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FINAL REPORT

TWO-AXIS ANGULAR RATE AND ACCELERATION MULTISENSOR TEST

CRAIG H. PRICE, LT, USAF
RICHARD E. RUMPH, LT USAF
ROBERT R. THEDE, MR.

AIR FORCE SPECIAL WEAPONS CENTER
Air Force Systems Command
Kirtland Air Force Base
New Mexico

PREPARED BY

CENTRAL INERTIAL GUIDANCE TEST FACILITY
6585th TEST GROUP
HOLLOMAN AIR FORCE BASE, NEW MEXICO

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THIS REPORT HAS BEEN REVIEWED AND IS APPROVED.

Richard E. Clark

RICHARD E. CLARK, Lt Colonel, USAF
Director, Guidance Test Division

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

Two Litton MS-4 Multisensors, S/N 17 and S/N 23 were tested at the Central Inertial Guidance Test Facility, 6585th Test Group, Holloman AFB, New Mexico during the period from November 1973 to June 1975. The purpose of the tests was to collect performance and environmental data on the instruments. The laboratory tests included gyro and accelerometer coefficient determination; drift tests; voltage, frequency and temperature sensitivity tests; and scale factor linearity tests. A hot soak was the

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only environmental test performed due to failure of one instrument and damage to the other.

The report contains test results for the complete laboratory phase of testing on Multisensor S/N 17 and results of coefficient determination and drift tests on Multisensor S/N 23.

FOREWORD

This report documents the results of tests performed by the Central Inertial Guidance Test Facility (CIGTF) on two Litton MS-4 Multisensors. The Air Force Avionics Laboratory (AFAL) was the responsible development organization with reimbursable expenses being provided by the Space and Missile Systems Organization (SAMSO) as a part of Project 6095.

ABSTRACT

Two Litton MS-4 Multisensors, S/N 17 and S/N 23 were tested at the Central Inertial Guidance Test Facility, 6585th Test Group, Holloman AFB, New Mexico during the period from November 1973 to June 1975. The purpose of the tests was to collect performance and environmental data on the instruments. The laboratory tests included gyro and accelerometer coefficient determination; drift tests; voltage, frequency and temperature sensitivity tests; and scale factor linearity tests. A hot soak was the only environmental test performed due to failure of one instrument and damage to the other.

The report contains test results for the complete laboratory phase of testing on Multisensor S/N 17 and results of coefficient determination and drift tests on Multisensor S/N 23.

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1. INTRODUCTION

1.1 Authority

Laboratory testing of the Litton built two-axis angular rate and linear acceleration multisensor by the Guidance Test Division was requested by the Air Force Avionics Laboratory, Wright-Patterson AFB, Ohio in a letter dated 2 April 1973, titled "Two Axis Rate and Acceleration Sensor", and an attached Program Introduction, undated, with the same title.

In accordance with AFSC Supplement 1 to AFR 80-14, the Guidance Test Division of the 6585th Test Group documented this test program in a Statement of Capability dated 23 April 1973 and titled "Two Axis Rate and Acceleration Sensor".

The multisensor and its support equipment are unclassified to both visual and physical access. All test plans, procedures, schedules and laboratory test data are unclassified.

1.2 Test Objective

The objective of this test program was to determine environmental and functional capabilities of the two axis angular rate and acceleration Multisensor.

1.3 Test History

Testing on Multisensor began in November of 1973 and continued through the laboratory phase of testing and an environmental hot soak until March of 1974. At this time, a long series of difficulties began as described in the Failure and Repair Log (Appendix A) which delayed the program for one year.

Testing resumed in April 1975 with the environmental phase of testing. On 24 April 1975, the linear vibrator came to an abrupt halt during the first vibration test on the Multisensor (See Appendix B). The resulting high-g shock damaged the instrument and brought a premature end to the program. For this reason, the March 1974 hot soak was the only environmental test performed on the instrument.

2. TEST ITEM DESCRIPTION

2.1 General

The Multisensor (Figure 1) is an instrument capable of measuring two axes of angular rate information as well as two axes of linear acceleration. This is accomplished by two rotors freely suspended from a single motor drive shaft. One rotor is balanced with a high angular momentum to measure rates and the other rotor is pendulous along the spin axis with low angular momentum to measure acceleration. Each rotor has associated pickoffs and torquers about two principal axes. An electronics package mounted on the case provides preamplification of gyro output signals and a closed two axis servo loop for the accelerometer rotor. Loop currents are monitored externally as a measure of acceleration.

The rotor suspension is a "vibragimbal" type, which consists of two gimbals oriented 90° relative to each other and attached to the shaft and rotor by means of flexures (Figure 2). By proper choice of gimbal inertias, a negative spring rate can be obtained at the chosen operating speed to exactly cancel the positive spring rate of the flexures. The result is a free rotor gyro.

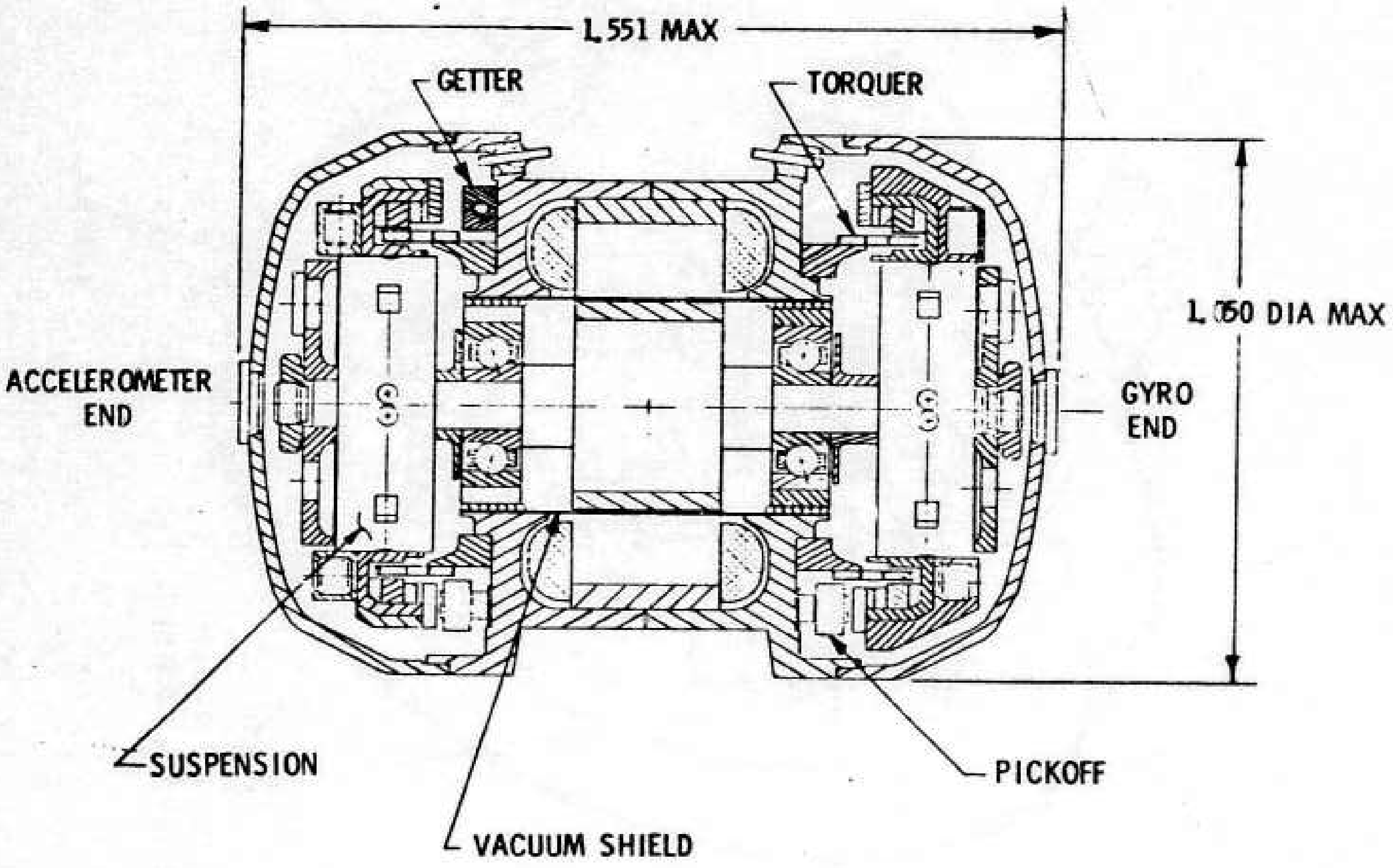


FIGURE 1. MULTISENSOR CUTAWAY VIEW

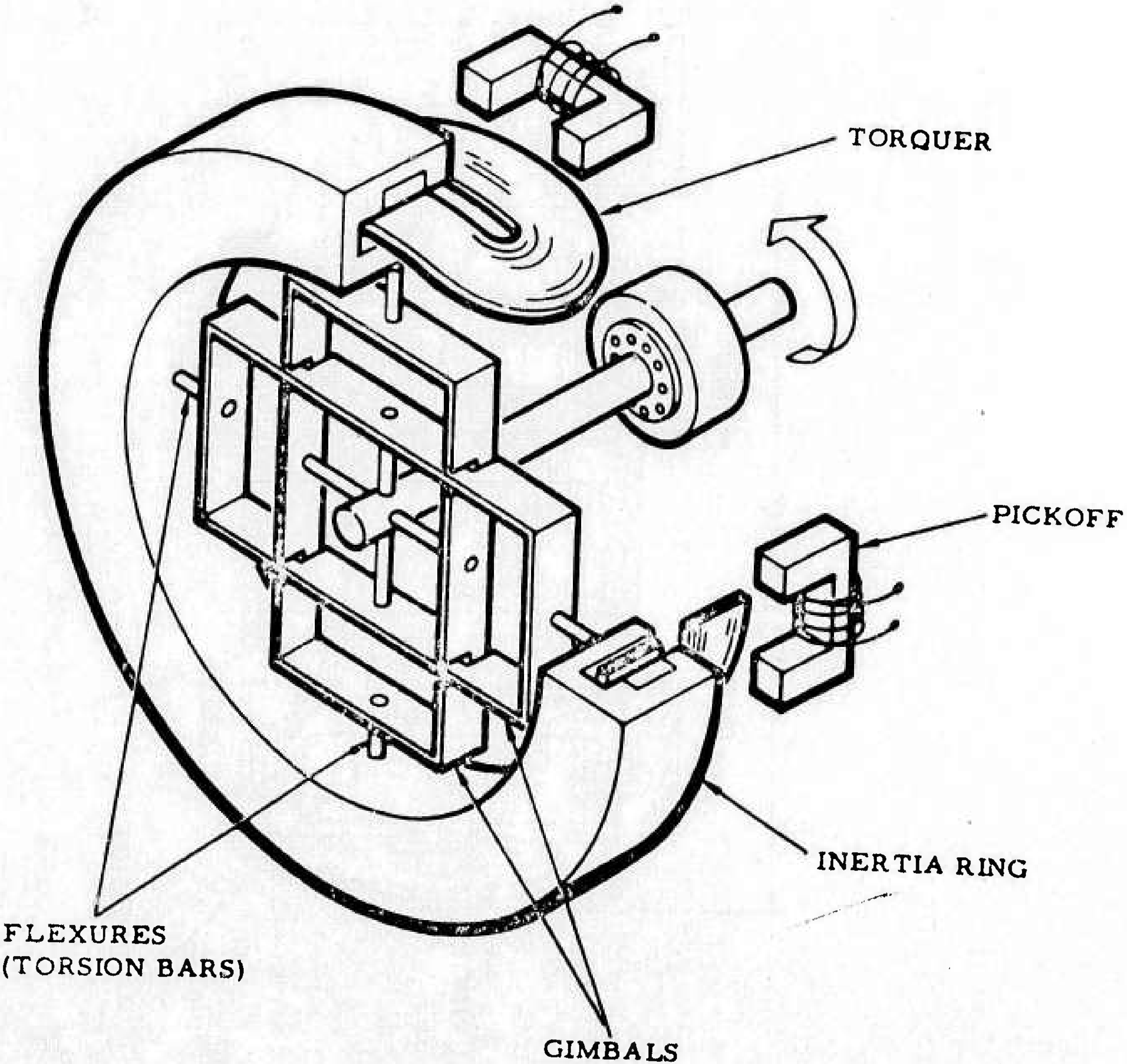


FIGURE 2. ROTOR SUSPENSION CONCEPTUAL VIEW

The two gimbal system provides basic cancellation of twice-spin-speed vibration rectification common to other types of vibratory suspensions.

