2.

DEVELOPMENT OF FLEXIBLE SPACECRAFT CONTROL SYSTEMS: ACCELEROMETER INSTALLATION

DYNACON REPORT DAISY-21
(DOC-CR-SP-86-007)

DYNACON

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W. G. Sincarsin

March 1986

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Government of Canada / Gouvernement du Canada

Department of Communications

DOC CONTRACTOR REPORT DOC-CR-SP-86-007

DEPARTMENT OF COMMUNICATIONS - OTTAWA - CANADA

SPACE PROGRAM

TITLE: DEVELOPMENT OF FLEXIBLE SPACECRAFT CONTROL SYSTEMS: ACCELEROMETER INSTALLATION

AUTHOR(S): W. G. Sincarsin

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SUMMARY

A subset of the motion sensors required to fully instrument DAISY, a dynamic emulator used to study the control of large flexible space structures, is discussed. The sensors under consideration are those required to detect DAISY rib motions. These motions have low natural frequencies, are lightly damped and experience small angle perturbations. Accelerometers are chosen for this purpose. In fact, two such devices were purchased and installed on one rib. Preliminary sets of data obtained from these accelerometers, that confirm them to be functioning correctly, are also presented.

PREFACE

This work was sponsored by the Department of Communications under Contract No. 06ST.36001-4-1212.

Acknowledgements

The author is pleased to thank A. H. Reynaud of the Communications Research Centre, the Scientific Authority for this contract, for his assistance and advice over the duration of this project.

The author also thanks R. Hui for performing software modifications to the TAURUS data aquisition programs, Mrs. J. Hughes for assistance in typing this report and Mrs. I. Krauze for preparing the figures.

Units and Spelling

This report uses British units and North American spelling.

TABLE OF CONTENTS

1. INTRODUCTION

DAISY is a facility for testing the control of large flexible space structures. It is a dynamic emulator with twenty-three degrees of freedom, two degrees for each of ten ribs connected to a hub, and three for the hub about its mounting gimbal (see Fig. 1.1). Each rib is connected to the hub by two orthogonal pivots, although the hub and ribs themselves are rigid. One pivot allows in-cone the other out-of-cone motion. These have stiffnesses and low damping factors that produce rib resonances similar to those projected for large flexible space structures. By properly locating sensors and actuators on DAISY, a control system can experimentally simulate the dynamic responses one would anticipate for such structures. This report is concerned with the choice and placement of the rib sensors for DAISY. The hub sensors have already been chosen and positioned as described in Sincarsin and Sincarsin [1985].

To produce coupled motion and clustered resonant frequencies, each rib is connected to its two adjacent ribs by weak springs. Though modal identification may be accomplished without a sensor on every rib, each is assumed to be instrumented for simplicity.

Although many types of sensors are available for the ribs, some are not applicable to spacecraft. If DAISY is to accurately simulate a large space structure, its sensors must be indicative of such systems. For example, while potential rib sensors include devices such as accelerometers, angular encoders, inclinometers, linear variable differential transformers (LVDTs), l.e.d. and laser optical sensors or gryos (integrating, rate, rate-integrating), spacecraft sensors form only a subset of this list. The inclinometer can be eliminated immediately for space use since its operation requires a strong force from a gravity field, something not available in the 'zero-g' environment of orbit. An angular encoder can measure rib motion about a pivot, but the rib motion simulates a flexing member on a spacecraft that has no pivot. Implementation of this sensor becomes complex if no

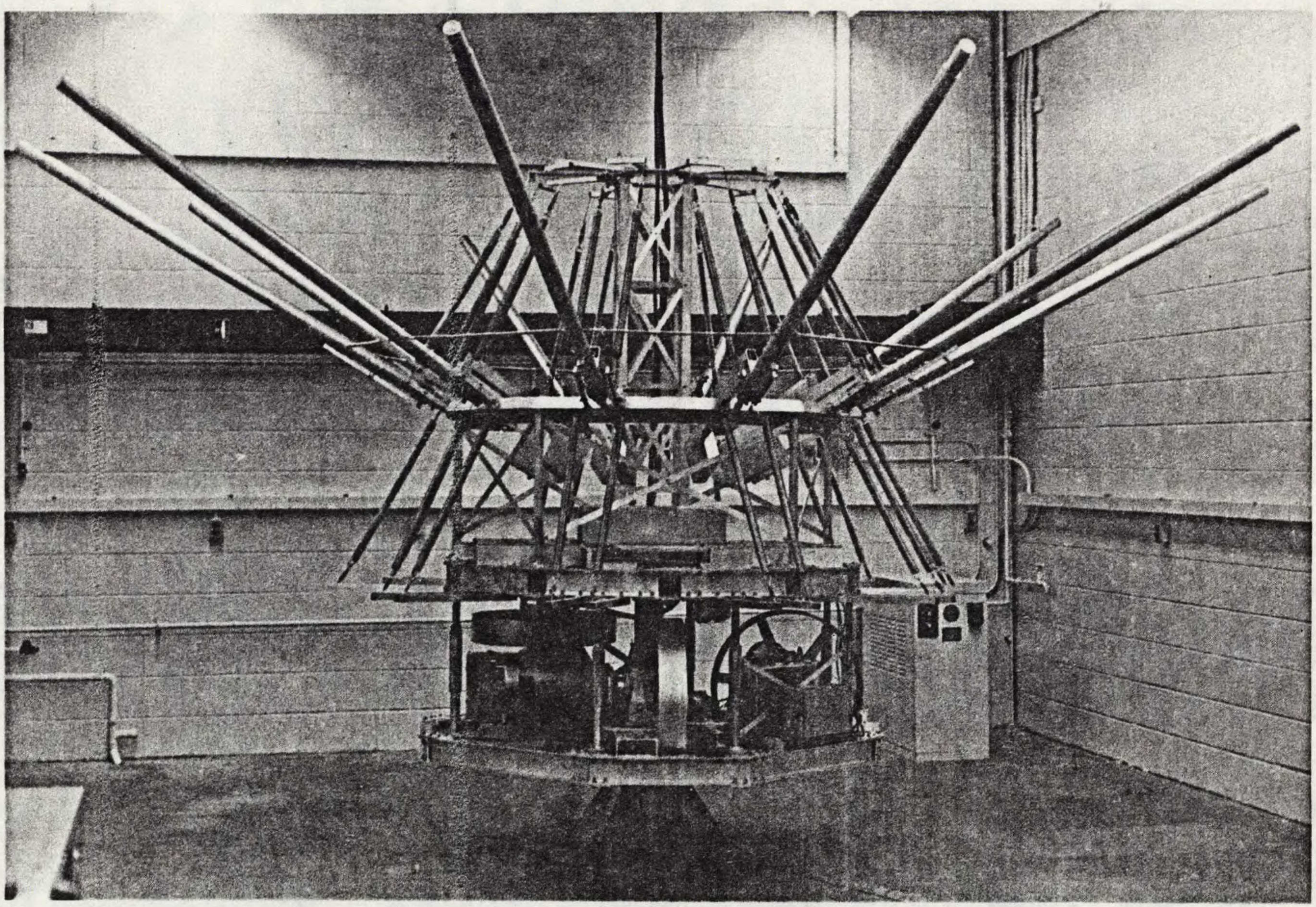


Figure 1.1: The DAISY Structure

pivot is present. An LVDT gives a local displacement relative to some reference point. This means a secondary structure must be created in space to produce the reference point, again a difficult system to implement. The three remaining sensors, accelerometers, optical sensors and gyros, are all applicable from the viewpoint of the intended research. At present, however, no sensibly-priced 'off-the-shelf' optical system exists that can be used on DAISY (the submission of a proposal to develop a custom laser optical system is being considered). Furthermore, because accelerometers are typically lighter and less exspensive than gyros, they were selected as the Daisy rib sensors.

2. RIB SENSOR REQUIREMENTS

As stated in the previous section, accelerometers are the sensor of choice for use on the simulated flexible components of DAISY, namely the ribs. The required threshold and range of the accelerometers can be obtained by considering the motion of a single rib in conjunction with the resolution limits now inherent in the control system. To keep the entire facility as uniform as possible, from the perspective of sensor resolution, it was decided that the accelerometers should have a resolution that matched or was better than the present limiting case. Now while an accelerometer typically produces an analog output, ultimately a digital signal is required before the control computers can utilize it. Thus a conversion that establishes the upper resolution possible must be performed. This is accomplished, in the case of DAISY, by a 12 bit A/D converter in the Taurus data aquisition system. The result is a resolution of one part in 4096 (1:4096). However, although only a 12 bit A/D conversion is possible, the Taurus can handle 16 bit numbers (1:65,536 resolution) and transmit them to the main computer (a PDP 11/73) by making two 'calls' to its internal 8 bit bus. The PDP is capable of doing double precision calculations. The hub sensors are absolute encoders that represent one complete revolution by the 16 bit number 65536. Since the hub is restricted to move ±14 degrees this translates into a integer value between ±2549 (1:5098 resolution). Hence, because of the limitations of the Taurus A/D converter, it is not possible ,at present, to match the accelerometer resolution with that of the hub encoders. Still, since hardware modifications may improve this situation in the future the accelerometers are assumed to have to yield a resolution of 1:5098.

