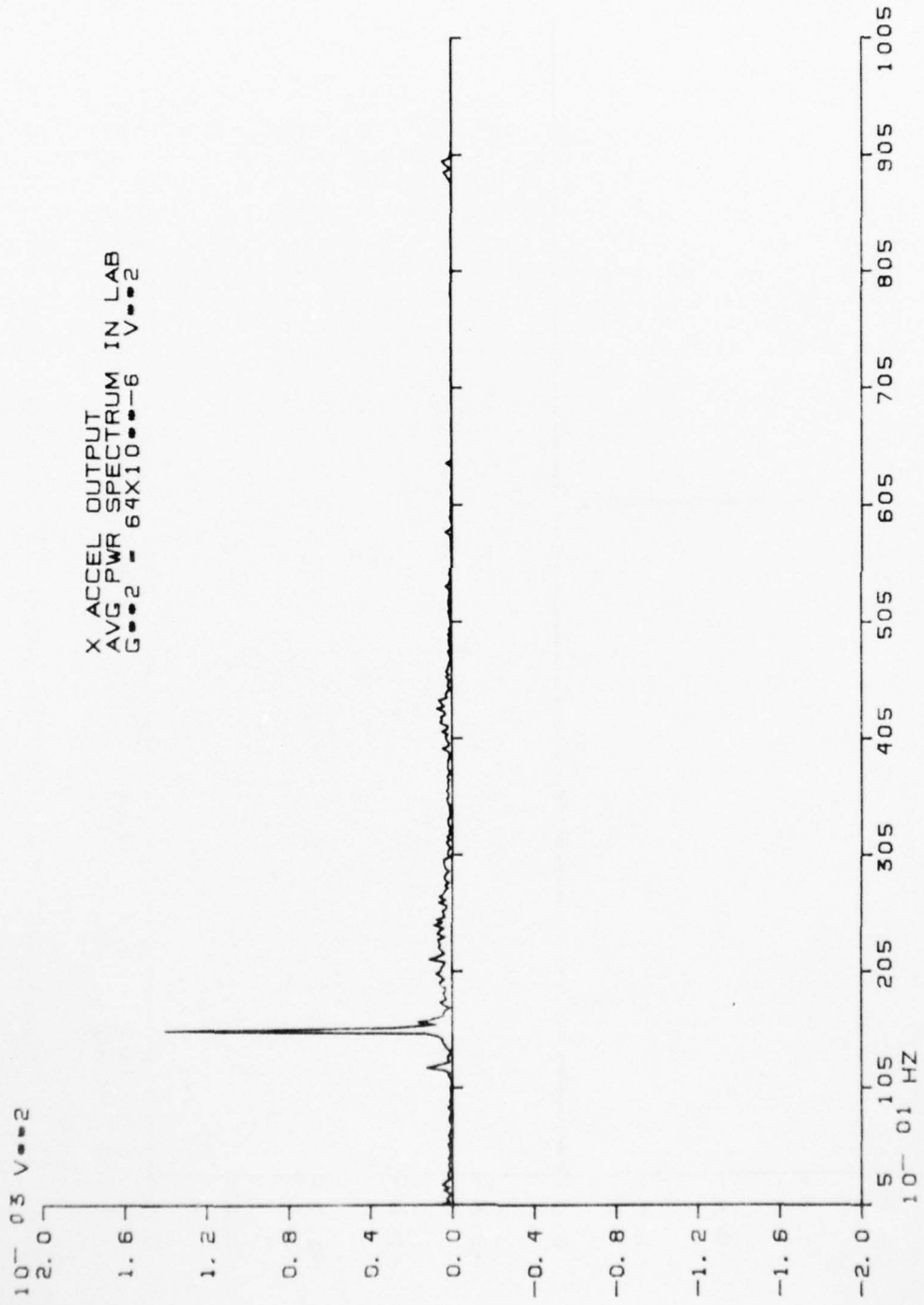


Figure C-29. X acceleration output for laboratory operation.

Appendix D. SUMMARY OF TEST RESULTS

Tables D-1 through D-8 contain a summary of gyrocompass test results at each of eight azimuth headings. Gyrocompass error for each individual run is contained in the column labeled ϵ_0 (arc sec). The root mean square (RMS), average (AVG), and standard deviation (σ) of the eight error values are shown at the bottom of this column. Other pertinent data are given including IMU channel drifts, azimuth resolver readings, environmental conditions, and power turn-on/turn-off operations.

The original data taken at 225° on 13 December 1976, as shown in Table D-6, was noted to yield the largest errors. The system was re-emplaced at 225° on 14 December 1976 and five additional test runs were made to gain assurance that potential errors in the test setup and operations were not contributing to the large gyrocompass errors. Data obtained from the five test reruns are presented in Table D-9.

Table D-10 presents a summary of pretest, field-test and post-test errors on an RMS, AVG, and σ basis versus azimuth heading. Also shown are composite statistics for pretest, field-test, and post-test errors based on the total of 64 runs for each of the 3 test conditions.