2.2 Instruments Provided to CIGTF

Two instruments were provided to CIGTF for testing, S/N 17 and S/N 23. S/N 17 was intended to be the primary test instrument with S/N 23 available as a backup and for additional data from some of the laboratory tests.

2.3 Excitation Requirements

The instruments provided to CIGTF were designed to operate at a temperature of 165°F and with a wheel excitation of around 11 volts at 1125 Hz. The pick-off excitation was 650 mV at 54 KHz. These operating parameters were used until the return of S/N 23 on 1 April 1975 when Litton engineers suggested using an 1127 Hz wheel excitation frequency and a 150°F operating temperature.

The wheel speed of a Multisensor is selected to be slightly different from the resonant frequency. Since S/N 23 had been retuned while at Litton, a new resonant frequency was produced and therefore a new wheel excitation frequency was required.

The lower operating temperature was suggested to reduce noise in the instrument.

3. TEST EQUIPMENT

The basic test equipment interfacing diagram and a comprehensive list of the test equipment used are shown in Appendix C.

The Multisensor Control Panel provided unfiltered DC voltages proportional to the X and Y gyro and the X and Y accelerometer torquer currents. On a signal from the calculator, the four integrating DVM's accumulated data for 1, 10, or 100 seconds while the digital multimeter sampled the resistance of the instrument's "stick-on" temperature sensor. At the conclusion of the integration time the calculator took the digital readings from each of the 5 instruments and stored the data onto magnetic tape. Depending on the type of test being run, the calculator also output raw data or the results of calculations onto the line printer and displayed instructions to the technician running the test.

4. TEST PROCEDURES AND RESULTS

4.1 Litton Test

4.1.1 Procedure

The Multisensor was mounted on a rate table with its spin axis vertical and parallel to the table axis, X axis north and Y axis west. The gyro and accelerometer torquer currents were integrated for 10 seconds (100 seconds for all tests after 1 April 1975). The table was then rotated clockwise in 90° increments for 360° and data was taken at each position. The instrument was then reoriented by rotating the table on its trunion axis such that the spin axis was north and parallel to the table axis, X axis down and Y axis west. Again the table was rotated clockwise in 90° increments for 360° and data was taken at each position. Approximately 10 minutes settling time was allowed after reorientation of the instrument and two minutes after each 90° rotation.

The Litton test described in the test plan was found to provide redundant information and was therefore reduced to the test described above and referred to as an eight position test.

4.1.2 Test Results

Eight position tests were conducted periodically throughout the test program. The data reduction procedures and the coefficients obtained from these tests are presented in the test plan..

4.1.2.1 S/N 17 Results

The coefficients obtained from these tests are presented in Tables I and II for the gyro and the accelerometer functions of the multisensor, respectively. Also shown on these tables are the means and the standard deviations (σ) of each of the coefficients over the entire test period. This multisensor was subjected to hot soaks from 11 through 15 March 1974. The means and standard deviations of the coefficients from only the tests before hot soak and from only the tests

TABLE I

EIGHT POSITION TEST GYRO COEFFICIENTS (S/N 17)

DATE 1973-74	S_{TX} (deg/hr/ma)	S_{TY} (deg/hr/ma)	$D(X)_B$ (deg/hr)	$D(Y)_B$ (deg/hr)	$D(X)_X$ (deg/hr/g)	$D(X)_Y$ (deg/hr/g)	$D(Y)_Y$ (deg/hr/g)	$D(Y)_X$ (deg/hr/g)
15 Nov	43.68	-43.29	3.47	-1.82	-.62	.17	.63	.09
16 Nov	43.35	-43.00	3.18	-1.63	-.62	.14	.72	.13
16 Jan	43.68	-43.21	3.17	-1.97	-.63	-.10	.55	-.01
24 Jan	43.74	-43.20	3.11	-1.91	-.54	.25	.73	.03
25 Jan	43.62	-43.15	3.64	-2.19	-.60	.13	.47	.20
28 Jan	43.81	-43.20	3.32	-1.72	-.72	.18	.59	.06
29 Jan	43.74	-43.24	3.54	-1.83	-.61	.14	.62	.24
30 Jan	43.83	-43.25	3.71	-1.94	-.54	.13	.59	.18
5 Mar	43.77	-43.27	3.44	-2.77	-.35	.21	.43	.08
18 Mar*	43.75	-43.22	3.87	-2.05	-.60	.21	.50	.06
19 Mar	43.74	-43.32	3.90	-2.08	-.55	.21	.48	.06
20 Mar	43.76	-43.22	3.90	-1.92	-.57	.22	.52	.10
21 Mar	43.84	-43.29	4.05	-1.83	-.55	.23	.53	.13
Mean	43.72	-43.22	3.56	-1.97	-.58	.16	.57	.11
σ	.12	.08	.31	.28	.08	.09	.09	.07
Before Hot Soak								
Mean	43.69	-43.20	3.40	-1.98	-.58	.14	.59	.12
σ	.14	.09	.22	.36	.10	.10	.10	.08
After Hot Soak								
Mean	43.77	-43.26	3.93	-1.97	-.57	.22	.51	.09
σ	.05	.05	.08	.12	.02	.10	.02	.03

*First Test After Hot Soak

TABLE II

EIGHT POSITION TEST ACCELEROMETER COEFFICIENTS (S/N 17)

DATE 1973-74	X SCALE FACTOR (ma/g)	Y SCALE FACTOR (ma/g)	X 1G BIAS (μg)	X NULL BIAS (μg)	Y 1G BIAS (μg)	Y NULL BIAS (μg)	KX_ω (μa/deg/hr)	KY_ω (μa/deg/hr)
15 Nov	-9.0454	-9.0392	-4052.	-4413.	-1366.	-1239.	-2.93	-2.93
16 Nov	-9.0475	-9.0407	-4098.	-4077.	-1764.	-1598.	-2.91	-2.94
16 Jan	-9.0464	-9.0338	-3664.	-3891.	-1445.	-1240.	-2.92	-2.92
24 Jan	-9.0432	-9.0346	-3984.	-3930.	-1220.	-1203.	-2.90	-2.91
25 Jan	-9.0448	-9.0367	-3554.	-3753.	-1248.	-1284.	-2.90	-2.90
28 Jan	-9.0447	-9.0376	-3787.	-4032.	-1260.	-1267.	-2.85	-2.87
29 Jan	-9.0434	-9.0347	-3601.	-3775.	-1337.	-1290.	-2.92	-2.92
30 Jan	-9.0417	-9.0339	-3485.	-3769.	-1009.	-1548.	-2.93	-2.93
5 Mar	-9.0369	-9.0306	-3349.	-3869.	-1246.	-1361.	-2.92	-2.92
18 Mar*	-9.0477	-9.0322	-2752.	-2625.	-1123.	-1573.	-2.91	-2.90
19 Mar	-9.0467	-9.0368	-2851.	-3460.	-1077.	-1447.	-2.63	-2.84
20 Mar	-9.0510	-9.0394	-2475.	-2718.	- 860.	-1032.	-2.44	-2.93
21 Mar	-9.0481	-9.0377	-3211.	-3597.	-1203.	-1327.	-2.93	-2.92
Mean	-9.0452	-9.0360	-3451.	-3685.	-1243.	-1339.	-2.85	-2.91
σ	386 ppm	330 ppm	510.	506.	220.	164.	.15	.03
Before Hot Soak								
Mean	-9.0438	-9.0358	-3730.	-3945.	-1322.	-1337.	-2.91	-2.92
σ	344 ppm	343 ppm	266.	209.	205.	141.	.02	.02
After Hot Soak								
Mean	-9.0484	-9.0365	-2822.	-3100.	-1066.	-1345.	-2.73	-2.90
σ	204 ppm	341 ppm	304.	499.	147.	231.	.24	.04

* First test after hot soak

following hot soak are also presented in Tables I and II. The only gyro coefficient which exhibited any significant change following hot soak was the X axis bias, $D(X)_B$. Its mean value increased by .53 deg/hr after hot soak. Accelerometer coefficients which exhibited significant changes following hot soak were the X axis scale factor, the X axis 1 g and null biases, the Y axis 1 g bias, and the X axis rate sensitivity, KX_ω. The standard deviations of the X axis null bias and rate sensitivity also increased significantly following hot soak.

4.1.2.2 S/N 23 Results

The coefficients obtained from the eight position tests on this instrument are presented in Tables III and IV. Means and standard deviations (σ) are presented for the three tests before the instrument failure, for the two tests following the repair by Litton and for the five tests following the failure of the linear vibration system which resulted in overtesting of the instrument. None of the coefficients exhibited any significant shifts following the repairs by Litton. All of the accelerometer coefficients became more stable following this repair. The coefficients which changed significantly as a result of the vibration overtest are indicated on the Tables. The stability of most of the coefficients did not increase significantly following the vibration overtest, and the stability of the accelerometer scale factors improved significantly following this overtest.