Now, given the motion of the rib can be linearized for small angles about its rest position and assuming the damping is negligable, the equations of motion become

$$J_{y,z}\ddot{\theta}_{y,z} + k_{y,z}\theta_{y,z} = 0 \qquad (2.1)$$

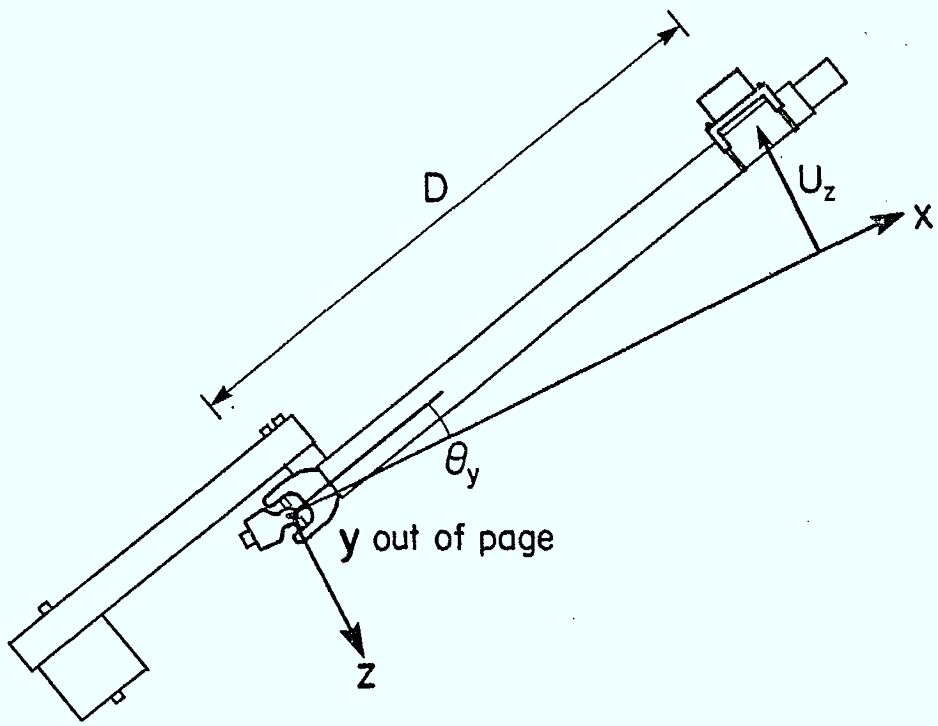
with the solution

$$\theta_{y,z} = \theta^{o}_{y,z} \sin \omega_{y,z}t \qquad (2.2)$$

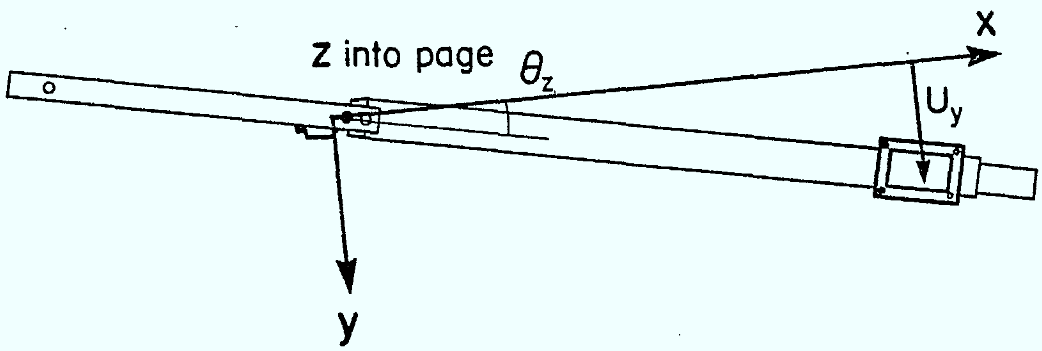
where $J_{y,z}$ and $k_{y,z}$ are the inertia and stiffness about the y and z axis, respectively (see Fig. 2.1). $\theta^{o}_{y,z}$ is the maximum amplitude of the oscillations about each of the axes, $\theta_{y,z}$ is the angular rotation about y and z, with the corresponding derivatives given by $\dot{\theta}_{y,z}$ and $\ddot{\theta}_{y,z}$. Here, $\omega_y = (k_y/J_y)^{\frac{1}{2}}$, and $\omega_z = (k_z/J_z)^{\frac{1}{2}}$. Since most accelerometers measure linear acceleration in a preselected direction, the magnitude of the reading from an accelerometer mounted on one of DAISY's ribs will depend on its position and orientation on the rib. As implied above, accelerations will be measured both in the local y and z rib directions. Thus, each of the two accelerometers is mounted so as to align with one of these directions. To permit the maximum output and therefore the maximum resolution, for a given acceleration, these accelerometers are placed at the rib tip. The linear acceleration then becomes

$$\ddot{u}_{z,y} = D\theta^{o}_{y,z}\omega^{2}_{y,z}\sin\omega_{y,z}t \qquad (2.3)$$

where $\ddot{u}_{z,y}$ is the linear acceleration in the z and y directions and D is the distance from the rib pivot to the accelerometers. For the present DAISY ribs the maximum acceleration is 80.8 mg in the y-direction and 8.89 mg in the z-direction, when (2.3) is evaluated at $t = \pi/(2\,\omega_z)$ and $t = \pi/(2\,\omega_y)$, respectively.



Side View



Top View

Figure 2.1: DAISY's Rib Parameters

With a maximum acceleration of 8.89 mg and a required resolution of one part in 5098, the threshold of the accelerometer becomes 1.7 μg at the rib resonant frequency of 0.1 Hz. This approaches the limit of present day off-the-shelf technology, as well as typical values anticipated for large flexible space structures. The upper limit must be greater than 80.8 mg. but still be capable of reading down to 1.7 μg. The upper limit must extend well above 80.8 mg. since higher frequency oscilations, which are also of interest, correspond to larger accelerations. Ranges of tens of g's are easily obtainable from many accelerometers so that this requirement does not pose a problem.

The availability of accelerometers with approximately a 1 μg threshold, at low operating frequencies, has already been investigated for CRC by Ancon Ltd. A table of companies, from G. B. Lang [1982], that responded to their inquiries is reproduced in Table 2.1. Only five companies produce individual accelerometers with such a low threshold. Even though Marconi Avionics Limited has a electronics division in Canada it does not have a components representative on this continent, Thus it was excluded from further consideration. Of the four remaining companies, the cheapest accelerometer capable of the 1 μg threshold was the Sunstrand QA2000, which was adopted as the rib sensor. It is a 'Q-flex rebalance' type of device. It uses a proof mass mounted on a thin flexing quartz bar which acts as a hinge. The output is related to the electrostatic force used to rebalance (or null balance) the proof mass. The specifications of the QA2000 are given in Appendix A.

Table 2.1

ANCON's Vendor Response
Summary

Vendor	Potential Supplier	Comments
1. British Aerospace	No	None for space applications
2. Delco Electronics	No	Systems supplier, not components
3. Durham Instruments	Yes	Canadian representatives for Schaevitz
4. Endevco	No	Piezoelectric and pizoresistive
5. General Electric	No	None to suit space applications
6. Honeywell	No	Systems only, not components
7. Humphrey Inc.	No	Potentiometric- unsatisfactory resolution
8. Litton Systems Canada Ltd	Yes	1 mu-g resolution with A-2 and A-4 (triad)
9. Marconi Avionics Ltd	Yes	SUPERGEE has 10 mu-g resolution AP-G6 has 2 milli-g accuracy; improvement possible AP-S1 has 0.1 milli-g resolution
10. Misner Marketing Ltd	No	Canadian representative for Endevco
11. Northrop	No	Systems only, not components
12. Schaevitz Engineering	Yes	LSM series has 2.5 mu-g resolution
13. Singer, Kearfott Division	Yes	C70 2401 MOD II- threshold < 0.1 mu-g space proven K120A029- threshold <1 mu-g K120A027- threshold <1 mu-g K120A007- threshold <10 mu-g
14. Sunstrand	Yes	979-0148 and 979-0138 recommended QA-1100, QA-1200, QA-1300- 1 mu-g threshold QA-1400, QA-2000- <1mu-g threshold