The error data contained in Table D-10 are plotted in Figures D-1 through D-3 to provide a visual comparison of pretest, field-test and post-test gyrocompass performance.

Pretest and post-test calibration results are presented in Tables D-11 and D-12.

TABLE D-1. PII IMU MISSILE-MOUNTED GYROCOMPASS FIELD TEST

IMU S/N: 001
 Date: 2 Dec 1976
 Heading: 0°
 Weather: Sunny

Remarks Legend: (1) Temperature (°F) Range

(2) Wind Speed (mph); and Direction (deg) Range

(3) Other

Run No.	α (deg, min, sec)	α_0 (deg, min, sec)	ϵ_0 (arc sec)	DN (°/hr)	DW (°/hr)	RSV (deg, min, sec)	Remarks
1	358 17 08	358 18 43	-95	0.1045	/	359 59 26	(1) 35-40 (2) 3-5, 310-340 CW (3) 9 min IMU warmup; Veh traffic
2	358 18 36	358 18 50	-14	0.1015	0.0166	359 59 24	(1) 42-44 (2) 3-5, 350-50 CW (3) Veh traffic
3	358 19 36	358 19 30	6	0.0992	0.0130	359 59 04	(1) 45-47 (2) 2-5, 340-70 CW (3) 28 VDC pwr off/on; veh idling beside EL
4	358 19 19	358 19 21	-2	0.0992	0.0140	359 59 24	(1) 48-49 (2) 2-4, 270-80 CW (3) veh traffic
5	358 19 15	358 18 50	25	0.0971	0.0126	359 59 24	(1) 50-50 (2) 2-4 270-10 CW (3) 28 VDC pwr off/on; veh idling beside EL
6	358 19 16	358 19 28	-12	0.0970	0.0139	359 59 24	(1) 51-51 (2) 1-5, 240-10 CW (3) no veh traffic
7	358 20 43	358 21 17	-34	0.0952	0.0145	359 59 28	(1) 52-52 (2) 2-5, 260-350 CW (3) all IMU pwr off/on; 9 min warmup; veh traffic
8	358 21 22	358 20 33	49	0.0971	0.0094	359 59 24	(1) 53-53 (2) 2-4, 240-10 CW (3) veh traffic
					0.0080		

Lat = 034° 38' 33"; should be 034° 37' 52"
 EL Jacks not extended

RMS	41
Avg	-10
σ	43

TABLE D-2. PII IMU MISSILE-MOUNTED GYROCOMPASS FIELD TEST

IMU S/N: 001 Remarks Legend: (1) Temperature (°F) Range
 Date: 9 Dec 1976 (2) Wind Speed (mph); and Direction (deg) Range
 Heading: 40° (3) Other
 Weather: Sunny

Run No.	α (arc sec) (deg, min, sec)	α_0 (arc sec) (deg, min, sec)	ϵ_0 (arc sec)	DN (°/hr)	DW (°/hr)	RSV (deg, min, sec)	Remarks
1	038 35 20	038 36 13	-53	0.0776	/	359 59 26	(1) 31-34 (2) 2-4, 150-180 CW (3) 1 hr IMU warmup veh idling beside EL
2	038 34 47	038 35 15	-28	0.0787	0.0844	358 54 30	(1) 34-37 (2) 3-7, 150-180 CW (3) veh traffic
3	038 34 35	038 35 31	-56	0.0740	0.0840	359 59 23	(1) 39-41 (2) 2-5, 80-150 CW (3) 28 VDC pwr off/on; veh traffic
4	038 34 23	038 34 54	-31	0.0741	0.0866	359 59 26	(1) 40-42 (2) 3-5, 70-170 CW (3) veh idling beside EL
5	038 34 27	038 35 39	-72	0.0735	0.0865	359 59 31	(1) 43-44 (2) 3-5, 100-180 CW (3) 28 VDC pwr off/on; veh traffic
6	038 34 20	038 35 45	-85	0.0753	0.0856	359 59 23	(1) 46-47 (2) 3-6, 90-160 CW (3) veh idling beside EL
7	038 33 25	038 35 01	-96	0.0786	0.0809	359 59 28	(1) 48-49 (2) 3-6, 60-150 CW (3) 28 VDC pwr off/on; vehicle idling beside EL
8	038 53 40	038 33 25	15	0.0762	0.0838	000 00 23	(1) 49-51 (2) 2-5, 80-150 CW (3) no veh traffic
					0.0802		

RMS	61
AVG	-51
σ	36

TABLE D-3. PII IMU MISSILE-MOUNTED GYROCOMPASS FIELD TEST

IMU #/hr. 031 Remarks Legend: (1) Temperature (°F) Range
 Date: 7 Dec 1976 (2) Wind Speed (mph); and Direction (deg) Range
 Heading: 70° (3) Other