TABLE III

EIGHT POSITION TEST GYRO COEFFICIENTS (S/N 23)

DATE 1974-75	S_{TX} (deg/hr/ma)	S_{TY} (deg/hr/ma)	$D(X)_B$ (deg/hr)	$D(Y)_B$ (deg/hr)	$D(X)_X$ (deg/hr/g)	$D(X)_Y$ (deg/hr/g)	$D(Y)_Y$ (deg/hr/g)	$D(Y)_X$ (deg/hr/g)
24 Mar	45.17	-45.48	3.60	.52	-.35	.63	1.03	.42
26 Mar	45.03	-45.70	2.16	.97	-.06	.64	1.07	.37
28 Mar	45.07	-45.75	3.41	1.61	-.18	.68	1.07	.39
Mean	45.09	-45.64	3.06	1.03	-.20	.65	1.06	.39
σ	.07	.14	.78	.55	.15	.03	.02	.03
Multisensor Returned to Litton for Repairs								
7 Apr	45.01	-45.63	3.72	.85	-.46	.45	1.00	.36
17 Apr	45.04	-45.47	3.81	1.11	-.58	.51	.97	.36
Mean	45.02	-45.55	3.76	.98	-.52	.48	.98	.36
σ	.02	.11	.06	.18	.08	.04	.02	.00
Vibration Overtest								
24 Apr	45.14	-45.69	.31	1.40	4.54	.04	-4.07	-.07
2 May	45.20	-45.68	.59	1.18	4.39	-.10	-4.00	-.19
2 May	45.12	-45.64	.57	1.21	4.43	-.01	-3.98	-.07
3 May	45.19	-45.59	.57	1.15	4.38	.01	-4.01	-.08
4 May	45.19	-45.67	.62	1.12	4.46	.01	-3.98	-.10
Mean	45.17	-45.65	.53*	1.21	4.44*	-.01*	-4.01*	-.10*
σ	.04	.04	.13	.11	.06	.05	.04	.05

* Changed significantly as a result of vibration overtest.

TABLE IV

EIGHT POSITION TEST ACCELEROMETER COEFFICIENTS (S/N 23)

DATE 1974/75	X SCALE FACTOR (ma/g)	Y SCALE FACTOR (ma/g)	X 1 G BIAS (μg)	X NULL BIAS (μg)	Y 1 G BIAS (μg)	Y NULL (μg)	KX_ω (μa/deg/hr)	KY_ω (μa/deg/hr)
25 Mar	-3.0121	-3.0347	-611.	-715.	-8390.	-8507.	-1.01	-1.09
26 Mar	-3.0095	-3.0336	-26.	-631.	-7829.	-7763.	-2.90	-2.93
28 Mar	-3.0077	-3.0310	718.	502.	-5437.	-5391.	-2.90	-2.91
Mean	-3.0098	-3.0331	27.	-281.	-7219.	-7220.	-2.27	-2.31
σ	735 ppm	626 ppm	666.	680.	1568.	1627.	1.09	1.06
Multisensor Returned to Litton for Repairs								
7 Apr	-3.0096	-3.0341	746.	645.	-3536.	-4118.	-2.91	-2.93
17 Apr	-3.0105	-3.0352	473.	553.	-4397.	-4237.	-2.91	-2.93
Mean	-3.0100	-3.0346	609.	599.	-3966.	-4177.	-2.91	-2.93
σ	211 ppm	256 ppm	193.	65.	609.	84.	.00	.00
Vibration Overtest								
24 Apr	-3.0099	-3.0329	2716.	3424.	-5020.	-4914.	-2.91	-2.94
2 May	-3.0100	-3.0332	2671.	1400.	-4797.	-4458.	-2.93	-2.96
2 May	-3.0100	-3.0329	2608.	3111.	-5129.	-5211.	-2.95	-2.97
3 May	-3.0100	-3.0331	2752.	2478.	-5086.	-3859.	-2.90	-2.93
4 May	-3.0100	-3.0330	2721.	2429.	-5097.	-5201.	-2.91	-2.94
Mean	-3.0100	-3.0330	2694.*	2860.*	-5026.	-4729.	-2.92	-2.95
σ	15 ppm	43 ppm	56.	487.	134.	574.	.02	.02

* Changed significantly as a result of vibration overtest

4.2 Table Horizontal Pause Torque to Balance Test

4.2.1 Procedure

The Multisensor was mounted on a rate table with its spin axis south and parallel to the table axis, X axis west and Y axis down. The table was rotated counterclockwise in 30° increments for 360° and the gyro and accelerometer signals were integrated for 100 seconds at each point. The test was repeated for two other orientations: X axis horizontal north and antiparallel to the table axis, Y axis down and spin axis west; Y axis south and parallel to the table axis, X axis west and spin axis up.

4.2.2 Test Results

PTB tests were conducted to determine gyro and accelerometer performance model coefficients. These performance models are presented in Appendix D. Descriptions of the analysis procedures used to obtain these coefficients are presented in the Test Plan.

4.2.2.1 S/N 17 Results

The gyro coefficients obtained from five PTB tests conducted before hot soak and two tests conducted after hot soak are presented in Tables V and VI for the X and Y axes respectively. The only significant acceleration squared sensitive coefficients were $D(X)_{SS}$ and $D(X)_{XS}$. The only gyro coefficients which showed any change following hot soak were $D(X)_f$, $D(X)_Y$, and $D(X)_{SS}$. The changes in $D(X)_F$ and $D(X)_Y$ were not seen in the eight position test results.

TABLE V

X GYRO PTB TEST RESULTS (S/N 17)

Date 1974	$0(X)_F$ (°/hr)	$0(X)_X$ (°/hr/g)	$D(X)_Y$ (°/hr/g)	$D(X)_{XX}$ (°/hr/g^2)	$0(X)_{SS}$ (°/hr/g^2)	$D(X)_{XY}$ (°/hr/g^2)	$0(X)_{XS}$ (°/hr/g^2)	$0(X)_{YS}$ (°/hr/g^2)	σ_{res} (°/hr)
Before Hot Soak									
1/23	2.90	-.48	.19	.01*	.04	.02	.21	-.02	.02
1/24	3.04	-.46	.21	.12*	.04	.02	.11	.02*	.03
1/25	3.15	-.52	.18	.02*	.06	.02	.12	.03*	.01
1/28	3.63	-.49	.20	.07	.03	.08	.12	.00*	.01
1/29	3.52	-.50	.15	.10	.04	-.01*	.10	.01*	.01
Mean	3.25	-.49	.18	.06*	.04	.03*	.15	.01*	.02
σ	.31	.02	.02	.05	.01	.03	.05	.02	.01
After Hot Soak									
3/21	4.75	-.29	-.05	.01*	-.27	.03	.12	-.08*	.05
3/22	4.74	-.32	-.06	.01*	-.32	.03	.09	-.07*	.04
Mean	4.74	-.30	-.06	.01*	-.30	.03	.10	-.07*	.04
σ	.01	.02	.01	.00	.03	.00	.02	.01	.01

* Not significantly different from zero at the 1 percent level.

TABLE VI

Y GYRO PTB TEST RESULTS (S/N 17)

Date 1974	$D(Y)_F$ (°/hr)	$D(Y)_Y$ (°/hr/g)	$D(Y)_X$ (°/hr/g)	$D(Y)_{YY}$ (°/hr/g^2)	$D(Y)_{SS}$ (°/hr/g^2)	$D(Y)_{YX}$ (°/hr/g^2)	$D(Y)_{YS}$ (°/hr/g^2)	$D(Y)_{XS}$ (°/hr/g^2)	σ_{res} (°/hr)
Before Hot Soak									
1/23	-1.99	.55	-.07	.01*	-.03*	.04*	.02*	-.37	.02
1/24	-1.35	.56	-.14	.02*	-.56	-.03	.00*	.03*	.07
1/25	-1.47	.58	-.04*	-.01*	-.45	.02*	-.02*	-.15*	.08
1/28	-1.78	.56	-.08*	.01*	-.10*	.00*	.00*	-.20	.07
1/29	-1.71	.73	-.07*	.05*	-.12*	.01*	.01*	.01*	.06
Mean	-1.66	.60	-.08*	.02*	-.25*	.01*	.00*	-.14*	.06
σ	.25	.08	.04	.02	.23	.02	.01	.16	.02
After Hot Soak									
3/21	-1.68	.51	-.05	.00*	-.19	.01*	-.02*	.02*	.10
3/22	-1.68	.37	-.08	.02*	-.22	-.01*	.29*	-.04*	.11
Mean	-1.68	.44	-.09*	.01*	-.21	.00*	.13*	-.01*	.10
σ	.00	.10	.04	.01	.02	.01	.22	.04	.01

* Not significantly different from zero at the 1 percent level.

The accelerometer coefficients obtained from these tests are presented in Tables VII and VIII for the X and Y axes respectively. Significant second order coefficients were KX_{XS}, $KY_{YY}-KY_{SS}$, KY_{XY}, and KY_{YS}. All of these coefficients exhibited significant changes following hot soak.

4.2.2.2 S/N 23 Results

The gyro coefficients obtained from tests conducted before and after the vibration overtest are presented in Tables IX and X for the X and Y axes respectively. All of the second order coefficients obtained from the tests before the vibration overtest were less than .09 $deg/hr/g^2$. Following the vibration overtest all of these coefficients increased in magnitude and became very unrepeatable.

Accelerometer coefficients obtained from these tests are presented in Tables XI and XII for the X and Y axes respectively. The only significant higher order coefficient was $KX_{XX} - KX_{YY}$. This coefficient became less repeatable following the vibration overtests.

4.3 Standard Torque to Balance Test

4.3.1 Procedure

The Multisensor was mounted on the precision rate table with its spin axis parallel to the table axis and to the earth's spin axis. Starting with the X axis west the table was rotated clockwise one revolution at 20 earth rate. Gyro and accelerometer data was integrated for 10 seconds every 5° of table rotation. The procedure was then repeated rotating

TABLE VII

X ACCELEROMETER PTB TEST RESULTS (S/N 17)

Date 1974	KX_0+KX_{YY} (µg)	KX_0+KX_{SS} (µg)	KX_X (ma/g)	$KX_{XX}-KX_{YY}$ ($\mu g/g^2$)	$KX_{XX}-KX_{SS}$ ($\mu g/g^2$)	KX_{XXX} ($\mu g/g^3$)	KX_{XY} ($\mu g/g^2$)	KX_{XS} ($\mu g/g^2$)	σ_{res} (µg)
Before Hot Soak									
1/23	-4071.	-3985.	-9.0477	-65.	-14.*	-5.*	48.	48.	10.
1/24	-4179.	-3836.	-9.0477	-22.	-65.	-79.*	43.	43.	12.
1/25	-4011.	-3919.	-9.0448	-22.	-56.	-27.*	49.	89.	13.
1/28	-3987.	-4054.	-9.0418	-12.	-23.*	134.	-40.*	51.	17.
1/29	-3976.	-3781.	-9.0436	8.	29.*	-10.*	39.	98.	9.
Mean	-4045.	-3915.	-9.0451	-23.*	-26.*	3.*	29.*	66	12.
σ	84.	110.	286 ppm	27.	37.	79.	34.	25.	3.
After Hot Soak									
3/21	-2546.	-2498.	-9.0469	17.*	148.	130.*	229.	220.	41.
3/22	-3387.	-3557.	-9.0438	59.*	165.	4.*	101.	143.	54.
Mean	-2966.	-3027.	-9.0453	38.*	156.	67.*	165.*	181.	47.
σ	595.	749	242 ppm	30.	12.	89.	91.	54.	9.

* Not significantly different from zero at the 1 percent level.