3. SENSOR IMPLEMENTATION

The dimensions of the accelerometer chosen as the rib sensor are given in Appendix A. Each accelerometer is worth $4,300 net, in Canadian dollars. Twenty accelerometers, the full compliment for DAISY, would cost $86,000, a very large investment. At present one rib is instrumented, hence only two accelerometers are used. A satisfactory mounting mechanism for a pair of accelerometers was not available from Sunstrand so a custom device was built. The two major components of the device, a mounting 'block' and 'rib saddle' are shown in Fig.3.1, with an exploded view and a photograph of the installation provided in Fig. 3.2. The cable links neccessary to permit the Taurus data aquisition to read the output of the two accelerometers through two of A/D input ports have also been completed. In addition, a small software program has been written that can read and plot the accelerometer outputs using existing driving routines. Two tests were conducted. In each case the hub was restrained and only the instrumented rib was free to move. In the first test a perturbation about the z axis was applied, while in the second the perturbation was provided in the y direction. The plots obtained from these tests are given in Fig. 3.3 and 3.4. The perturbations were induced by physically moving the rib by hand. Hence, activation of only one degree of freedom at a time was virtually impossible. Thus small oscillations are apparent in the 'unperturbed' degree of freedom in each plot. The large sinusoidal signals in the two figure correspond, to the in-cone and out-of-cone resonant frequencies of a single rib, respectively, with all other ribs fixed. Higher frequency oscillations of about 3 Hz. are noticeable for both degrees of freedom in each figure. Although an indepth analysis has not yet been accomplished, it is believed that this is a resonant frequency of the long y-axis (out-of-cone) springs.

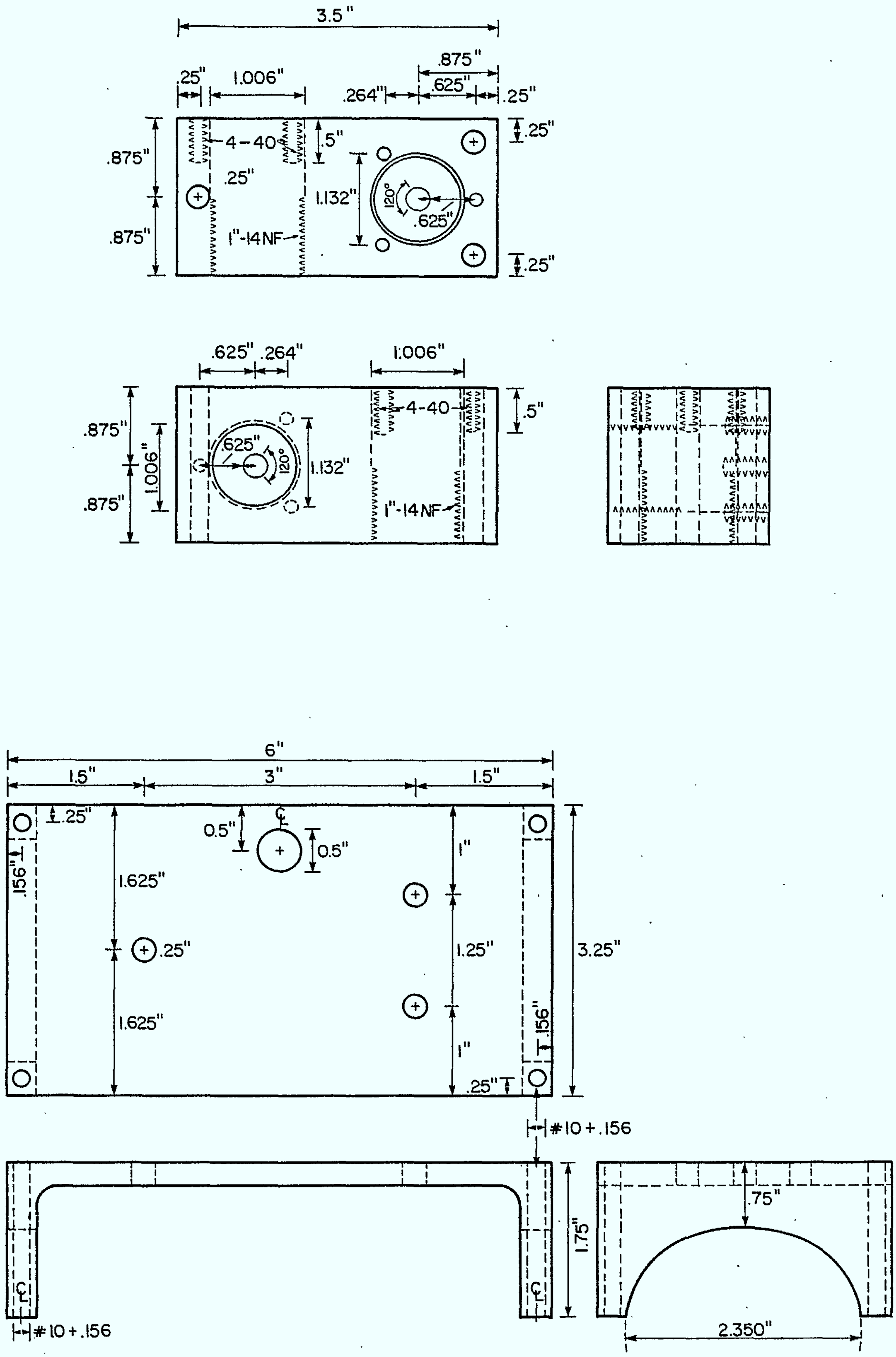
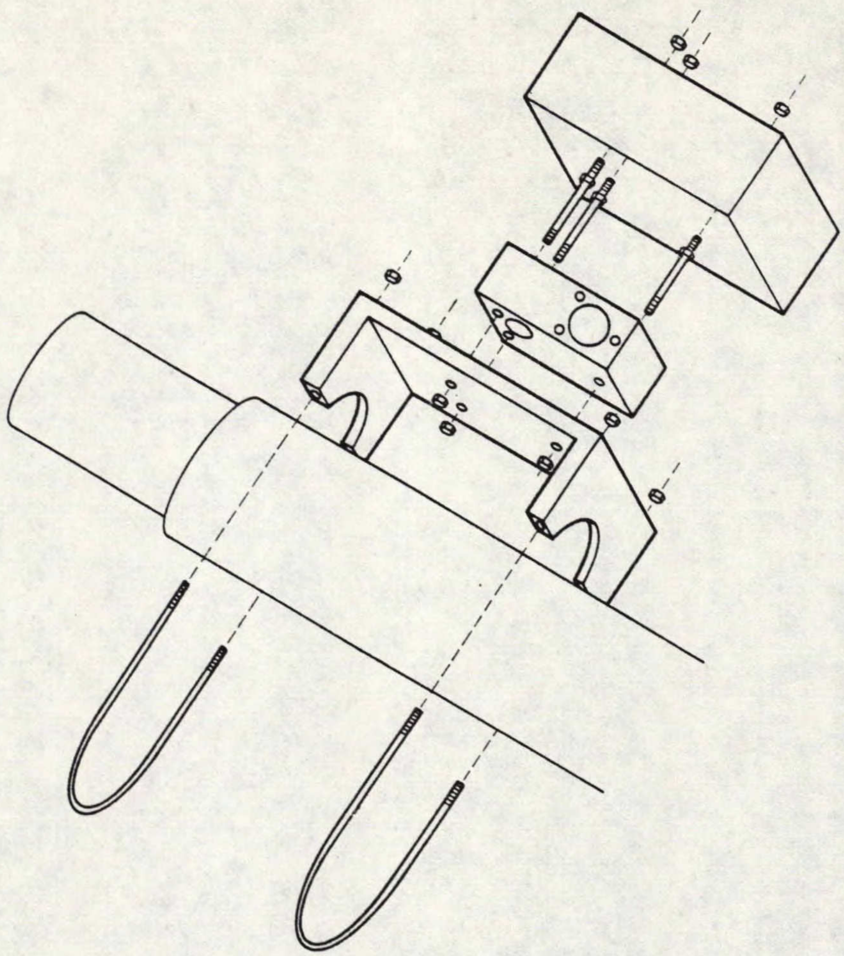