Weather: Cloudy

Run No.	α (deg, min, sec)	α_0 (deg, min, sec)	α_0 (arc sec)	ϵ_0 (arc sec)	DN (°/hr)	RSV (deg, min, sec)	Remarks
1	069 30 16	069 31 00	-44		0.0137	359 59 28	(1) 42-43 (2) 2-5, 300-340 CW (3) 9 min IMU warmup; veh traffic
2	069 29 50	069 29 55	-5		0.1065	359 59 31	(1) 42-43 (2) 2-5, 300-400 CW (3) veh idling beside EL
3	069 30 05	069 29 57	8		0.0321	359 59 39	(1) 42-42 (2) 3-7, 310-330 CW (3) 28 VDC pwr off/on; veh idling beside EL
4	069 30 14	069 30 07	7		0.0321	359 59 39	(1) 42-43 (2) 4-7, 300-330 CW (3) veh idling beside EL
5	069 29 42	069 30 15	-33		0.0198	359 59 26	(1) 29-31 (2) no wind data, sensors frozen (3) 9 min IMU warmup; no veh traffic
6	069 30 44	069 30 26	18		0.0174	359 59 55	(1) 32-34 (2) no wind data, sensors frozen (3) veh traffic
7	069 30 36	069 30 25	11		0.0189	359 59 36	(1) 35-36 (2) no wind data, sensors frozen (3) 28 VDC off/on; veh idling beside EL
8	069 30 51	069 30 33	18		0.0210	359 59 58	(1) 32-38 (2) no wind data, sensors frozen (3) veh idling beside EL

Lat = 034° 38' 33"; should be 034° 37' 52"
 EL Jacks not extended

RMS	22
AVG	-2
σ	24

TABLE D-4. PII IMU MISSILE-MOUNTED GYROCOMPASS FIELD TEST

IMU S/N: 001 Remarks Legend: (1) Temperature (°F) Range
 Date: 6 Dec 1976 (2) Wind Speed (mph); and Direction (deg) Range
 Heading: 135° (3) Other

Weather: Cloudy, light rain

Run No.	α (arc sec) (deg, min, sec)	α_0 (arc sec) (deg, min, sec)	ϵ_0 (arc sec)	DN (°/hr)	DW (°/hr)	RSV (deg, min, sec)	Remarks
1	133 51 22	133 49 00	142	-0.0830	/	359 59 21	(1) 52-54 (2) 7-13, 100-120 CW (3) 1 hr IMU warmup; no veh traffic
2	133 50 30	133 49 35	55	-0.0834	0.0669	359 59 26	(1) 53-54 (2) 7-12, 110-140 CW (3) veh traffic
3	133 50 18	133 48 10	128	-0.0880	0.0677	359 59 26	(1) 53-53 (2) 4-8, 100-120 CW (3) 28 VDC pwr off/on; no veh traffic
4	133 50 11	133 49 15	56	-0.0876	0.0714	359 59 23	(1) 54-54 (2) 1-5, 60-110 CW (3) veh traffic
5	133 51 31	133 50 14	77	-0.0873	0.0719	359 59 26	(1) 54-54 (2) 2-7, 100-130 CW (3) 28 VDC pwr off/on, veh idling beside EL
6	133 51 59	133 50 09	110	-0.0863	0.0608	359 59 29	(1) 54-54 (2) 4-9, 100-130 CW (3) no veh traffic
7	133 50 32	133 49 51	41	-0.0847	0.0608	359 59 21	(1) 54-54 (2) 4-8, 110-130 CW (3) 28 VDC pwr off/on; veh idling beside EL
8	133 51 00	133 50 08	52	-0.0849	0.0726	359 59 29	(1) 54-54 (2) 6-13, 100-120 CW (3) veh idling beside EL
					0.0733		

Lat = 034° 38' 33"; should be 034° 37' 52"
 EL Jacks not extended

RMS	90
AVG	83
σ	59

TABLE D-5, PII IMU MISSILE-MOUNTED GYROCOMPASS FIELD TEST

Run /N: 001
 Date: 13 Dec 1976
 Heading: 180°
 Weather: Cloud AM, Sunny PM

Remarks Legend: (1) Temperature (°F) Range
 (2) Wind Speed (mph); and Direction (deg) Range
 (3) Other