TABLE VIII

Y ACCELEROMETER PTB TEST RESULTS (S/N 17)

Date 1974	KY_0+KY_{XX} (μg)	KY_0+KY_{SS} (μg)	KY_Y (ma/g)	$KY_{YY}-KY_{XX}$ ($\mu g/g^2$)	$KY_{YY}-KY_{SS}$ ($\mu g/g^2$)	KY_{YYY} ($\mu g/g^3$)	KY_{XY} ($\mu g/g^2$)	KY_{YS} ($\mu g/g^2$)	σ_{res} (μg)
Before Hot Soak									
1/23	-1192.	-1169.	-9.0367	-138.	-104.	-49.*	105.	117.	14.
1/24	- 737.	-1262.	-9.0357	- 94.	-116.	-88.*	73.	75.	18.
1/25	-1017.	-1044.	-9.0337	- 42.*	- 99.	-97.*	40.*	101.	21.
1/28	- 860.	-820.	-9.0332	- 38.	-137.	-72.*	72.	79.	24.
1/29	- 695.	-849.	-9.0327	- 75.	-112.	-103.	56.	94.	17.
Mean	- 900.	-1029.	-9.0344	- 77.*	-114.	-82.*	69.	93.	19.
σ	205.	193.	190 ppm	41.	15.	22.	24.	17.	4.
After Hot Soak									
3/21	- 674.	-1367.	-9.0338	-281.	523.	-77.*	40.*	404.	57.
3/22	-1067.	-1579.	-9.0354	-165.	720.	-450.	42.*	819.	96.
Mean	- 871.	-1473.	-9.0346	-193.*	621.	-263.*	41.*	612.	76.
σ	277.	150.	125 ppm	124.	139.	264.	1.	293.	28.

* Not significantly different from zero at the 1 percent level.

TABLE IX

X GYRO PTB TEST RESULTS (S/N 23)

Date 1975	$D(X)_F$ (°/hr)	$D(X)_X$ (°/hr/g)	$D(X)_Y$ (°/hr/g)	$D(X)_{XX}$ (°/hr/g^2)	$D(X)_{SS}$ (°/hr/g^2)	$D(X)_{XY}$ (°/hr/g^2)	$D(X)_{XS}$ (°/hr/g^2)	$D(X)_{YS}$ (°/hr/g^2)	σ_{res} (°/hr)
Before Vibration Overtest									
4/7	3.22	-.48	.41	-.07*	.06	.08	.00*	.00*	.03
4/8	3.10	-.48	.43	-.08	.07	-.00*	.10	.01*	.03
4/9	3.14	-.49	.43	-.08	.04*	-.00*	.02*	-.01*	.04
4/9	3.07	-.49	.40	-.11	.03*	.07*	.07*	.03*	.03
4/9	3.03	-.48	.40	-.09	.04*	.05*	-.01*	.01*	.03
Mean	3.11	-.48	.41	-.09	.05	.04*	.04*	.01*	.03
σ	.07	.01	.01	.01	.02	.04	.05	.02	.01
After Vibration Overtest									
5/2	.14	4.38	-.29	.25	-.44	-1.02	-1.03	-.06*	.11
5/12	.12	4.39	-.12*	.05*	-.22*	-.42	-.28	1.26	.12
5/12	.02	4.56	-.05*	.10*	-.26*	-.46	-.29	1.29	.11
5/16	.12	4.52	-.00*	.32	-.58	-.18	-.36	-.76	.15
Mean	.10*	4.46	-.12*	.18*	-.38*	-.52*	-.49*	.43*	.12
σ	.05	.09	.13	.13	.16	.35	.36	1.01	.02

* Not significantly different from zero at the 1 percent level.

TABLE X

Y GYRO PTB TEST RESULTS (S/N 23)

Date 1975	$D(Y)_F$ (°/hr)	$D(Y)_Y$ (°/hr/g)	$D(Y)_X$ (°/hr/g)	$D(Y)_{YY}$ (°/hr/g^2)	$D(Y)_{SS}$ (°/hr/g^2)	$D(Y)_{YX}$ (°/hr/g^2)	$D(Y)_{YS}$ (°/hr/g^2)	$D(Y)_{XS}$ (°/hr/g^2)	σ_{res} (°/hr)
Before Vibration Overtest									
4/7	1.00	1.02	.28	-.02*	-.01*	.01*	-.08	.03	.01
4/8	1.40	1.01	.29	-.02*	-.01*	.03	-.09	.01*	.01
4/9	1.31	1.01	.30	-.05	-.00*	.03	-.08	.02*	.01
4/9	1.33	1.02	.29	-.01	-.01*	.02	-.08	.01*	.01
4/9	1.34	1.02	.28	-.01*	-.01*	.02	-.08	.03	.01
Mean	1.28	1.01	.29	-.02*	-.01*	.02	-.08	.02*	.01
σ	.16	.01	.01	.02	.00	.01	.01	.01	.00
After Vibration Overtest									
5/2	.53	-4.06	-.25	.78	-.23	-.21	2.53	-.68	.15
5/12	.41	-3.96	-.37	-.01*	.10*	.43	.07*	.34	.17
5/12	.38	-4.36	-.35	-.15*	.10*	.45	.09*	.34	.17
5/16	.61	-4.22	-.24	.43	-.06*	-.33	1.02	-.64	.11
Mean	.48	-4.15	-.30	.26*	-.02*	.08*	.93*	-.16*	.15
σ	.11	.17	.07	.42	.16	.41	1.16	.58	.03

* Not significantly different from zero at the 1 percent level.

TABLE XI

X ACCELEROMETER PTB TEST RESULTS (S/N 23)

Date	KX_0+KX_{YY}	KY_0+KX_{SS}	KX_X	$KX_{XX}-KX_{YY}$	$KX_{XX}-KX_{SS}$	KX_{XXX}	KX_{XY}	KX_{XS}	σ_{res}
1975	(μg)	(μg)	(ma/g)	(μg/g^2)	(μg/g^2)	(μg/g^3)	(μg/g^2)	(μg/g^2)	(μg)
Before Vibration Overtest									
4/7	**	926.	-3.00976	**	76.*	122.*	**	80.*	40.
4/8	675.	955.	-3.00973	-89.	48.*	45.*	30.*	82.	24.
4/9	696.	982.	-3.00978	-82.	34.*	47.*	43.	149.	20.
4/9	641.	**	-3.00980	-83.	**	43.*	43.*	**	26.
4/9	656.	**	-3.00981	-90.	**	29.*	50.*	**	34.
Mean	667.	954.	-3.00978	-89.	53.*	57.*	41.*	104.*	29.
σ	24.	28.	10.7 ppm	4.	21.	37.	8.	39.	8.
After Vibration Overtest									
5/2	2837.	3534.	-3.01007	-235.	-96.	10.*	11.*	-51.	28.
5/12	2769.	**	-3.01021	-138.	**	61.*	16.*	**	24.
5/12	2636.	**	-3.01031	- 69.	**	114.	28.*	**	20.
5/16	2363.	**	-3.01059	-130.	**	186.	62.	**	24.
Mean	2652.	3534.	-3.01029	-143.*	-96.	93.*	29.*	-51.	24.
σ	210.	-	73.1 ppm	69.	-	75.	23.	-	3.

* Not significantly different from zero at the 1 percent level.

** Not determined because of table positioning errors.

TABLE XII

Y ACCELEROMETER PTB TEST RESULTS (S/N 23)

Date 1975	KY_0+KY_{XX} (μg)	KY_0+KY_{SS} (μg)	KY_Y (ma/g)	$KY_{YY}-K_{XX}$ ($\mu g/g^2$)	$KY_{YY}-KY_{SS}$ ($\mu g/g^2$)	KY_{YYY} ($\mu g/g^3$)	KY_{XY} ($\mu g/g^2$)	KY_{YS} ($\mu g/g^2$)	σ_{res} (μg)
Before Vibration Overtest									
4/4	**	**	**	**	**	**	**	**	**
4/8	-3527.	-3527.	-3.03418	-86.	34.	-39.	-6.*	-16.	.17
4/9	-4220.	-4200.	-3.03423	-156.	-75.	-29.*	6.*	5.*	25.
4/9	-4541.	-4221.	-3.03444	-46.*	-44.	86.	35.*	-35.*	32.
4/9	-4534.	-4219.	-3.03438	-103.	-54.*	0.*	-57.*	-16.*	17.
Mean	-4205.	-4042.	-3.03431	-98.*	-35.*	19.*	-6.*	-16.*	23.
σ	476.	343.	40.4 ppm	46.	48.	60.	38.	16.	7.
After Vibration Overtest									
5/2	-5068.	-4849.	-3.03303	-57.	88.	-18.*	-71.*	-75.	23.
5/12	-4972.	-4649.	-3.03336	70.	63.	22.*	-54*	15.*	26.
5/12	-5191.	-4780.	-3.03339	16.*	60.	65.	-77.*	-27.*	31.
5/16	-4784.	-4784.	-3.03346	-16.*	32.*	2*	-62.*	-87.	31.
Mean	-5004.	-4765.	-3.03331	3.*	61.*	18.*	-63.*	-44.*	28.
σ	172.	84.	63.1 ppm	53.	23.	35.	10.	47.	4.

* Not significantly different from zero at the 1 percent level.

** Not determined because of table positioning errors.

the table counterclockwise one revolution. The Multisensor was then reoriented with its spin axis antiparallel to the table axis and earth spin axis and the entire procedure was repeated.

4.3.2 Test Results (S/N 17)

STB tests were conducted to determine the magnitudes, standard errors, and shutdown instabilities of the gyro's performance model coefficients. This performance model is presented in Appendix D and the data analysis procedures are described in the test plan. The magnitudes, standard errors, and shutdown instabilities of the coefficients obtained from a seven set STB test are presented in Tables XIII and XIV for the X and Y gyro axes respectively. The large shutdown instabilities listed for $D(X)_S$ and $D(Y)_S$ indicate that these coefficients vary greatly over instrument shutdown. All acceleration squared sensitive coefficients were less than .06 $deg/hr/g^2$.

4.4 Earth Fixed Drift Test

4.4.1 Procedure

The Multisensor was mounted with the X axis up, Y axis west and spin axis south. The gyro and accelerometer signals were integrated for 100 seconds every two minutes for an eight hour period starting with turn on of the instrument. The test was repeated for Y axis up, X axis east, spin axis south and for spin axis up, Y axis west, X axis north with the instrument shutdown a minimum of two hours between tests.