Figure 3.1: Accelerometer Mounting Block and Rib Saddle



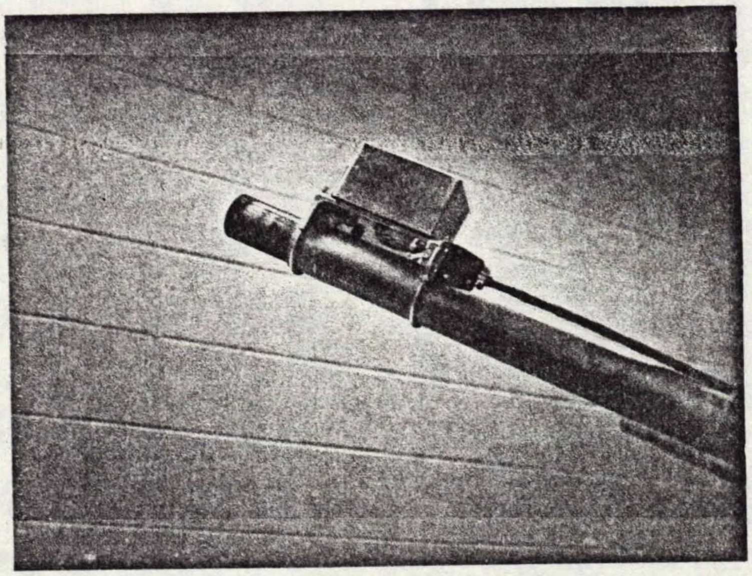
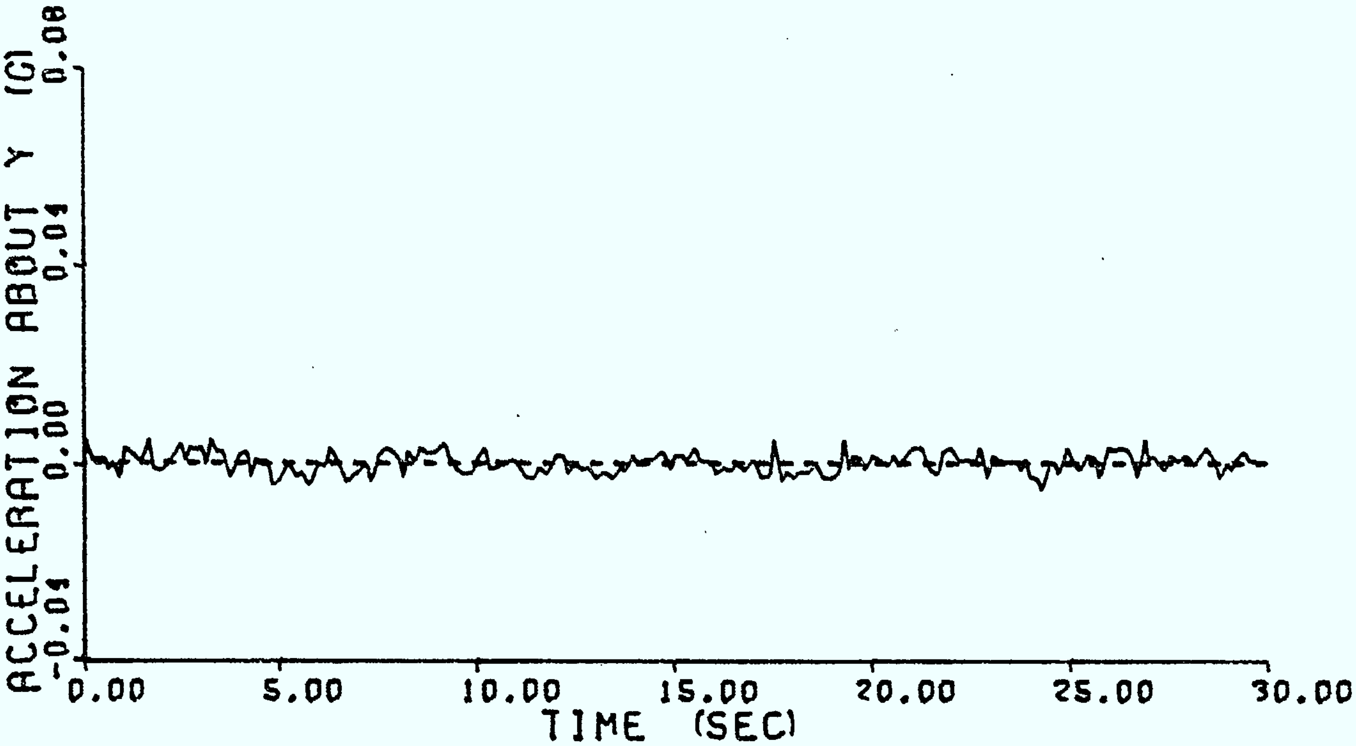