Run No.	α (arc sec)	α_0 (deg, min, sec)	α_0 (arc sec)	ϵ_0 (arc sec)	DN (°/hr)	DW (°/hr)	RSV (deg, min, sec)	Remarks
1	225 45 15	225 46 20	-65	-0.0559	-0.0933	359 59 31	(1) 37-41 (2) 4-7, 350-10 CW (3) 9 min IMU warmup; veh traffic	
2	225 47 59	225 45 37	142	-0.0656	-0.0880	359 59 24	(1) 41-43 (2) 4-8, 360-20 CW (3) no veh traffic	
3	225 48 47	225 46 14	153	-0.0301	-0.0856	359 59 57	(1) 49-50 (2) 3-6, 330-10 CW (3) all pwr off for 45 min, 9 min IMU warmup; veh idling beside EL	
4	225 48 00	225 46 30	90	-0.0247	-0.0857	359 59 57	(1) 51-52 (2) 3-7, 330-10 CW (3) veh idling beside EL	
5	225 48 36	225 46 25	131	-0.0609	-0.0948	359 59 28	(1) 55-56 (2) 3-5, 350-20 CW (3) all pwr off for 45 min, 9 min IMU warmup; veh traffic	
6	225 47 16	225 44 39	157	-0.0625	-0.0951	359 59 28	(1) 56-56 (2) 2-5, 340-20 CW (3) veh traffic	
7	225 46 54	225 45 05	109	-0.0736	-0.0859	359 59 57	(1) 56-56 (2) 2-4, 350-20 CW (3) 28 VDC pwr off/on; veh idling beside EL	
8	225 47 33	225 44 42	171	-0.0767	-0.0857	359 59 31	(1) 56-56 (2) 2-4, 340-20 CW (3) veh idling beside EL	

RMS	132
Avg	111
σ	76

TABLE D-6. PII IMU MISSILE-MOUNTED GYROCOMPASS FIELD TEST

IMU S/N: 001 Remarks Legend: (1) Temperature (°F) Range
 Date: 14 Dec 1976 (2) Wind Speed (mph); and Direction (deg) Range
 Heading: 225° (3) Other
 Weather: Sunny

Run No.	α (arc sec) (deg, min, sec)	α_0 (arc sec) (deg, min, sec)	ϵ_0 (arc sec)	DN (°/hr)	DW (°/hr)	RSV (deg, min, sec)	Remarks
1	181 24 28	181 23 22	66	-0.1032	/	359 59 31	(1) 39-41 (2) 3-5, 90-130 CW (3) 20 min system warmup; veh idling beside EL
2	181 27 16	181 25 41	95	-0.1037	-0.0362	559 59 58	(1) 46-48 (2) 3-9, 100-130 CW (3) veh idling beside EL
3	181 26 25	181 25 28	57	-0.0982	-0.0343	000 00 03	(1) 48-52 (2) 4-7, 110-130 CW (3) 28 VDC pwr off/on, veh traffic
4	181 26 01	181 25 23	38	-0.0992	0.0345	359 59 58	(1) 52-52 (2) 3-7, 90-150 CW (3) veh traffic
5	181 25 10	181 25 20	-10	-0.0982	-0.0350	359 59 28	(1) 53-54 (2) 3-8, 90-130 CW (3) 28 VDC off-on; veh traffic
6	181 26 03	181 25 06	57	-0.0981	-0.0199	359 59 29	(1) 55-55 (2) 3-8, 110, 150 CW (3) veh traffic
7	181 25 27	181 24 29	58	-0.1017	-0.0227	359 59 28	(1) 56-56 (2) 3-7, 100-150 CW (3) 28 VDC pwr off/on; veh idling beside EL
8	181 25 34	181 24 10	84	-0.1026	-0.0148	359 59 22	(1) 56-57 (2) 3-8, 100-150 CW (3) veh traffic
					-0.0167		

RMS	63
Avg	56
σ	32

TABLE D-7. PII IMU MISSILE-MOUNTED GYROCOMPASS FIELD TEST

IMU S/N: 001 Remarks Legend: (1) Temperature (°F) Range
 Date: 10 Dec 1976 (2) Wind Speed (mph); and Direction (deg) Range
 Heading: 270° (3) Other
 Weather: Cloudy

Run No.	α (arc sec) (deg, min, sec)	α_0 (arc sec) (deg, min, sec)	ϵ_0 (arc sec)	DN (°/hr)	DW (°/hr)	RSV (deg, min, sec)	Remarks
1	257 42 30	267 40 54	96	0.0089	-0.1068	359 59 29	(1) 42-44 (2) 2-4, 130-180 CW (3) 9 min system warmup; no veh traffic
2	267 39 27	267 38 27	60	0.076	-0.1065	359 59 24	(1) 44-46 (2) 2-4, 120-170 CW (3) veh traffic
3	267 41 17	267 38 58	139	0.0053	-0.1130	359 59 31	(1) 47-49 (2) 2-4, 110-150 CW (3) 28 VDC pwr off/on; veh traffic
4	267 40 30	267 38 57	93	0.0050	-0.1111	359 59 29	(1) 49-51 (2) 2-4, 120-150 CW (3) veh idling beside EL
5	267 40 38	267 38 34	124	0.0240	-0.1187	359 59 28	(1) 51-51 (2) 2-4, 110-150 CW (3) 28 VDC pwr off/on; veh traffic
6	267 40 41	267 39 25	76	0.0188	-0.1171	359 59 29	(1) 52-52 (2) 2-5, 120-150 CW (3) veh idling beside EL
7	267 39 41	267 39 22	101	0.0126	-0.1089	359 59 26	(1) 52-53 (2) 2-7, 120-170 CW (3) 28 VDC pwr off/on; veh traffic
8	267 39 41	267 38 30	71	0.0132	-0.1096	359 59 31	(1) 53-53 (2) 2-6, 120-150 CW (3) veh idling beside EL