TABLE XIII

X GYRO STB TEST RESULTS - S/N 17

	SET 1	SET 2	SET 3	SET 4	SET 5	SET 6	SET 7	MEAN	SE OF MEAN	SHUTDOWN INSTABILITY
$D(X)_F$ (°/hr)	3.324	3.512	3.433	3.476	3.467	3.315	3.510	3.434	.031	.083
SE	.002	.002	.002	.002	.002	.002	.003			
$D(X)_X$ (°/hr/g)	-.472	-.419	-.450	-.444	-.459	-.485	-.416	-.449	.010	.026
SE	.002	.002	.002	.002	.002	.002	.003			
$D(X)_Y$ (°/hr/g)	.215	.179	.188	.186	.192	.211	.178	.192	.006	.015
SE	.002	.002	.002	.002	.002	.002	.003			
$D(X)_S$ (°/hr/g)	-.167	.341	.261	.468	-.112	-.089	.344	.149*	.099	.263
SE	.002	.002	.002	.003	.002	.002	.003			
$D(X)_{XX}$ (°/hr/g^2)	.044	.049	.048	.048	.052	.029	.055	.046	.003	.008
SE	.004	.004	.005	.006	.004	.005	.008			
$D(X)_{XY}$ (°/hr/g^2)	.031	.031	.039	.028	.020	.014	.033	.028	.003	.008
SE	.004	.004	.005	.006	.004	.005	.008			
$D(X)_{XS}$ (°/hr/g^2)	.059	.058	.053	.076	.017	.095	.060	.059	.009	.024
SE	.003	.003	.004	.004	.003	.004	.006			
$D(X)_{YS}$ (°/hr/g^2)	-.014	-.019	-.065	-.033	.044	-.024	-.016	-.018*	.012	.032
SE	.003	.003	.004	.004	.003	.004	.006			
$\sigma_{residuals}$ (°/hr)	.018	.017	.022	.024	.019	.023	.032	$\sigma_{residuals}$ (RMS) =		.023

* Not significantly different from zero at the 1 percent level.

TABLE XIV

Y GYRO STB TEST RESULTS - S/N 17

	SET 1	SET 2	SET 3	SET 4	SET 5	SET 6	SET 7	MEAN	SE OF MEAN	SHUTDOWN INSTABILITY
$D(Y)_F$ (°/hr)	-2.620	-2.376	-2.431	-2.420	-2.414	-2.560	-2.376	-2.457	.036	.095
SE	.002	.001	.001	.001	.001	.002	.003			
$D(Y)_Y$ (°/hr/g)	.481	.454	.457	.467	.485	.485	.452	.468	.006	.015
SE	.001	.001	.001	.001	.001	.002	.003			
$D(Y)_X$ (°/hr/g)	.111	.130	.124	.125	.122	.117	.129	.123	.003	.007
SE	.001	.001	.001	.001	.001	.002	.003			
$D(Y)_S$ (°/hr/g)	.146	-.308	.386	-.201	-.509	.199	-.307	-.085*	.124	.329
SE	.002	.001	.001	.001	.002	.001	.002			
$D(Y)_{YY}$ (°/hr/g^2)	-.008*	-.041	-.019	-.030	-.024	-.006*	-.041	-.024	.005	.014
SE	.004	.003	.003	.003	.003	.004	.006			
$D(Y)_{YX}$ (°/hr/g^2)	.018	.023	.022	.027	.037	.018	.022	.024	.003	.007
SE	.004	.003	.003	.003	.003	.004	.006			
$D(Y)_{YS}$ (°/hr/g^2)	-.069	.053	-.007	.049	.002*	-.098	.053	-.002*	.023	.061
SE	.003	.002	.003	.003	.002	.003	.005			
$D(Y)_{XS}$ (°/hr/g^2)	.004*	-.037	.044	-.030	-.061	.013	-.037	-.015*	.014	.036
SE	.003	.002	.003	.003	.002	.003	.005			
$\sigma_{residuals}$ (°/hr)	.015	.013	.014	.014	.012	.016	.026	$\sigma_{residuals}$	(RMS) =	.016

* Not significantly different from zero at the 1 percent level.

4.4.2 Test Results

Eight hour earth fixed drift tests were conducted to determine the Multisensor's warm up time and its short term drift rate. Examination of the drift data revealed that in all cases all signals from the instrument had stabilized within three hours of instrument turnon. The standard deviations of these signals about a straight line over the last five hours of each test were therefore used as an indication of the instrument's stabilized drift rate.

4.4.2.1 S/N 17 Results

The slope of the line and the standard deviation about the line for each of the multisensor's signals are presented in Table XV. Also shown on this table are the means and standard deviations of each of these parameters over all of the tests before hot soak and all of the tests after hot soak. In all cases the Y gyro drift rate was significantly greater than that of the X gyro. The Y accelerometer drift rate was significantly smaller for orientations in which the spin axis was up. Both accelerometer drift rates increased following hot soak.

4.4.2.2 S/N 23 Results

Drift test results for multisensor S/N 23 are presented in Table XVI. Means and standard deviations for the tests before instrument repair, the tests after instrument repair but before vibration and the tests following the vibration overtest are presented. The instrument drift rate was not significantly affected by the vibration overtest.

TABLE XV

DRIFT TEST RESULTS (S/N 17)

		X GYRO		Y GYRO		X ACCELEROMETER		Y ACCELEROMETER	
Date 1973-74	Orientation	Slope (deg/hr/hr)	σ (deg/hr)	Slope (deg/hr/hr)	σ (deg/hr)	Slope (μg/hr)	σ (μg)	Slope (μg/hr)	σ (μg)
12/17	Y Up X East	.0013	.0041	-.0037	.0228	-1.0	3.7	28.0	10.0
12/18	Y Up X North	.0023	.0013	-.0034	.0049	-2.7	3.0	9.3	6.6
12/20	Y Up X East	.0029	.0051	.0117	.0187	.9	8.5	1.8	11.2
12/26	S Up Y East	.0082	.0043	-.0087	.0110	.1	3.7	0.0	.3
1/2	S Up Y East	.0010	.0023	.0060	.0059	-3.1	4.5	.2	.3
1/3	Y Up X North	.0047	.0025	-.0042	.0064	2.7	2.8	-9.0	8.9
1/4	X Up X North	-.0008	.0024	.0018	.0070	-.2	2.6	3.9	7.3
1/7	S Up Y East	-.0052	.0083	.0033	.0150	-2.6	4.1	-.1	.4
1/8	Y Up X East	.0073	.0074	-.0162	.0161	-4.5	5.4	10.8	8.6
	Mean	.0023	.0042	-.0015	.0120	-1.2	4.3	5.0	6.0
	σ	.0044	.0024	.0083	.0064	2.3	1.8	10.4	4.4
After Hot Soak									
3/19	S Up X East	.0012	.0018	.0051	.0065	6.0	54.8	-3.0	11.0
3/20	X&Y 45° Up	.0009	.0035	-.0022	.0109	-6.1	65.6	.6	36.1
	Mean	.0010	.0026	.0014	.0087	0.0	60.2	-1.2	23.6
	σ	.0002	.0012	.0052	.0031	8.6	7.6	2.5	17.7

TABLE XVI

DRIFT TEST RESULTS (S/N 23)

		X GYRO		Y GYRO		X ACCELEROMETER		Y ACCELEROMETER	
Date 1973-74	Orientation	Slope (deg/hr/hr)	σ (deg/hr)	Slope (deg/hr/hr)	σ (deg/hr)	Slope (μg/hr)	(μg)	Slope (μg/hr)	(μg)
3/25	Y Up X East	.0013	.0016	-.0294	.0140	-8.2	36.4	-37.0	14.3
3/25	Y Up X North	.0015	.0022	-.0125	.0180	- .5	31.9	-33.5	12.4
	Mean	.0014	.0019	-.0209	.0160	-4.3	34.1	-35.2	13.3
	σ	.0001	.0004	.0119	.0028	5.4	3.2	2.5	1.3
Multisensor Returned to Litton for Repairs									
4/11	Y Up X East	.0024	.0110	.0033	.0042	-18.8	28.3	31.9	48.6
4/15	X Up Y West	-.0127	.0139	-.0005	.0015	2.5	14.9	-2.9	12.0
4/16	S Up Y West	-.0019	.0200	.0000	.0023	13.2	18.1	13.5	11.8
	Mean	-.0041	.0150	.0009	.0027	-1.0	20.4	14.2	24.1
	σ	.0078	.0046	.0021	.0014	16.3	7.0	17.4	21.2
Vibration Overtest									
4/25	Y Up X East	.0163	.0068	.0032	.0046	14.7	15.6	12.0	25.4
4/28	X Up Y West	-.0007	.0095	-.0028	.0064	17.8	22.5	11.5	28.6
4/29	S Up Y West	.0069	.0038	-.0012	.0021	7.8	18.4	6.3	24.2
5/3	Y Up X East	-.0012	.0070	.0070	.0056	5.8	14.0	26.3	33.9
5/4	S Up Y West	.0017	.0042	-.0014	.0042	-8.3	17.6	-.7	23.7
	Mean	.0046	.0063	-.0010	.0046	7.6	17.6	11.1	27.2
	σ	.0073	.0023	.0041	.0016	10.1	3.2	9.9	4.2

4.5 Voltage, Frequency and Temperature Control Sensitivity Tests

4.5.1 Procedure

The multisensor was mounted with the spin axis vertical up. Data was taken at pick-off excitation voltages of +10 percent of nominal value for 5 minutes at the rate of a ten second integration every 15 seconds. At the end of 5 minutes, an eight point test was performed as described in Section 4.1.1. This procedure was repeated for pick-off excitation voltages of +5 percent, 0 percent, -5 percent and -10 percent of nominal.

The frequency sensitivity test was identical to that described above with the variations in pick-off excitation voltage replaced by identical percentage variations in wheel excitation frequency.

The temperature control sensitivity test also was similar to that described above with variations in pick-off excitation voltage replaced by identical percentage variations in control temperature and with data recording time increased to 30 minutes at each temperature. Temperature control on the Multisensor is accomplished through control of wheel voltage therefore this test measured the combined sensitivity to temperature and wheel voltage.

4.5.1 Voltage Sensitivity Tests (S/N 17)

None of the coefficients determined from eight position tests showed any sensitivity to variations in the excitation voltage over the test range of 600 mv to 700 mv.

4.5.2 Frequency Sensitivity Tests (S/N 17)

All eight position test coefficients except the accelerometer scale factors showed some sensitivity to variations in the Multisensor's excitation frequency. These sensitivities are shown in Table XVII.

4.5.3 Temperature Sensitivity Tests (S/N 17)

The coefficients which exhibited sensitivities to temperature were the gyro and accelerometer scale factors and two of the gyro mass unbalance terms. These sensitivities were:

S_{TX} $-.012$ deg/hr/ma/deg F
S_{TY} $.012$ deg/hr/ma/deg F
$D(X)_X$ $-.020$ deg/hr/g/deg F
$D(Y)_Y$ $.021$ deg/hr/g/deg F
X Accelerometer Scale Factor 220 PPM/deg F
Y Accelerometer Scale Factor 220 PPM/deg F

4.6 Scale Factor Linearity Test

4.6.1 Procedure

The Multisensor was mounted on the precision rate table with the X axis vertical and parallel to the table axis. The table was then rotated at rates of 25, 50, 75, 100, 150, 200, 250, and 300 °/hr in both clockwise and counterclockwise directions. At each rate, data was integrated for 10 seconds every 15 seconds for 20 minutes after a one minute stabilization period. The entire procedure was then repeated with the Y axis vertical and parallel to the table axis.