Figure 3.2: Exploded and Installed Views of Accelerometer Mount



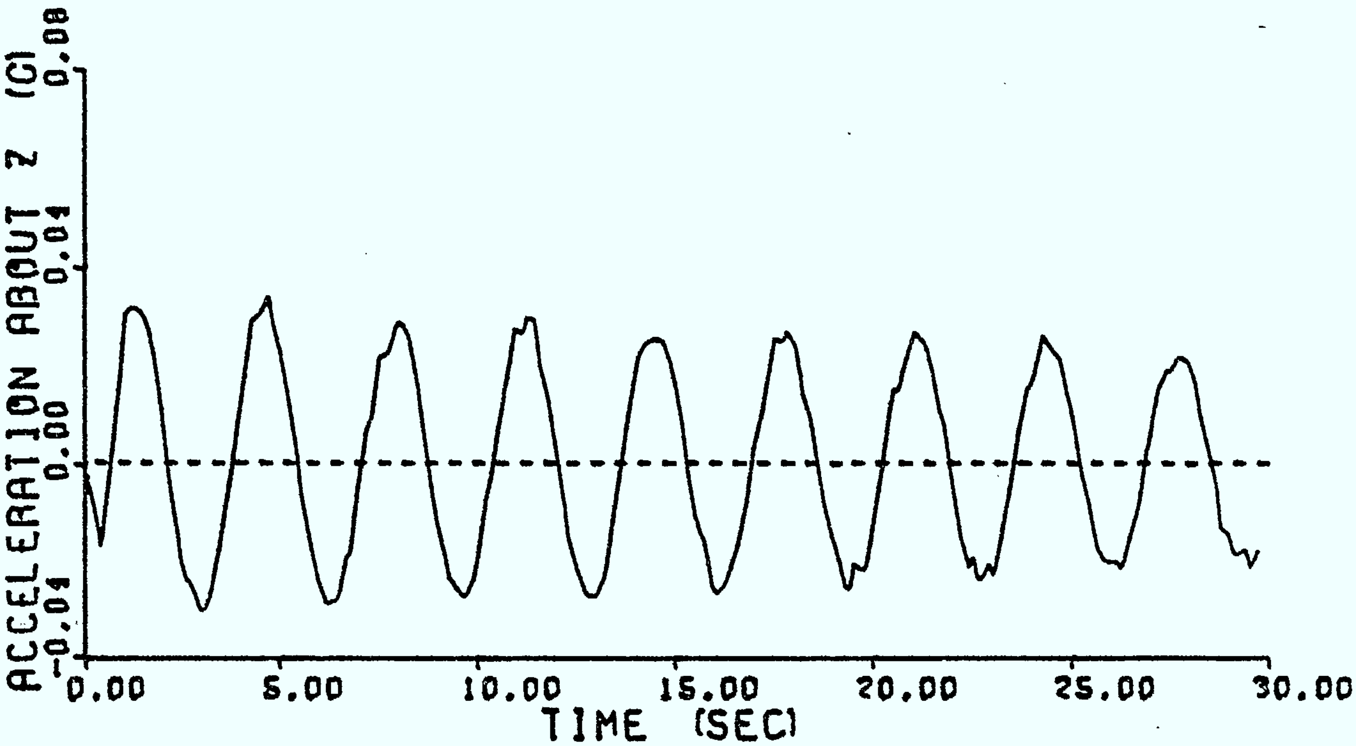


Figure 3.3: Accelerometer Output for Perturbation about z-axis

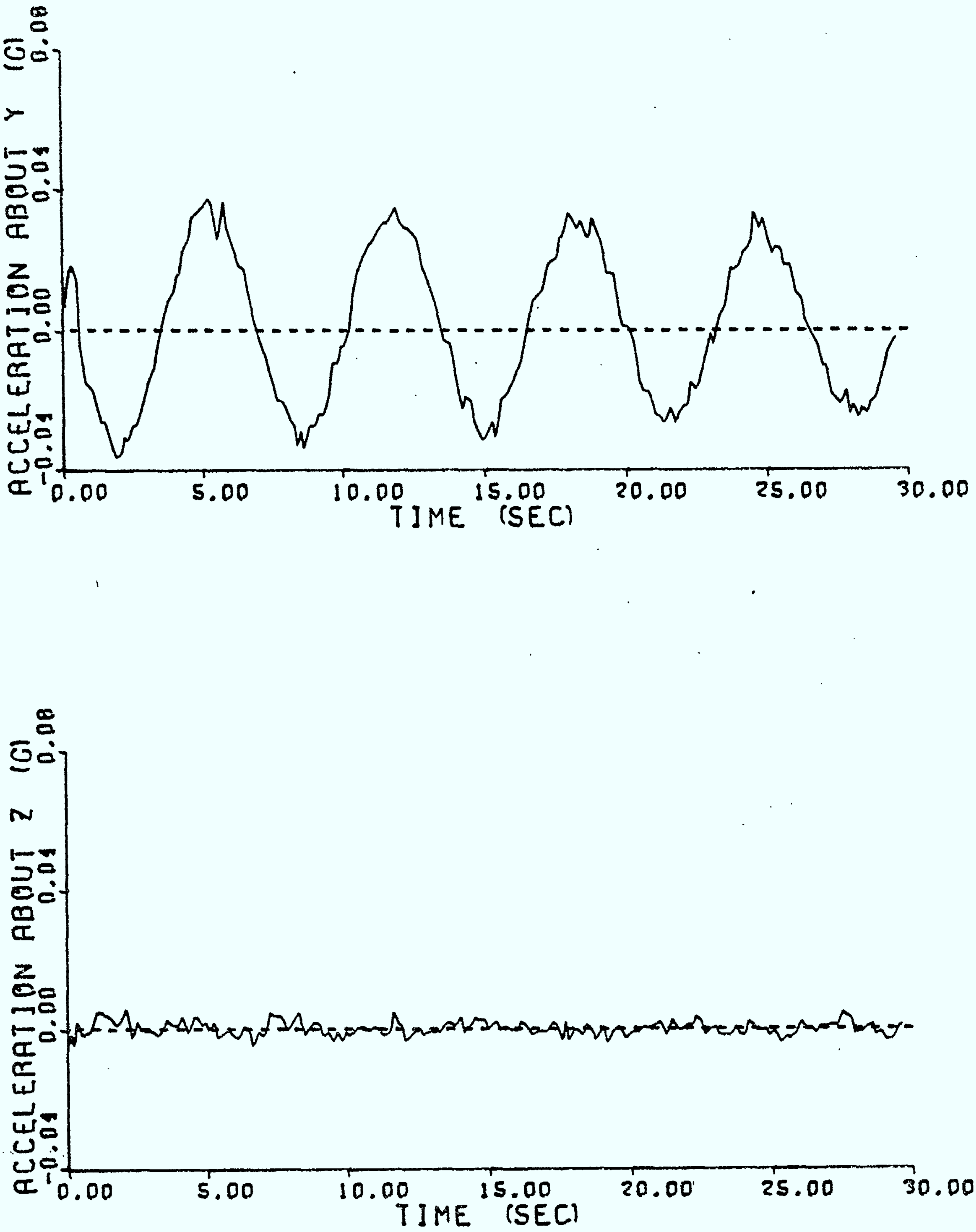


Figure 3.4: Accelerometer Output for Perturbation about y-axis

4. CONCLUSIONS

Two of the twenty sensors required to measure the rib motion of DAISY, the simulated flexible components of a large space structure, have been obtained and installed. These two sensors, Sunstrand QA2000 accelerometers, are used to instrument one of the ten DAISY ribs. They have a 1μ g threshold and a maximum output of 40g's. Using existing driver routines the output from the accelerometers, for a one-rib-free case, has been read by the control computer and plotted. At present, an indepth analysis has not been performed on the data; however, there does appear to be at least one higher-frequency non-rib resonance present. Ideally, with one rib free, there should be only one resonant frequency for the rib in each of the two excited degrees of freedom. It is believed that the additional resonant frequency corresponds to a spring mode, all of which are not modeled in the baseline DAISY dynamics model. A later version of this model does incorporate some spring modes, but not those due to the rib root-springs. In any case, it is worrisome that any spring modes can become large enough in magnitude to flood acceleration readings from small-amplitude rib motions. This potential problem warrants further investigation.

Still, the two rib accelerometers that have been procured, mounted, interfaced and tested are performing well. In fact, a possible problem area has already been identified based on their initial outputs.

5. REFERENCES

(1) Sincarsin and Sincarsin, [Sept. 1985] - Dynacon Enterprises Ltd.;
"Fabrication of DAISY Structure", Dynacon Report DAISY-17,
DOC-CR-85-067.

(2) Lang G. B., [Aug. 1982] - Ancon Ltd.;
"Report on the Result of an Accelerometer technology survey", Ancon-R.815
DOC-CR-SP-82-060.

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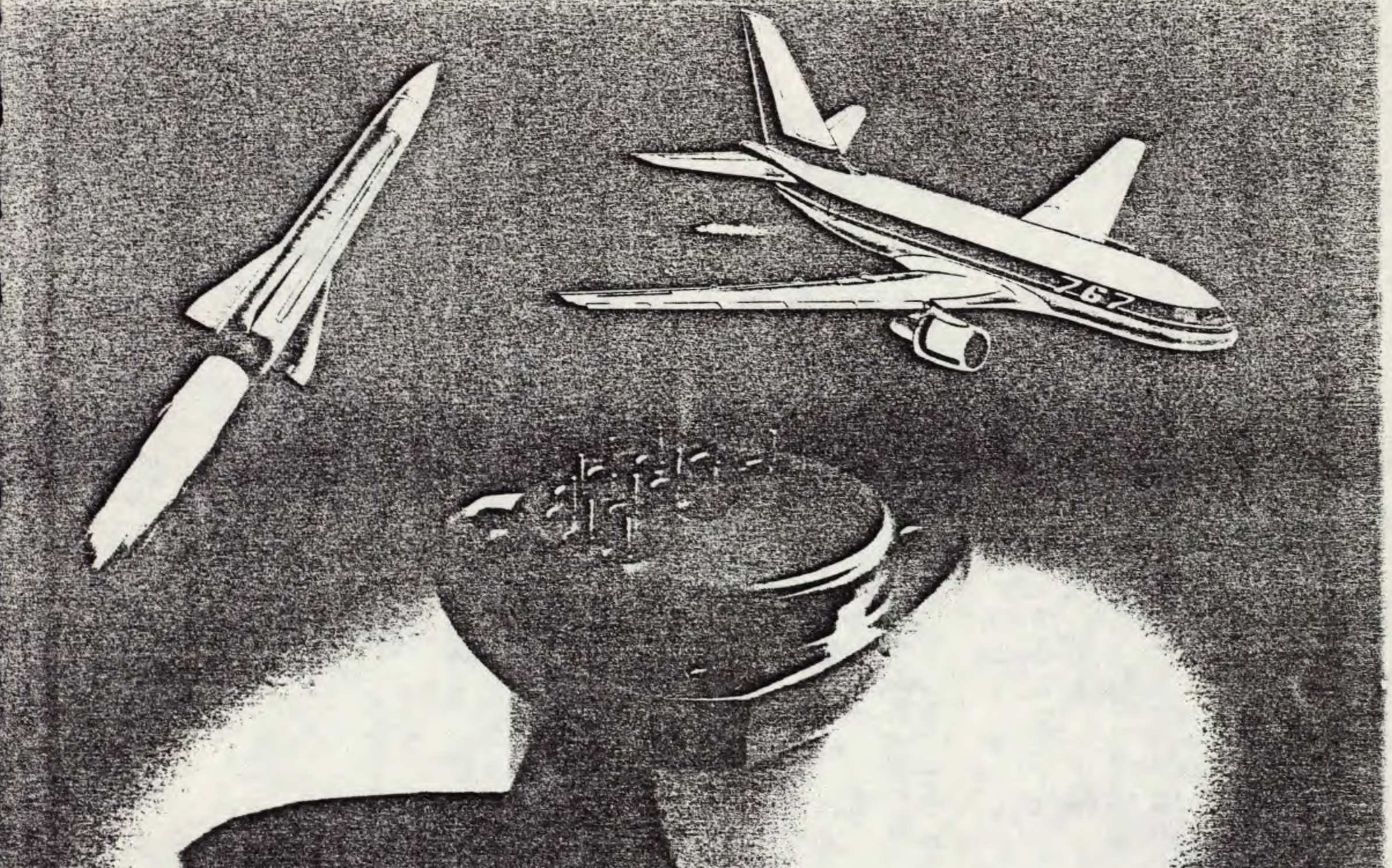
Appendix A

Accelerometer Specifications



Sundstrand Data Control

QA-2000 Inertial Accelerometer

DESCRIPTION

The Sundstrand Data Control QA-2000 accelerometer is a state-of-the-art development in cost-effective inertial grade accelerometers.

This accelerometer has evolved during the past ten years of refinements to Sundstrand's Q-Flex™ product line - QA-1100, QA-1200, and QA-1300.

The QA-2000 is an inertial grade accelerometer that has been designed and tested to meet the stringent requirements of military usage.

The QA-2000 is being utilized on the AV8B aircraft, the 757, and 767 aircraft in inertial reference systems.

The QA-2000 utilizes a highly stable, linear current output temperature sensor mounted directly on the internal magnet structure. One year stability of the accelerometer is better than 60 μ g bias, 150 ppm scale factor and 80 μ radians axis alignment. For fast reaction unheated systems operating from -55 to 95°C, the temperature sensor allows accurate error compensation with temperature modeling. Operation to 125°C for special applications is available with the QA-2000.