RMS	98
AVE	95
σ	27

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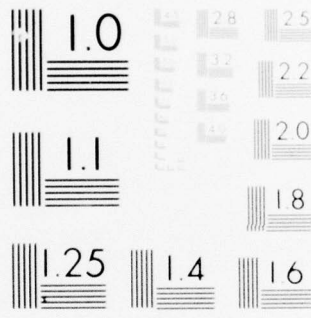
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TABLE D-8. PII IMU MISSILE-MOUNTED GYROCOMPASS FIELD TEST

IMU S/N: 001 Remarks Legend: (1) Temperature (°F) Range
 Date: 3 Dec 1976 (2) Wind Speed (mph); and Direction (deg) Range
 Heading: 315° (3) Other

Weather: Partly Cloudy

Run No.	α (arc sec) (deg, min, sec)	α_0 (arc sec) (deg, min, sec)	ϵ_0 (arc sec)	DN (°/hr)	DW (°/hr)	RSV (deg, min, sec)	Remarks
1	318 22 34	318 22 41	-7	0.0800	/	359 59 26	(1) 43-45 (2) 2-6, 100-180 CW (3) 1 hr IMU warmup; veh traffic
2	318 24 14	318 24 02	12	0.0792	-0.0594	359 59 28	(1) 48-50 (2) 3-4, 80-130 CW (3) veh traffic
3	318 24 30	318 23 48	42	0.0804	-0.0580	359 59 28	(1) 52-55 (2) 2-4, 30-210 CW (3) 28 VDC pwr off/on; veh traffic
4	318 27 49	318 26 16	93	0.0805	/	359 59 26	(1) 57-58 (2) 2-3, 0-290 CW (3) veh traffic
5	318 26 36	318 25 43	53	0.0814	-0.0612	359 59 24	(1) 64-66 (2) 2-4, 70-0 CW (3) all pwr off for 1 hr, 9 min IMU warmup; veh traffic
6	318 25 14	318 24 42	32	0.0830	-0.697	359 59 28	(1) 67-68 (2) 2-5, 150-250 CW (3) veh traffic
7	318 24 52	318 24 15	37	0.0760	-0.0720	359 59 26	(1) 68-70 (2) 2-8, 170-230 CW (3) 28 VDC pwr off/on; no veh traffic
8	318 25 16	318 24 45	31	0.0779	-0.0545	359 59 28	(1) 67-67 (2) 3-7, 180-220 CW (3) veh traffic
		RMS	46				Lat = 034° 38' 33"; should be 034° 37' 52"3
		AVG	37				EL Jacks not extended
		σ	29				

TABLE D-9. PII IMU MISSILE-MOUNTED GYROCOMPASS FIELD TEST

IMU S/N: 001 Remarks Legend: (1) Temperature (°F) Range
 Date: 14 Dec 1976 (2) Wind Speed (mph); and Direction (deg) Range
 Heading: 225° (Rerun) (3) Other
 Weather: Partly Cloudy

Run No.	α (arc sec) (deg, min, sec)	α_0 (arc sec) (deg, min, sec)	c_0 (arc sec)	DN (°/hr)	DW (°/hr)	RSV (deg, min, sec)	Remarks
1	222 20 09	222 18 19	110	-0.0597	-0.0962	359 59 28	(1) 60-60 (2) 3-5, 90-130 CW (3) veh traffic
2	222 20 34	222 18 21	133	-0.0615	-0.0962	359 59 29	(1) 60-60 (2) 3-9, 110-130 CW (3) veh idling beside EL
3	222 19 02	222 17 50	72	-0.0676	-0.0896	359 59 24	(1) 59-60 (2) 4-6, 110-130 CW (3) 28 VDC pwr off/on; no veh traffic
4	222 18 09	222 16 20	109	-0.0613	-0.0929	359 59 31	(1) 59-60 (2) 3-7, 90-150 CW (3) veh traffic
5	222 20 53	222 18 32	141	-0.0651	-0.1039	359 59 28	(1) 58-59 (2) 2-8, 90-130 CW (3) 28 VDC pwr off/on; veh idling beside EL
6							
7							
8							
			RMS				
			AVG				
			σ				