TABLE XVII

FREQUENCY SENSITIVITY TEST RESULTS (S/N 17)

GYRO SENSITIVITIES

S_{TX}	-.013 deg/hr/ma Hz
S_{TY}	.0365 deg/hr/ma/Hz
$D(X)_B$	-.027 deg/hr/Hz
$D(Y)_B$	-.137 deg/hr/Hz
$D(X)_X$	.039 deg/hr/Hz
$D(X)_Y$	.004 deg/hr/g/Hz
$D(Y)_Y$	-.034 deg/hr/g/Hz
$D(Y)_X$	.009 deg/hr/g/Hz

ACCELEROMETER SENSITIVITIES

X Scale Factor	None
Y Scale Factor	None
X 1 g Bias	-1196.5 μg/Hz
X Null Bias	-1135.5 μg/Hz
Y 1g Bias	-246.8 μg/Hz
Y Null Bias	-252.0 μg/Hz
KX_ω	-2.6 μa/deg/hr/Hz
KY_ω	-2.6 μa/deg/hr/Hz

4.6.2 Test Results (S/N 17)

A least squares fit of the torquer current to the applied rate was made for S/N 17. The scale factors obtained from this test were:

S_{TX} 43.74 deg/hr/ma

S_{TY} -43.23 deg/hr/ma

These values compare very well with those obtained from the eight position tests and reported in Section 4.1.2. Examination of the residuals about the line revealed that there was no deterministic nonlinearity in the gyro's scale factors.

4.7 Hot Soak

4.7.1 Procedure

The instrument was placed in the temperature chamber with its spin axis vertical up and in a non-operating condition. The chamber temperature was raised from room temperature to 200°F at a rate of 2°F/minute. The temperature was held at 200°F for 16 hours and then lowered to room temperature at 2°F/minute and held there for at least 6 hours. This procedure was repeated four times. After completion of the sequence, drift, eight position and PTB tests were run to determine any ill effects of the hot soak.

4.7.2 Test Results

The results of the tests made after the 11-15 March 1974 hot soak are described in Sections 4.1, 4.2 and 4.4. In general, there was little change seen in the gyro and accelerometer coefficients as a result of the hot soak however there was a significant degradation in the accelerometer random drift. An investigation revealed that there were spurious signals on the accelerometer torquer lines which were apparently caused by problems in the Multisensor's electronics chip.

5. SUMMARY OF RESULTS

The functional capabilities of the multisensor were evaluated through a complete set of laboratory tests. The only environmental testing accomplished was a hot soak. Further environmental testing was suspended when a failure of the liner vibration system during vibration testing damaged the instrument. Several failures occured during testing on both of the test instruments, S/N 17 and S/N 23. All failures were attributed to the failure of an electronics chip in the Y accelerometer loop.

Test results showed a gyro mass unbalance coefficient, $D(X)_X$ of -.5 deg/hr/g on both instruments and a $D(Y)_Y$ of .6 deg/hr/g on S/N 17 and 1.0 deg/hr/g on S/N 23. The one sigma variation of these coefficients was less than .09 deg/hr/g during the entire test period. The $D(X)_S$ and $D(Y)_S$ coefficients varied about zero with an instability of .3 deg/hr/g. The gyro second order coefficients were less than .08 deg/hr/g^2 in magnitude in most cases.

The accelerometer biases exhibited instabilities as large as 500 micro g over the test period. The scale factor instabilities were about 360 ppm. The largest second order accelerometer coefficient was $KY_{YY} - KY_{SS}$ on S/N 17. Its magnitude was -114 $\mu g/g^2$. All higher order accelerometer coefficients on S/N 23 were insignificant.

The gyro's one sigma drift rate averaged .004 deg/hr for the X gyro and .012 deg/hr for the Y gyro on S/N 17. On S/N 23 the X gyro was noiser than the Y. The accelerometer drift rates were 5 μg for both axes of S/N 17 and 20 μg for S/N 23.

The multisensor showed no sensitivity to variations in the excitation voltage over the test range of 500 mv to 700 mv. All eight position test parameters except the accelerometer scale factors showed some sensitivity to variations in the excitation frequency. The largest sensitivities were shown by the accelerometer X axis bias. This sensitivity was -1150 μg/Hz. The accelerometer scale factors had a temperature sensitivity of 220 ppm/deg F. The gyro scale factor temperature sensitivities were -.012 deg/hr/ma/deg F for S_{TX} and .012 deg/hr/ma/deg F for S_{TY}. The gyro mass unbalance coefficients S_{TX} and S_{TY} had temperature sensitivities of -.02 and .02 deg/hr/g/deg F for $D(X)_X$ and $D(Y)_Y$ respectively.

The greatest change following hot soak occurred in the X accelerometer one sigma drift rate. This drift rate increased from 4 μg before hot soak to 60 μg after.

APPENDIX A
FAILURE AND REPAIR LOG

18 Mar 74	Y accelerometer torquer amplifier failed on S/N 17 following a hot soak.
3 Apr 74	Y accelerometer Torquer amplifier failed on S/N 23 during laboratory testing.
10 Apr 74	Both S/N 17 and S/N 23 shipped to Litton for diagnosis and repair.
2 Jul 74	While at Litton, S/N 17 lost vacuum and was eliminated from the test program.
22 Jul 74	S/N 23 was received from Litton. The Y accelerometer torquer amplifier was not operating on turn-on of the instrument.
29 Jul 74	Multisensor S/N 23 and the Multisensor Control Panel were shipped to Litton for diagnostic testing.
4 Dec 74	An accelerometer torquer amplifier failed on S/N 23 while at Litton following a cold soak. At this point an additional amplifier stage was added external to the instrument to buffer the accelerometer torquer amplifiers.
19 Feb 75	S/N 23 and the Control Panel were returned to CIGTF. The lead wire for the Y accelerometer torquer low was found to be broken at the instrument's wiring harness in an inaccessible place.

21 Feb 75	S/N 23 returned to Litton for repair.
19 Mar 75	While at Litton, very high frequency parasitic oscillations were found in the Y accelerometer loop due to impedance mis-match of the accelerometer torquer buffer amplifier.
1 Apr 75	S/N 23 was received from Litton.
24 Apr 75	Two vibrator halts during environmental testing imposed high g loads on S/N 23 damaging the rotor hinges and ending the test program.

APPENDIX B

VIBRATION SYSTEM FAILURE

On 24 April 1975, the vibration system experienced two successive shut-downs during sinusoidal vibration testing of Multisensor S/N 23. The instrument was undergoing test 5.11 of the test plan (curve AE of MIL-STD-810B) and had been mounted with X axis north and parallel to the vibrator axis, Y axis vertical up and spin axis east.

Figure B-1 shows a hand plot of the gyro and accelerometer torquer data taken during the first shut-down. The data was being integrated for 10 seconds every 16 seconds from 5 minutes before the test began to 5 minutes after it ceased. It should be pointed out that the X gyro torquer responds to rates about the Y axis and vice versa. The same convention holds for the accelerometer end which explains why vibration along the X axis resulted in noise in the Y accelerometer torquer.

Vibration started during the integration time for point 1 of Figure B-1 and the shut-down occurred during the integration time for point 16. Table B-I gives the relationship between data point number, elapsed time and the approximate frequency of vibration at that time.

Figure B-2 shows the output of the acceleration monitor on the vibrator during the shut-down. Prior to the halt, the vibrator was operating at 9 g's and 68 Hz. The peak acceleration seen by the instrument during the halt was