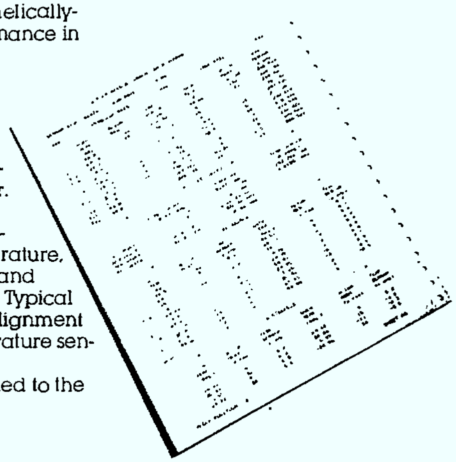
A keyed, high-mass, three point mounting flange has been designed to assure stable performance, mount-to-mount repeatability, and to reduce axis alignment error. This offers a dual advantage of more rigidity and less susceptibility to mechanical constraints due to uneven surface mounting, and thus prevents stress transmitted to the sensor.

The QA-2000, with current output for acceleration, is usuable over a wide dynamic range with voltage scaling determined by a single precision resistor. In addition, the QA-2000 is enclosed in a hermetically-sealed, laser-welded case to assure performance in severe environments.

MODELING

The QA-2000 is a high precision, temperature modeled Q-Flex® Servo Accelerometer. The QA-2000 is tested and modeled over its operating temperature range by computer-based test equipment which controls temperature, positions the accelerometer and measures and calculates the accelerometer's parameters. Typical data recorded from this test are bias, axis alignment and scale factor as a function of the temperature sensor output.

This highly accurate profile is then provided to the customer for use in total system integration.



TECHNICAL DESCRIPTION

The QA-2000 is a complete, self-contained miniature servo mechanism weighing less than 80 grams and measuring approximately 25mm in diameter.

SENSOR KEY ELEMENTS:

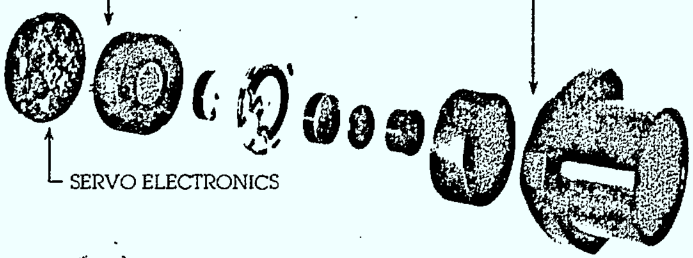
The sensor consists of the following key elements:

A PICKOFF that can sense extremely small displacements of the proof mass

A RESTORER CIRCUIT, or servo electronics, that produces a proportional electrical current through the torquer coil in response to the pickoff signal. The resulting electromagnetic force exactly balances the inertial reactive forces.

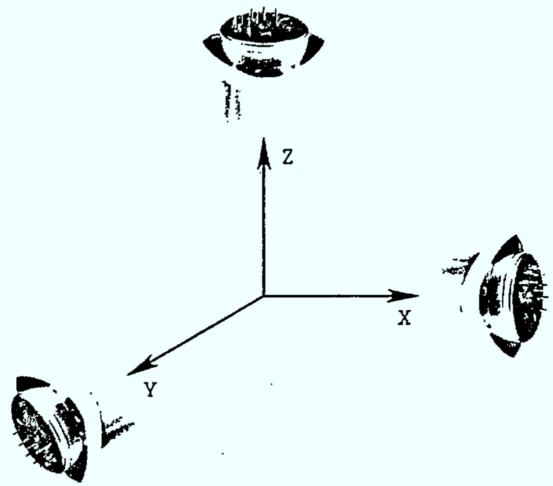
A TORQUER COIL positioned within a permanent magnetic field and attached to the proof mass.

A PROOF MASS, pendulously supported and ideally constrained so as to allow only one degree of freedom about a well defined axis.



FEATURES

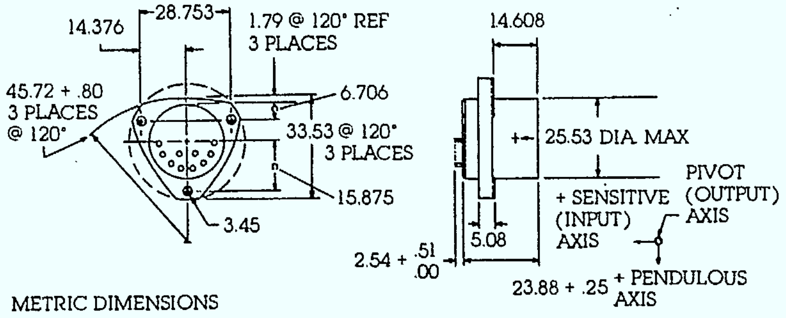
- COMPLETELY ELASTIC SEISMIC SUSPENSION, Amorphous Quartz
- SENSOR DESIGN For Long Term Bias and Scale Factor Stability
- PRECISION 3-POINT MOUNTING FLANGE Assures Stable Alignment Performance, Mount-to-Mount Repeatability
- ADVANCED HYBRID ELECTRONICS Combine All Functions On A Single Ceramic Substrate
- CURRENT OUTPUT TEMPERATURE SENSOR For Precise Thermal Modeling of Bias, Scale Factor, and Axis Alignment
- LASER WELDED HERMETIC PACKAGE Meets Stringent Military and Space Environments
- DUAL SELF TEST Capability
- SELF-CONTAINED SEISMIC SYSTEM and Servo Electronics

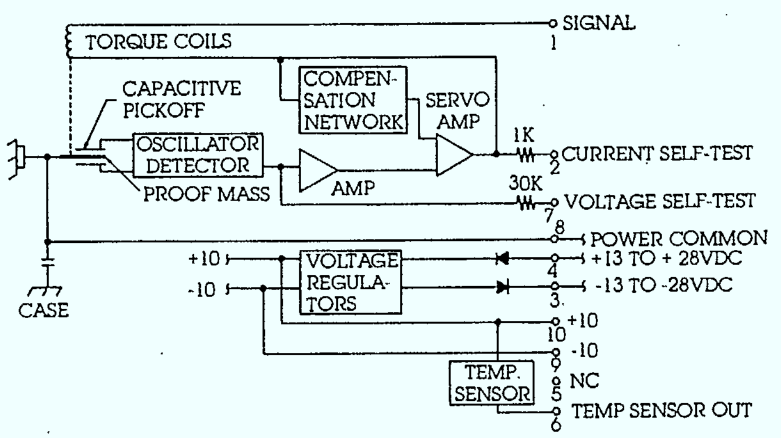


TRIAXIAL APPLICATIONS

APPLICATIONS

- Gimballed and strapdown inertial reference units for missiles and aircraft
- Precision leveling and inclination measurement system
- Long range shipboard inertial navigation platforms
- High performance autopilot and flight control functions





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REDMOND, WASHINGTON 98052
unit of Sundstrand Corporation

Printed in U.S.A.

2177/181

ACCEPTANCE TEST DATA

SUNDSTRAND DATA CONTROL

P/N 979-2000-001

7527

SENSOR S/N: GGJBH HYBRID S/N: 2591 DATE: 10/02/84

PARAMETER (per979-2000-700)	UNITS	LIMITS	ACTUAL	QA STAMP
BIAS:				
Bias	ug	max 4000	-1541	
BTC	ug/degC	max 30	3	
BTH (p-p)	ug	max 200	120	
SCALE FACTOR:				
SF	mA/g	1.20 to 1.46	1.27	
SFTC	ppm/degC	max 180	102	
SFTH (p-p)	ppm	max 400	93	
AXIS ALIGNMENT:				
MIP	uR	max 1000	362.0	
MIH	uR	max 1000	340.0	
MIPTC	uR/degC	max 5.0	-2.7	
MIHTC	uR/degC	max 5.0	-0.6	
MIPTH (p-p)	uR	max 100	29	
MIHTH (p-p)	uR	max 100	46	
VIBRATION 5g peak RECTIFICATION	ug	max +/-1875	per attached	
EXAMINATION OF PRODUCT		per 979-2000-201		SDC 66
ATTACH DATA SHEETS FROM 979-2000-700		ATTACHED AND IDENTIFED	check ( )	

S/N GGJBH does meet -001 limits.