TABLE D-10. PII IMU GYROCOMPASS FIELD TEST RESULTS
 IMU S/N: 001: COMPILATION OF PRETEST, FIELD AND
 POST-TEST DATA

Heading (deg)	Statistics for 8 Runs	Pretest Error (arc sec)	Field Test Error (arc sec)	Post-Test Error (arc sec)
0	RMS	31	(2 Dec) 41*	78
	Avg	-19	-10	-57
	σ	27	43	58
45	RMS	45	(9 Dec) 61	64
	Avg	-40	(40°) -51	-63
	σ	22	36	12
90	RMS	40	(7-8 Dec) 22*	55
	Avg	5	(70°) -2	-52
	σ	43	24	20
135	RMS	25	(6 Dec) 90*	41
	Avg	9	83	36
	σ	25	39	21
180	RMS	44	(14 Dec) 63	38
	Avg	32	56	23
	σ	31	32	32
225	RMS	48	(13 Dec) 132	20
	Avg	42	111	14
	σ	24	76	15
270	RMS	32	(10 Dec) 98	32
	Avg	7	95	20
	σ	34	27	27
315	RMS	40	(3 Dec) 46*	60
	Avg	25	37	38
	σ	33	29	50
Composite Statistics for 64 Runs for Each Test Condition	RMS	39	77	52
	Avg	8	40	-5
	σ	38	66	52

*Lat = 034° 38' 33"; should be 034° 37' 52"
 EL Jacks not extended

TABLE D-11. PRETEST CALIBRATION DATA, 40-FOOT CABLES,
2 NOVEMBER 1976

Entries are Deviations from Acceptance Test Values			
DFZ E	0.00777695 deg/hr	DIX E	0.06210616 deg/hr/G
DSZ E	0.00777695 deg/hr	DIY E	0.06210616 deg/hr/G
DIZ E	0.16653737 deg/hr/G	DELTYX	0.00005547 rad
KIY E	-156.24057007 μ G/G	DELTZY	-0.00001263 rad
KIYHE	-113.91108704 μ G/G	KOZ E	-97.67112732 μ G
KIX E	-179.68435669 μ G/G	KSZ E	-81.70867920 μ G
KIXHE	-154.54333496 μ G/G	KOZHE	-85.04553223 μ G
DOZ E	0.01000393 deg/hr/G	KSZHE	-90.18788147 μ G
DFX E	0.08050755 deg/hr	KOX E	26.49459839 μ G
KIZ E	50.74204254 μ G/G	KSX E	21.72198868 μ G
KIZHE	43.49652863 μ G/G	KOXHE	-5.78488159 μ G
DFY E	0.02019069 deg/hr	KSXHE	-27.40397263 μ G
DSX E	0.00466868 deg/hr	DELTZX	-0.00000712 rad
DSY E	-0.00466868 deg/hr	KOY E	2.69024658 μ G
KTXE	-0.00050398 deg/hr/deg/hr	KSY E	11.00490761 μ G
KTYE	-0.00039612 deg/hr/deg/hr	KOYHE	-52.97576904 μ G
KTZE	0.00032379 deg/hr/deg/hr	KSYHE	-50.74983978 μ G

TABLE D-12. POST TEST CALIBRATION DATA, 40-FOOT CABLES,
16 DECEMBER 1976

Entries are Deviations from Acceptance Test Values			
DFZ E	-0.04159076 deg/hr	DIX E	0.00174049 deg/hr/G
	-0.01083504 deg/hr/G	DIY E	0.00174049 deg/hr/G
DIZ E	0.10650995 deg/hr/G	DELTIX	0.00003333 rad
KIY E	-93.79339600 μ G/G	DELTZY	-0.00002276 rad
KIYHE	-47.91403198 μ G/G	KOZ E	-160.22668457 μ G
KIX E	-106.87594604 μ G/G	KSZ E	-111.99859619 μ G
KIXHE	-53.13750458 μ G/G	KOZHE	-99.77009583 μ G
DOZ E	-0.01711116 deg/hr/G	KSZHE	-71.48503113 μ G
DFX E	0.07787050 deg/hr	KOX E	44.75085449 μ G
		KSX E	48.16700745 μ G
KIX E	57.22663116 G/G	KOXHE	-12.49636841 μ G
KIZHE	20.30768967 G/G	KSXHE	-21.57628632 μ G
DFY E	0.03096781 deg/hr	DELTZX	0.00002585 rad
DSX E	-0.00273511 deg/hr	KOY E	39.71406555 μ G
DSY E	0.00273511 deg/hr	KSY E	44.71518707 μ G
KIXE	-0.00054308 deg/hr/deg/hr	KOYHE	-17.06207275 μ G
ICTYE	-0.0003451 deg/hr/deg/hr	KSYHE	-20.80200958 μ G
ICTZE	-0.00009416 deg/hr/deg/hr		