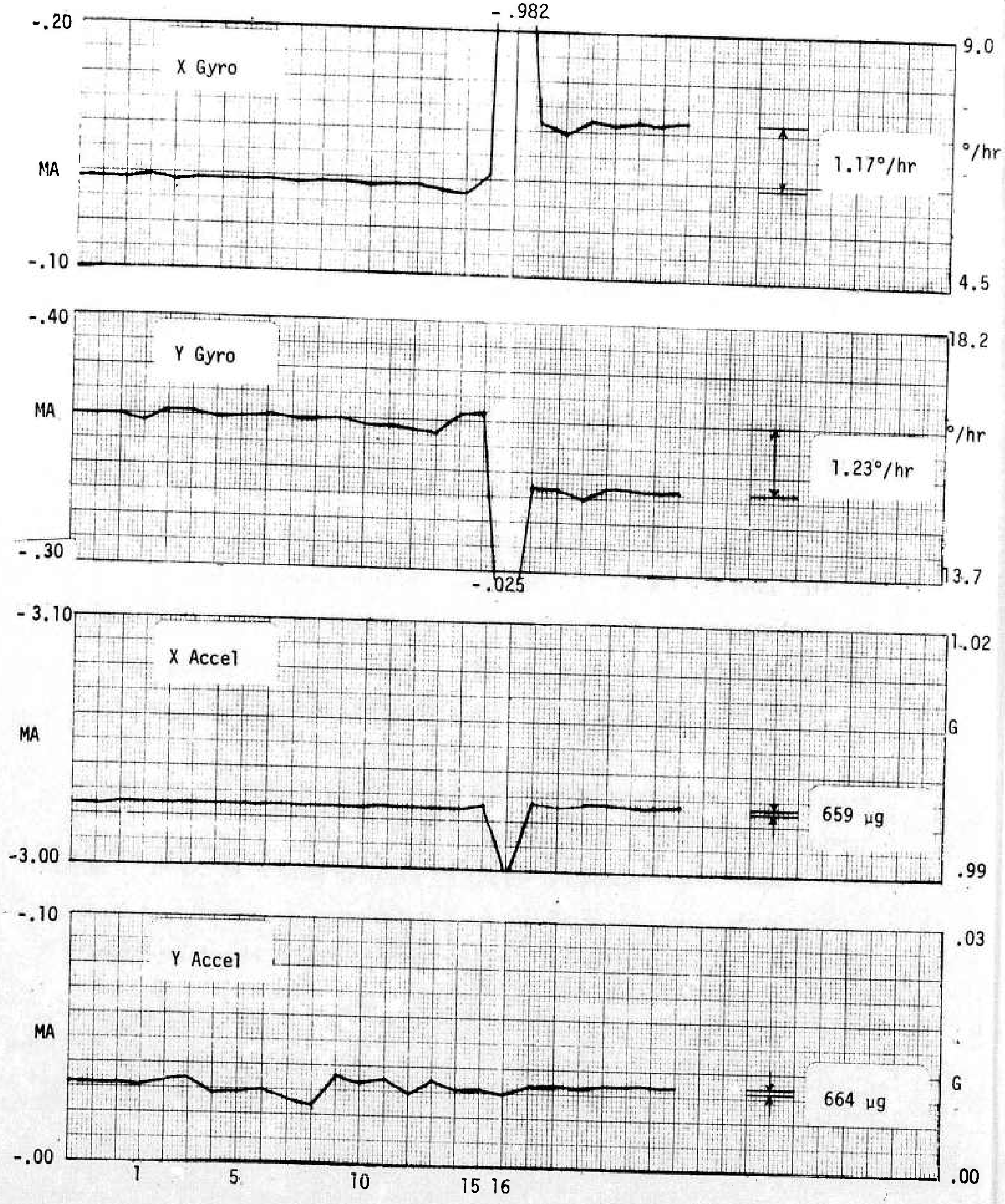


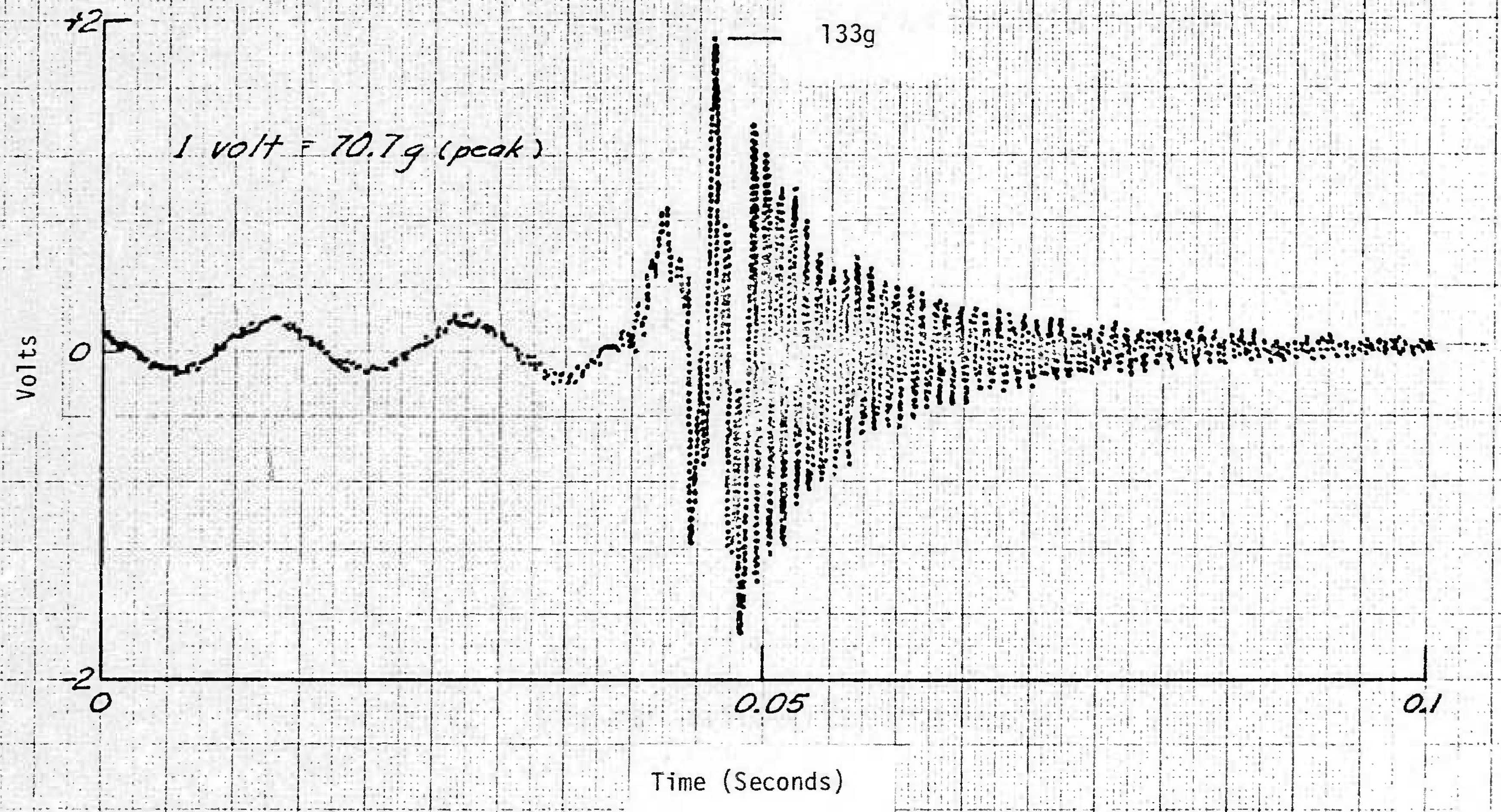
Figure B-1. Torquer Outputs - Vibration #1

TABLE B-I

SAMPLE POINT, TIME, FREQUENCY RELATIONS

N	TIME (SEC)	FREQUENCY (HZ)
1	16	5
2	32	7
3	48	8
4	64	10
5	80	11
6	96	13
7	112	16
8	129	19
9	145	22
10	161	26
11	177	31
12	193	36
13	209	42
14	225	50
15	241	59
16	257	69
17	273	82
18	289	97
19	305	114
20	321	134
21	337	158
22	354	186
23	370	220
24	386	259
25	402	305
26	418	359
27	434	425

Figure B-2. Acceleration Monitor
Vibration #1



133 g's after which the vibrator oscillated to a stop at its resonant frequency of 1025 Hz.

The torquer data taken during the second vibrator shut-down is shown in Figure B-3. The relationships of Table B-I hold for this plot also.

Figure B-4 shows the output of the acceleration monitor on the vibrator during the second shut-down. Prior to the halt, the vibrator was operating at 15 g's and 425 Hz. The peak acceleration seen by the instrument was 64 g's after which the vibrator again oscillated at 1025 Hz to a stop.

The several laboratory tests conducted after the shut-downs are covered in Section 4 of this report. An additional test was performed, however, to determine if there had been a significant change in the resonant frequency of the instrument. The test consisted of finding the wheel excitation frequency at which a change in the X pick-off offset on the Control Panel produced no change in the X gyro torquer current.

The test indicated that resonance was obtained at 1106.3 Hz as opposed to 1126.3 Hz measured earlier by Litton.

The test results indicated conclusively that the instrument's rotor hinges were damaged and dictated the cancellation of the program due to lack of an instrument for testing.

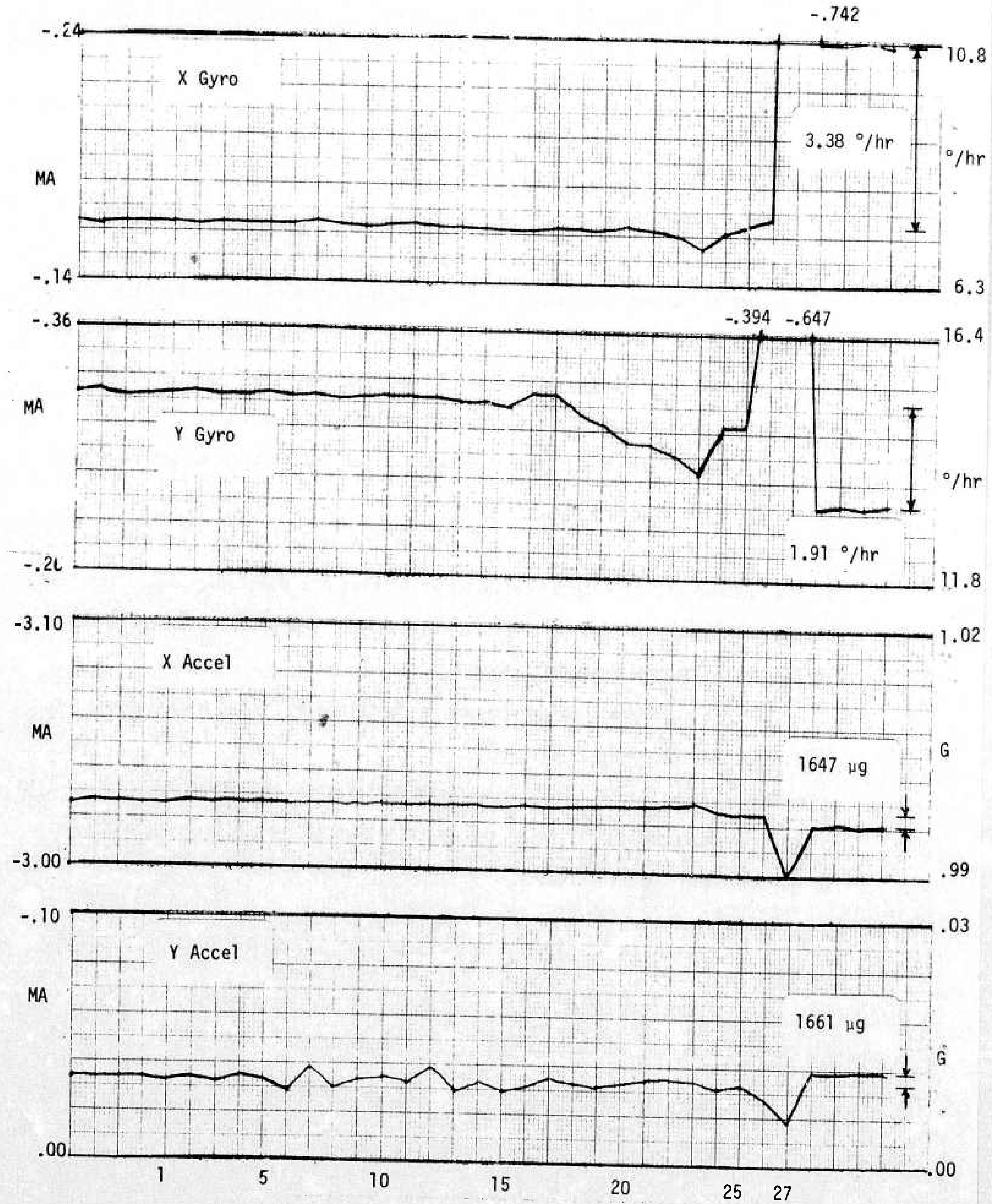
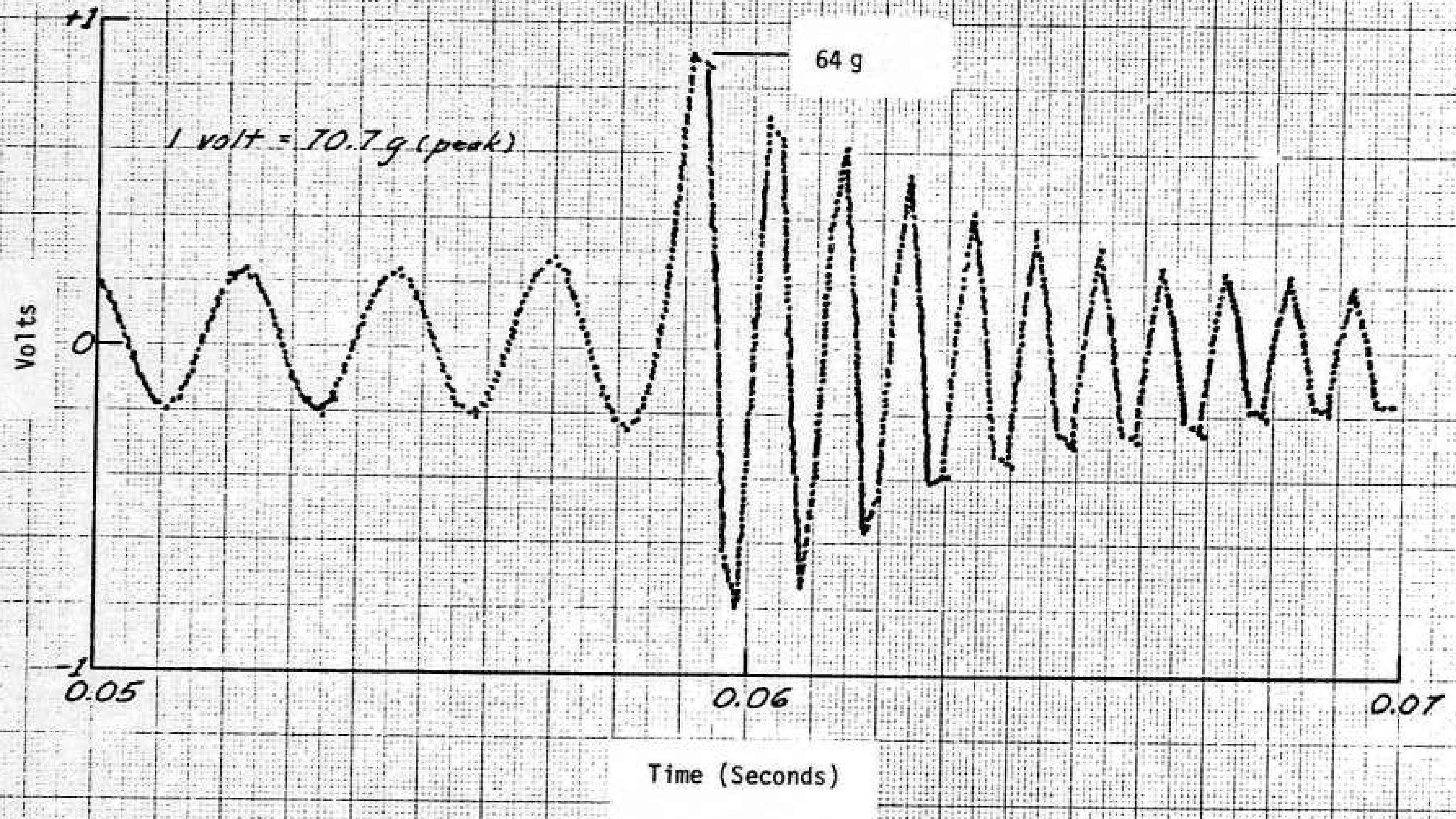