ACCEPTANCE TEST DATA

SUNDSTRAND DATA CONTROL

P/N 979-2000-001 S/N 394

SENSOR S/N: GDCGA HYBRID S/N: 1366 DATE: 09:29:82

PARAMETER (per979-2000-700)	UNITS	LIMITS	ACTUAL	QA	STAMP
BIAS:					
Bias	mg	max 4.0	-0.6	A	
BTC	ug/degC	max 30	-0	A	
BTH (p-p)	ug	max 200	35	A	
SCALE FACTOR:					
SF	mA/g	1.20 to 1.46	1.42	A	
SFTC	ppm/degC	max 180	82	A	
SFTH (p-p)	ppm	max 400	74	A	
AXIS ALIGNMENT:					
MIP	mR	max 1.0	-0.3	A	
MIH	mR	max 1.0	0.3	A	
MIPTC	uR/degC	max 5.0	-0.1	A	
MIHTC	uR/degC	max 5.0	0.1	A	
MIPTH (p-p)	uR	max 100	23	A	
MIHTH (p-p)	uR	max 80	40	A	
VIBRATION 5g peak RECTIFICATION	ug	max +/-1875	950		
EXAMINATION OF PRODUCT		per 979-2000-201			SDC 39
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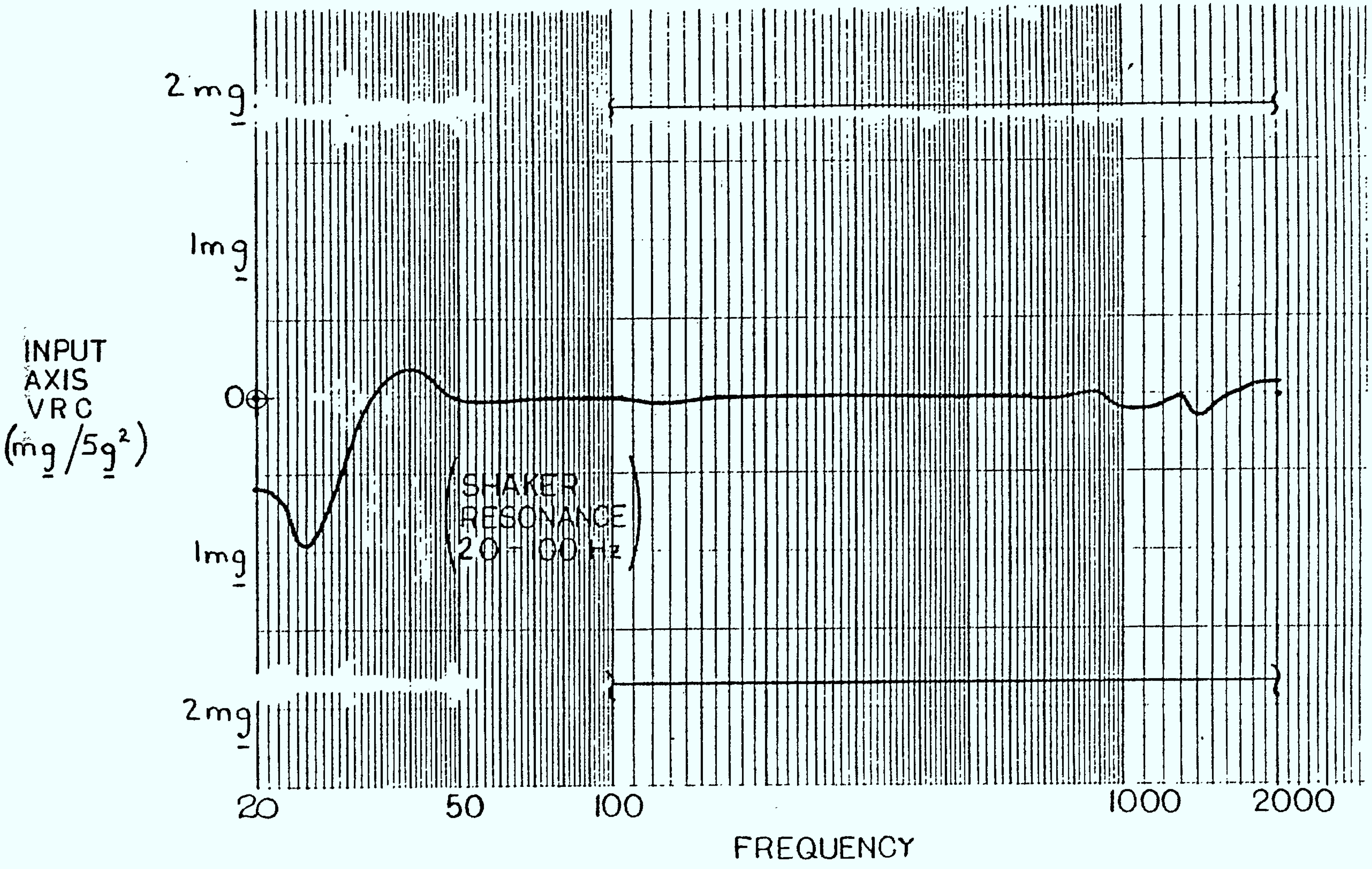
A: Accept, parameter meets -001 limit.
R: Reject, parameter does not meet -001 limit.

979-2000-701

A1



GDCGA

QA STAMP

DATE 2-20-82

CODE IDENT NO. 97896

SIZE A

979-2000-700 701

SCALE NONE

22

SHEET A4

SH REV E

ACCEPTANCE TEST DATA

SUNDSTRAND DATA CONTROL

P/N 617-4096-001

SENSOR S/N GDCGA

HYBRID S/N 1366

SEQUENTIAL DISK NUMBER ______

QA STAMP DATE 09/30/82

6.2 INSULATION RESISTANCE

res = >20 Megohms
(limit: 20 megohms minimum)

6.3 HERMETICITY

Leak rate <1x10^{-6} cc/sec
(limit: $\leq$ 1 x 10^{-6} cc/sec)

6.4 PERFORMANCE

Acceptance by 076-0408

6.5 EXAMINATION OF PRODUCT

Workmanship — SDC 39

Dimensional — SDC 39

CODE IDENT NO. 97896	SIZE A	979-2000-~~700~~ 701	SH REV F
SCALE NONE	23		SHEET A5

T3 TEST DATA SHEET 076-0414 Rev B

S/N 394

SENSOR S/N: GDCGA   RUN DATE: 08/29/82   LOCAL g: 980.708 cm/sec-sec

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T 2	64.78	-102	1.293506	339.950
T 3	34.64	518	1.289117	310.300
T 4	4.89	1180	1.285700	281.020
T 5	-24.89	1888	1.283362	251.540
T 6	-54.78	2687	1.282345	221.580
T 7	-24.90	1898	1.283414	251.550
T 8	4.85	1171	1.285764	280.960
T 9	34.61	479	1.289196	310.250
T10	64.91	-187	1.293593	340.020
T11	94.77	-717	1.298652	369.350
T12	34.67	525	1.289123	310.310

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CONSTANT:	B0=	893	C0=	1.287016	A0=	295.756
1st ORDER:	B1=	-23.17	C1=	114.06E-06	A1=	0.98636
2nd ORDER:	B2=	20.7E-03	C2=	586.8E-09		
3rd ORDER:	B3=	-10E-06	C3=	-1221E-12		
4th ORDER:	B4=	114E-08	C4=	144E-14		

TEMPERATURE (degrees-C)		RESIDUALS (u-g)	RESIDUALS (ppm)	RESIDUALS (u-amps)
T 1	94.77	-4	-2	-0.2
T 2	64.78	42	-30	0.0
T 3	34.64	19	-32	0.1
T 4	4.89	6	-28	0.2
T 5	-24.89	-6	-19	0.1
T 6	-54.78	0	0	-0.4
T 7	-24.90	5	20	0.1
T 8	4.85	-4	26	0.2
T 9	34.61	-21	35	0.1
T10	64.91	-42	29	0.0
T11	94.77	4	2	-0.2
SHIFT:		8	4	0.0
HYSTERESIS:				
Temp=	64.84	-91	55	0.0
Temp=	34.63	-45	64	0.0
Temp=	4.87	-14	53	0.0
Temp=	-24.89	9	39	0.0

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AL

AXIS ALIGNMENT DATA SUMMARY 076-0414 Rev B

SENSOR S/N: GDCGA RUN DATE: 08/16/82

S/N 394

	PENDULUM AXIS (MIP)			HINGE AXIS (MIH)		
	OVEN TEMP (deg-C)	ALIGN-MENT (u-rad)	TEMP SENSOR (u-amp)	OVEN TEMP (deg-C)	ALIGN-MENT (u-rad)	TEMP SENSOR (u-amp)
T 1	94.88	-78	369.180	94.89	169	369.140
T 2	64.67	-114	339.590	64.59	167	339.510
T 3	34.71	-197	310.190	34.57	217	310.060
T 4	4.71	-265	280.360	4.58	261	280.300
T 5	-24.95	-1	251.410	-24.98	0	251.530
T 6	-54.76	-1	221.270	-54.77	1	221.460
T 7	-24.67	-1	251.980	-24.74	1	252.000
T 8	5.32	-260	280.980	5.36	290	281.090
T 9	35.39	-196	310.820	35.41	253	310.850
T10	65.05	-131	339.930	65.08	185	339.960
T11	94.88	-84	369.180	94.89	173	369.140
T12	34.71	-202	310.150	34.58	221	310.040