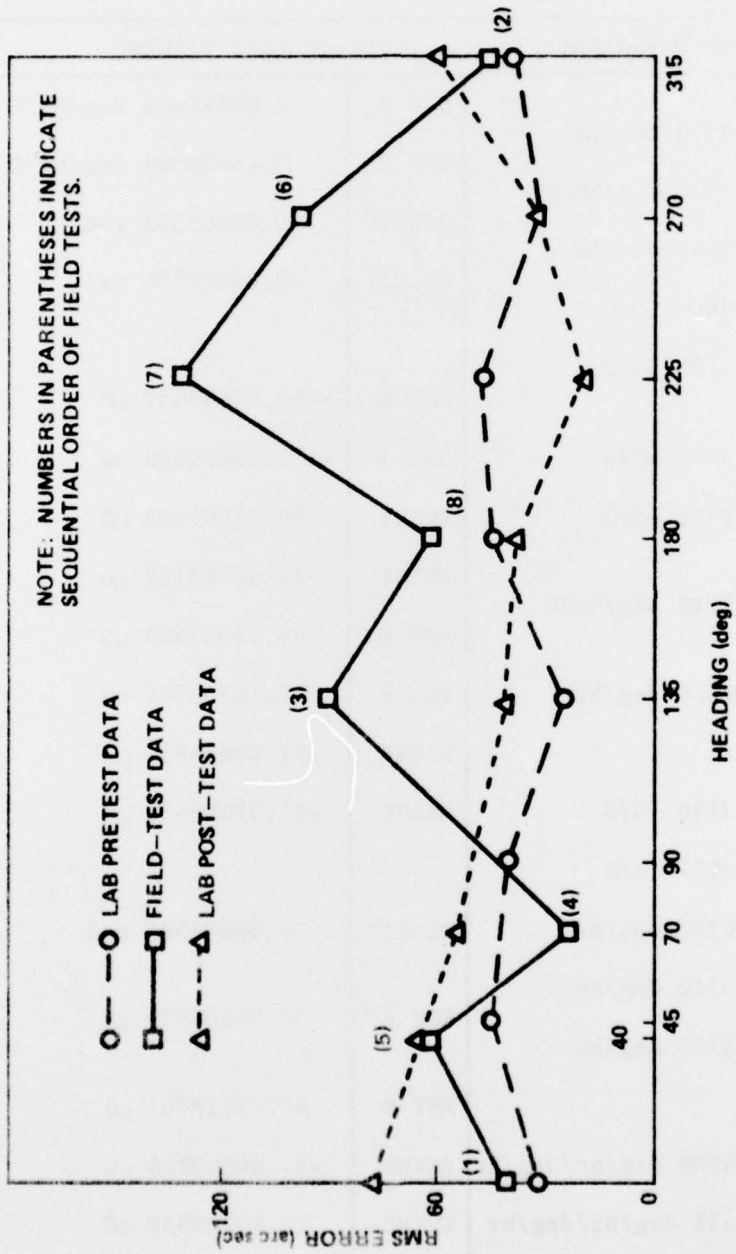


Figure D-1. PII IMU S/N 001 gyrocompass RMS error.