Figure B-3. Torquer Outputs - Vibration #2

FIGURE B-4
ACCELERATION MONITOR VIBRATION #2



APPENDIX C

TABLE C-I

TEST EQUIPMENT

QTY	MANUFACTURER	MODEL	DESCRIPTION
1	Hewlett Packard	9830	Calulator
1	Hewlett Packard	9866A	Line Printer
1	Hewlett Packard	2570A	Coupler Controller
1	Hewlett Packard	3480B/84A	Digital Multi-meter
4	Hewlett Packard	2401C	Integrating Digital Voltmeter
1	Hewlett Packard	K20-5208	Reversible counter
1	Kennedy	1610	Magnetic Tape Drive
1	Optimation	AC153S	3Ø Power Supply
1	Optimation	RCD 9/2040	Frequency Synthesizer
1	Rockland	5100	Frequency Synthesizer
1	Hewlett Packard	400H	AC Voltmeter
1	Tektronix	532	Dual Trace Oscilloscope
1	Goertz	T-500	Rate Table
1	Litton	-	Multisensor Control Panel

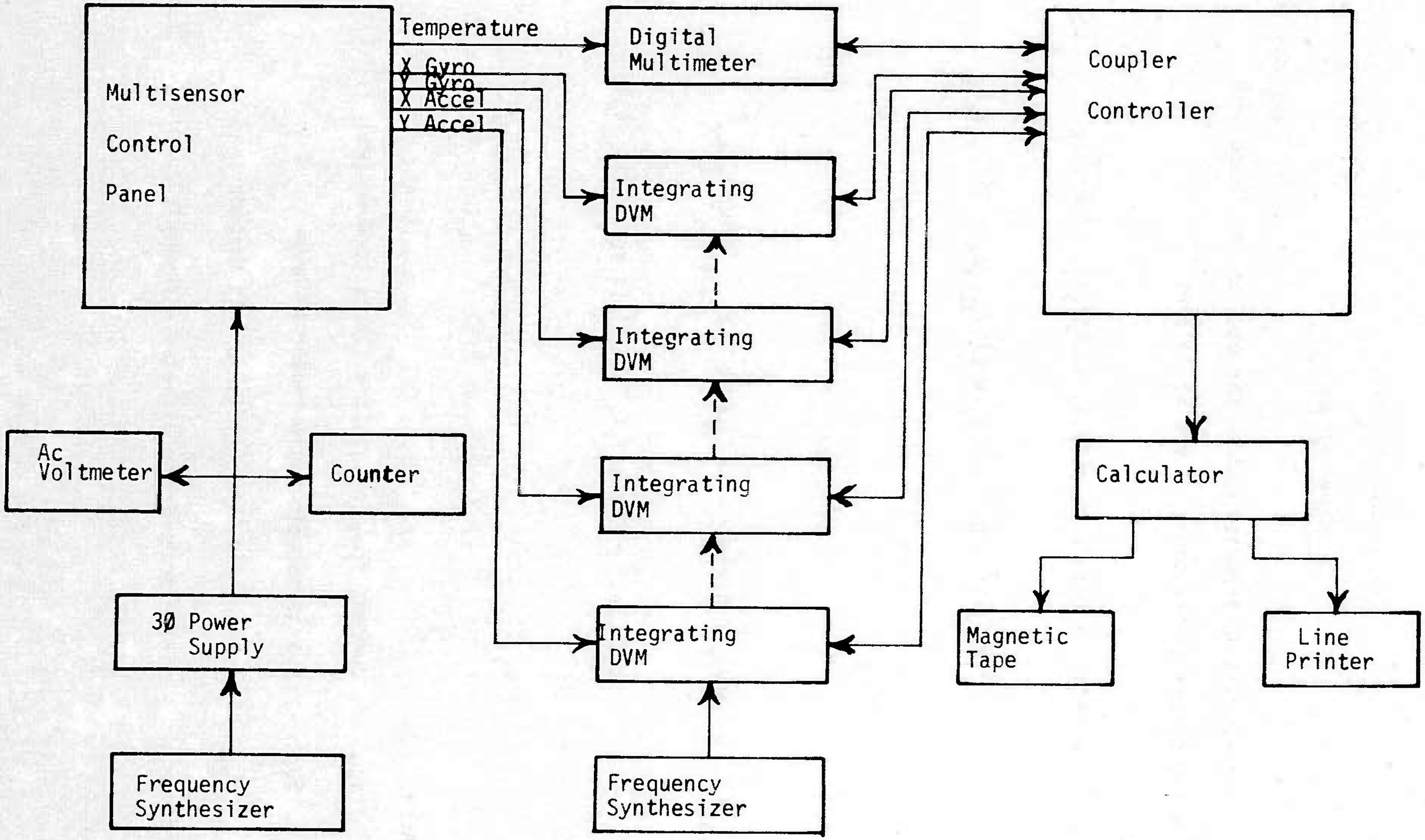


Figure C-1. Test Equipment Interfacing

APPENDIX D

PERFORMANCE MODELS

The assumed performance models for each of the input axes of a two degree of freedom gyro are as follows:

$$S_{TGY} i_Y = D(X)_F + D(X)_X a_X + D(X)_Y a_Y + D(X)_S a_S + D(X)_{XX} a_X^2 + D(X)_{SS} a_S^2 + D(X)_{XY} a_X a_Y + D(X)_{XS} a_X a_S + D(X)_{YS} a_Y a_S + \omega_X$$

$$S_{TGX} i_X = D(Y)_F + D(Y)_Y a_Y + D(Y)_X a_X + D(Y)_S a_S + D(Y)_{YY} a_Y^2 + D(Y)_{SS} a_S^2 + D(Y)_{YX} a_Y a_X + D(Y)_{YS} a_Y a_S + D(Y)_{XS} a_X a_S - \omega_Y$$

where

i_Y	current flow through the Y axis torquer (ma)
S_{TY}	Y axis torquer scale factor (°/hr/ma)
i_X	current flow through the X axis torquer (ma)
S_{TX}	X axis torquer scale factor (°/hr/ma)

D(X)	drift coefficient of the X axis
D(Y)	drift coefficient of the Y axis
a_X	acceleration, with respect to inertial space, of the gyro case along the X axis (g)
a_Y	acceleration, with respect to inertial space, of the gyro case along the Y axis (g)
a_S	acceleration, with respect to inertial space, of the gyro case about the X axis (g)
ω_X	angular velocity, with respect to inertial space, of the gyro case about the X axis (°/hr)
ω_Y	angular velocity, with respect to inertial space, of the gyro case about the Y axis (°/hr)

The assumed performance models for each of the input axes of the accelerometer end of the multisensor are as follows:

$$i_Y = KX_0 + KX_X\, a_X + KX_{XX}\, a_X^2 + KX_{XXX}\, a_X^3 + KX_{SS}\, a_S^2$$

$$+ KX_{SSS}\, a_S^3 + KX_{YY}\, a_Y^2 + KX_{YYY}\, a_Y^3 + KX_{XS}\, a_X\, a_S$$

$$+ KX_{XY}\, a_X a_Y + KX_{YS}\, a_Y\, a_S + KX_{\omega}\ \omega_X$$

$$i_X = KY_0 + KY_Y\, a_Y + KY_{YY}\, a_Y^2 + KY_{YYY}\, a_Y^3 + KY_{SS}\, a_S^2$$

$$+ KY_{SSS}\, a_S^3 + KY_{XX}\, a_X^2 + KY_{XXX}\, a_X^3 + KY_{YS}\, a_Y\, a_S$$

$$+ KY_{XY} a_X\, a_Y + KY_{XS}\, a_X\, a_S + KY_{\omega}\ \omega_Y$$

where

i_Y	current flow through the Y axis accelerometer torquer (ma)
i_X	current flow through the X axis accelerometer torquer (ma)

a_X	acceleration component along the X axis (g)
a_Y	acceleration component along the Y axis (g)
a_S	acceleration component along the spin axis (g)
KX_0	X axis bias (ma)
KY_0	Y axis bias (ma)
KX_X	X axis scale factor (ma/g)
KY_Y	Y axis scale factor (ma/g)
KX_{ijk}	X axis higher order coefficients (ma/g^2 or ma/g^3)
KY_{ijk}	Y axis higher order coefficients (ma/g^2 of ma/g^3)
KX_ω	X axis rate sensitivity coefficient (ma/deg/hr)
KY_ω	Y axis rate sensitivity coefficient (ma/deg/hr)
ω_X	rate about the X axis (deg/hr)
ω_Y	rate about the Y axis (deg/hr)

The biases and higher order coefficients in these performance models are normalized to universal units (μg, $\mu g/g^2$, or $\mu g/g^3$) by dividing the coefficient by the scale factor and multiplying by 10^6.

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