MODELED COEFFICIENTS

	PENDULUM AXIS (@293u-amp)	HINGE AXIS (@293u-amp)	TEMP SENSOR (@20deg-C)
CONSTANT:	-255 =P0	280 =H0	295.504 =A0
1st ORDER:	-1.676 =P1	2.369 =H1	0.98615 =A1
2nd ORDER:	134.6E-03 =P2	-136.2E-03 =H2	
3rd ORDER:	242E-06 =P3	-267E-06 =H3	
4th ORDER:	-1755E-08 =P4	1853E-08 =H4	

RESIDUALS

	OVEN TEMP (deg-C)	ALIGN-MENT (u-rad)	TEMP SENSOR (u-amp)	OVEN TEMP (deg-C)	ALIGN-MENT (u-rad)	TEMP SENSOR (u-amp)
T 1	94.88	8	-0.2	94.89	-6	-0.2
T 2	64.67	-15	0.0	64.59	12	0.0
T 3	34.71	48	0.2	34.57	-63	0.2
T 4	4.71	-51	-0.1	4.58	33	0.0
T 5	-24.95	22	0.2	-24.98	-21	0.4
T 6	-54.76	-5	-0.5	-54.77	4	-0.3
T 7	-24.67	25	0.5	-24.74	-24	0.6
T 8	5.32	-44	0.0	5.36	57	0.0
T 9	35.39	46	0.1	35.41	-26	0.1
T10	65.05	-33	0.0	65.08	32	0.0
T11	94.88	2	-0.2	94.89	-3	-0.2
SHIFT		6			-3	

HYSTERESIS

OVEN TEMP (deg-C)	ALIGN-MENT (u-rad)	TEMP SENSOR (u-amp)	OVEN TEMP (deg-C)	ALIGN-MENT (u-rad)	TEMP SENSOR (u-amp)
64.86	-23	-0.0	64.83	23	-0.0
35.05	-5	-0.0	34.99	40	-0.0
5.01	5	0.0	4.97	26	0.0
-24.81	2	0.3	-24.86	-2	0.2

BLOCK POSITION: 2

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LAST REVISION INCORPORATED C

SEE SHEET 3 FOR REVISIONS

TITLE SHEET

INDEX

WPC: 32/272

CONTRACT NO.			Sundstrand Data Control, Inc. REDMOND, WASHINGTON
DRAWN	[signature]	7/28/80	HIGH PERFORMANCE MODELED Q-FLEX ACCELEROMETER MODEL QA2000 PRODUCT DESCRIPTION
CHECK	D. L. Cooper	7/28/80	
ENGR	[signature]	7/28/80	
MFG	[signature]	7/30/80	SIZE A — CODE IDENT NO 97896 — 979-2000-602
QA	[signature]	7/30/80	
APPD	[signature]	8/6/80	26 — SHEET 1 of 7

CHANGE CATEGORY

INDEX OF REVISIONS

REV SYM	SHEET REVISED	SHEET ADDED	SHEET DELETED	REV SYM	SHEET REVISED	SHEET ADDED	SHEET DELETED	REV SYM	SHEET REVISED	SHEET ADDED	SHEET DELETED
A	1-3	—	—								
B	1-3 6										
C	1-3 6										

UCC FORM A5

REVISIONS

SYM	SHEET	DESCRIPTION	DR/CHK	APPROVED/DATE
A	1-3	SEQ NO. I00133 ADCN 1 1) SEE ADCN FOR CHANGES EFF PT: VIII DISP: NONE	1018 10/9/80	R. Hulsing DLCooper
B	6	SEQ NO. I01281 ADRN 2 Specification changes SFTC 120 MAX was 180 MAX SFTC Stab ±5 was ±10	3/18/82 3/12/82	S Foote DLCooper
C	6	SEQ NO. I02435 ADRN 3 Seal 1 x 10^{-6} was 5 x 10^{-8}	6/30/82 6/12/82	S Foote DLCooper

ER1580(C) ER1002(B)

CODE IDENT NO.	SIZE		SH REV
97896	A	979-2000-602	C
SCALE NONE	28	SHEET 3	

HIGH PERFORMANCE MODELED Q-FLEX ACCELEROMETER
MODEL QA2000 PRODUCT DESCRIPTION

1.0 SCOPE

This document describes a high performance, single axis accelerometer with integral servo electronics. Typical use of this accelerometer is in digital strapdown inertial reference systems.

2.0 APPLICABLE DOCUMENTS

The following documents form a part of this product description to the extent specified herein. In event of conflict between the referenced documents and this document, this document will be considered superseding.

2.1 Sundstrand Data Control Drawings:

979-2000	Top Assembly
979-2000-201	Outline
979-2000-701	ATP

2.2 Government Documents

Specifications

MIL-C-45662A	Test Equipment, Calibration and Certification of
MIL-E-5400R	Electronic Equipment, Airborne, General Specification for
MIL-P-9024F	Packaging, Materials Handling and Transportability, System and System Segments, General Specification for
MIL-Q-9858A	Quality Control Requirments, General
MIL-S-83490	Specifications

Standards

MIL-STD-129E	Marking for Shipment and Storage
MIL-STD-143B	Standards and Specifications, Order of Precedence for the Selection of
MIL-STD-454E	Standard General Requirements for Electronic Equipment
MIL-STD-965 Rev. NEW	Parts Control Program
MIL-STD-883	Test Methods, Procedures for Micro-electronics

2.3 Commercial Documents

RTCA DO-160	Environmental Conditions and Test Procedures for Airborne Electronics/electrical Equipment and Instruments.

2.4 Abbreviations and Symbols

The abbreviations and symbols used herein are defined as Standard Accelerometer Terminology by the Gyro and Accelerometer Panel of Accelerometer Parts Committee, Aerospace Industries Association.

3.0 GENERAL DESCRIPTION

The performance required of this accelerometer is achieved by analytically modeling bias, scale factor and alignment over temperature. These serialized polynomial models accompany the serialized accelerometer as a composite deliverable assembly.

The pendulous inertial sensor employs a quartz flexure suspended proof mass in an air damped mechanism. Proprietary hybrid microelectronics servo the proof mass, producing an acceleration output current independent of output load.

Also included is an internal temperature sensor which produces a current output as a function of temperature. This current (approx. 1uA/°K) is used as the basis for the bias, scale factor and alignment models.

4.0 MODELS

Bias and Scale Factor are modeled with 4th order polynomials. Hinge and Pendulous Alignment are modeled with best fit straight lines. These models are given as a function of temperature sensor current output, normalized at 293uA. A straight line model is also provided of temperature sensor current output as a function of flange temperature, normalized at 20°C.

5.0 PERFORMANCE

PARAMETER	UNITS	LIMITS	
BIAS:			
Bias	mg	4.0	max
BTC	μg/°C	30	max
BTH (p-p)	μg	120	max
Bias Stability (1 year)	μg	±140	max
BTC Stability (1 year)	μg/°C	±2	max
Input Voltage Sensitivity	μg /V	10	max
SCALE FACTOR:			
SF	mA/g	1.20 to 1.46	max
SFTC	ppm/°C	120	max
SFTH (p-p)	ppm	250	max
SF Stability (1 year)	ppm	±400	max
SFTC Stability (1 year)	ppm/°C	±5	max
Input Voltage Sensitivity	ppm/V	20	max
AXIS ALIGNMENT: (For each axis)			
Alignment	mR	1.0	max
AATC	μR/°C	4.0	max
AATH (p-p)	μR	75	max
AA Stability (1 year)	μR	±110	max
AATC Stability (1 year)	μR/°C	±1.0	max
Frequency Response (±5%)	Hz	300	min
Natural Frequency	Hz	800	min
Damping Ratio	-	0.3 to 0.7	
Vibration Rectification	$\mu g/g^2$(peak)	20	max
Linearity	$\mu g/g^2$(peak)	25	max
@ Max g Level	g	25	max
Shock	g	100	max
Seal	cc/sec	1×10^{-6}	max
Threshold & Resolution	μg	1.0	max
Temperature Range	°C	-55 to +95	
Weight	grams	70	nominal
	grams	80	max

TEMPERATURE SENSOR:

Current Output @ 20°C	uA	290 to 297	
Temperature Coefficient	uA/°C	1.0	nominal
Output Load Requirement	ohms	10KΩ	±5%

SELF TEST - Voltage or Current Torque available

6.0 EXCITATION

±15VDC ±5%
(Will operate over ±13 to ±28VDC range)

7.0 ATP

Vibration Rectification Coefficient
Insulation Resistance
Hermeticity
Temperature Modeling
Examination of Product