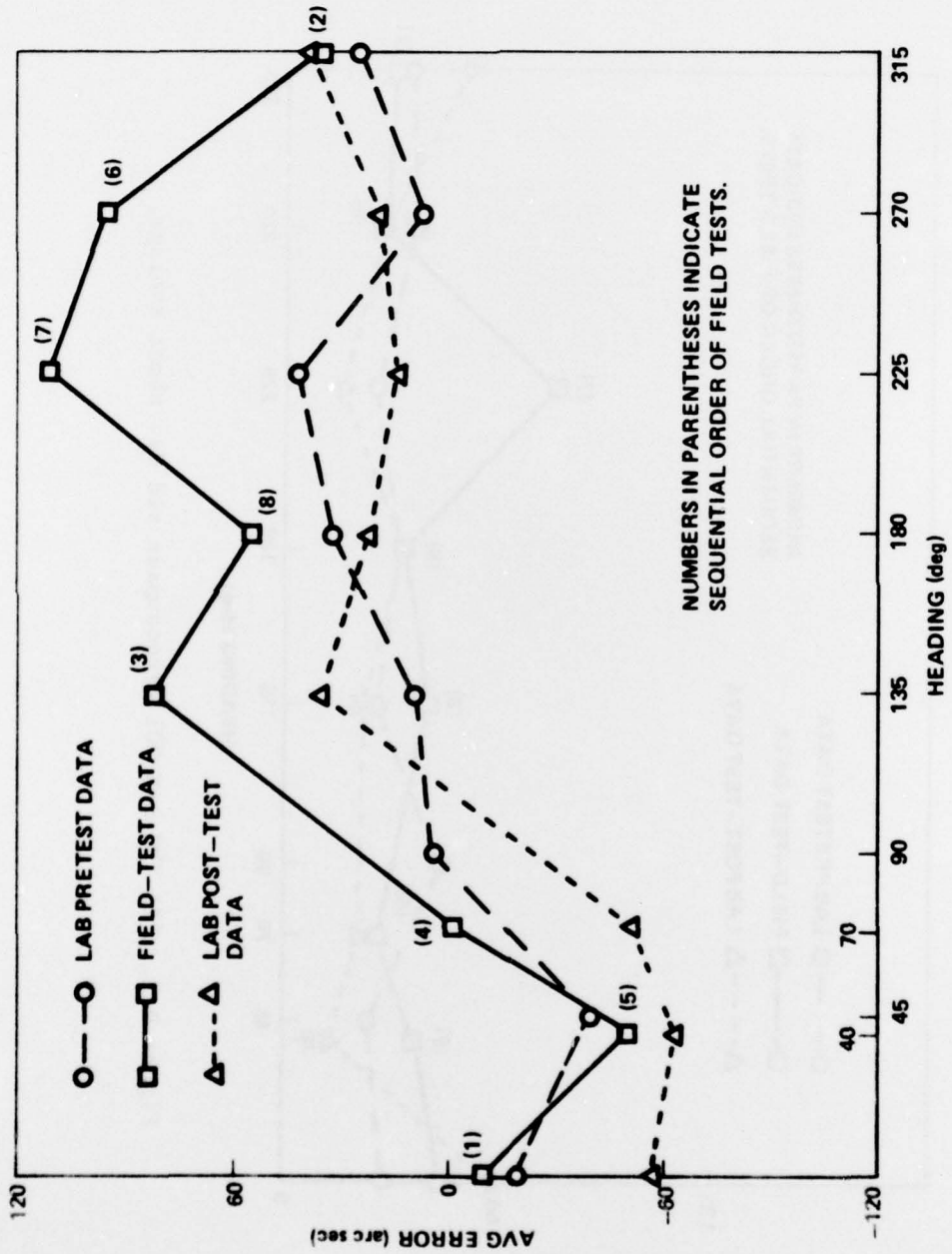


Figure D-2. PII IMU S/N 001 gyrocompass average error.

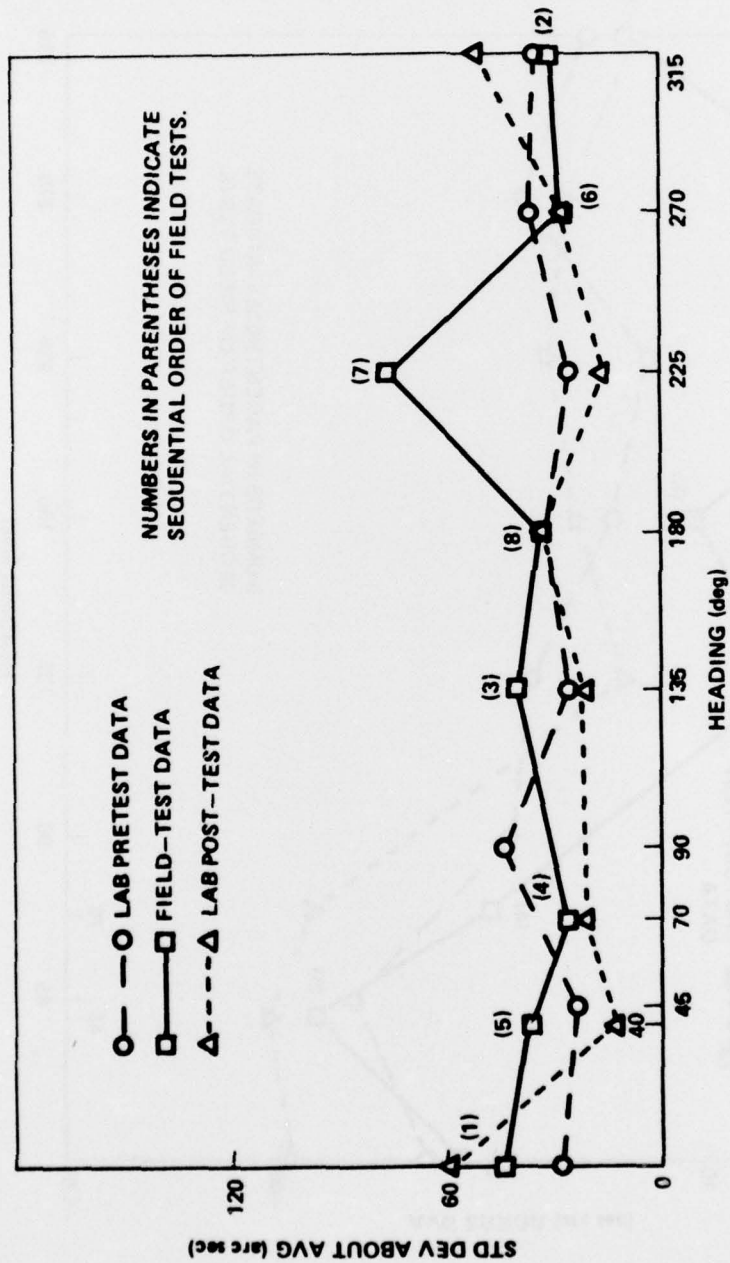


Figure D-3. PII IMU S/N 001 gyrocompass std dev about average.

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