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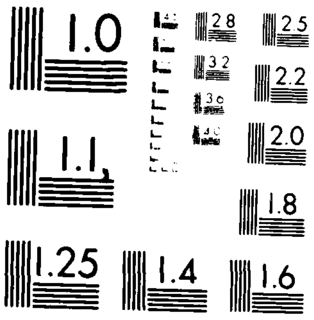
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REPORT
NADC 81189-60

ELECTROFLUIDIC ANGULAR RATE SENSOR FOR EJECTION SEAT THRUST VECTOR CONTROL

A Test and Evaluation Report of Dynamic Performance and Cross-Axis Sensitivity

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NAVAL AIR DEVELOPMENT CENTER
Warminster, PA 18974
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Three Hamilton Standard electrofluidic roll rate sensors were tested to measure their dynamic performance and their sensitivity to rotation about an orthogonal axis. An empirical dynamic mathematical model is derived for use in computer simulation of ejection seat dynamics. The test data are reported and evaluated. The data were used in part to develop a specification for a three-axis angular rate sensor intended for thrust vector control of an advanced escape system. The predominant dynamic response of this sensor is a transport delay of approximately 5 msec.

SUMMARY

Background

The need exists for a small, rugged 3-axis angular rate sensor which has an electronic output and has a very short start-up time. The intended application is for ejection seat steering control for the Maximum Performance Ejection System (MPES) Program. Three single-axis electrofluidic roll rate sensors manufactured by Hamilton Standard were tested to measure their dynamic performance and cross-axis sensitivity. This information was used to develop a specification for a combined three-axis angular rate sensor. In addition, the empirical, dynamic mathematical model of a three-axis sensor will be used in NADC computer simulations of seat ejections to refine the system performance requirements and control component design.

Conclusions

The Hamilton Standard design, combined into a three axis sensor, appears to have a high probability of meeting the requirements of advanced ejection seat steering control. The short "readytime", sufficient accuracy, apparently adequate dynamic response, and compatible electrical input/electronic output interfaces make this an excellent candidate for the MPES application.

Recommendations

It is recommended that further research be conducted to develop a three-axis angular rate sensor based on fluidic or fluid dynamic principles. Several such sensors should be fabricated to achieve the performance goals outlined in Appendix C. These sensors should be tested in NADC Laboratories to validate their suitability for MPES. The tests would include laboratory calibration, dynamic performance, appropriate MIL-STD-810C environmental tests, and ejection seat launches.

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INTRODUCTION

The need exists for a small, rugged 3-axis angular rate sensor which has a very short "readytime" and which has an electronic interface for advanced ejection seat steering control systems. The Hamilton Standard design appears to have a high probability of meeting the requirements of this system.

The "Superjet" electro-fluidic roll rate sensor is manufactured by Hamilton Standard, Farmington, Connecticut, as Part Number 9304100-099. The package includes a pump which directs a stream of helium between two resistive elements. The change in cooling of these elements by the gas stream is sensed to indicate angular rate as shown in Figure (1). The package also includes analog electronics for signal conversion; so all that is required is a ±15 V.d.c. power supply and a voltmeter to measure the output of the device (±6 V.d.c.). The only moving mechanical part in the sensor is the vibrating diaphragm pump. This is a ceramic piezoelectric crystal, flexibly mounted around its periphery, which has electrically excited faces perpendicular to the mounting plane. The "Superjet" is exceptionally tolerant to angular rate overranging because such overranging does not produce an internal mechanical force on stops, gimbals, or spin bearings as in conventional rate gyroscopes.

The steady speed and environmental tests were conducted by Martin Marietta and the results have been reported (1)* and summarized in Table 1.

Therein is a recommendation that further investigations of "g-

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*Numbers in parentheses denote the corresponding citation in the Reference section.

TABLE 1 PERFORMANCE SUMMARY

Full Scale Rate At ±2% Linearity	500 ±100 deg/sec
Scale Factor	.0062 ± .002 deg/sec
Null Bias (Calculated)	±2 deg/sec
Hysteresis	±0.6 deg/sec
Threshold	<0.1 deg/sec
Resolution	<0.1 deg/sec
Readytime	80 milliseconds maximum
Drift	+0.76 deg/sec/min
Null Offset (measured)	±2 deg/sec
G-Sensitivity	1.00 deg/sec/g/maximum
High Temperature Tested	+165°F
Low Temperature Tested	-30°F
Sensitivity to Jerk	Negligible
Acoustic Sensitivity	Negligible
Vibration Sensitivity	±2 deg/sec at approx. 2,000 Hz

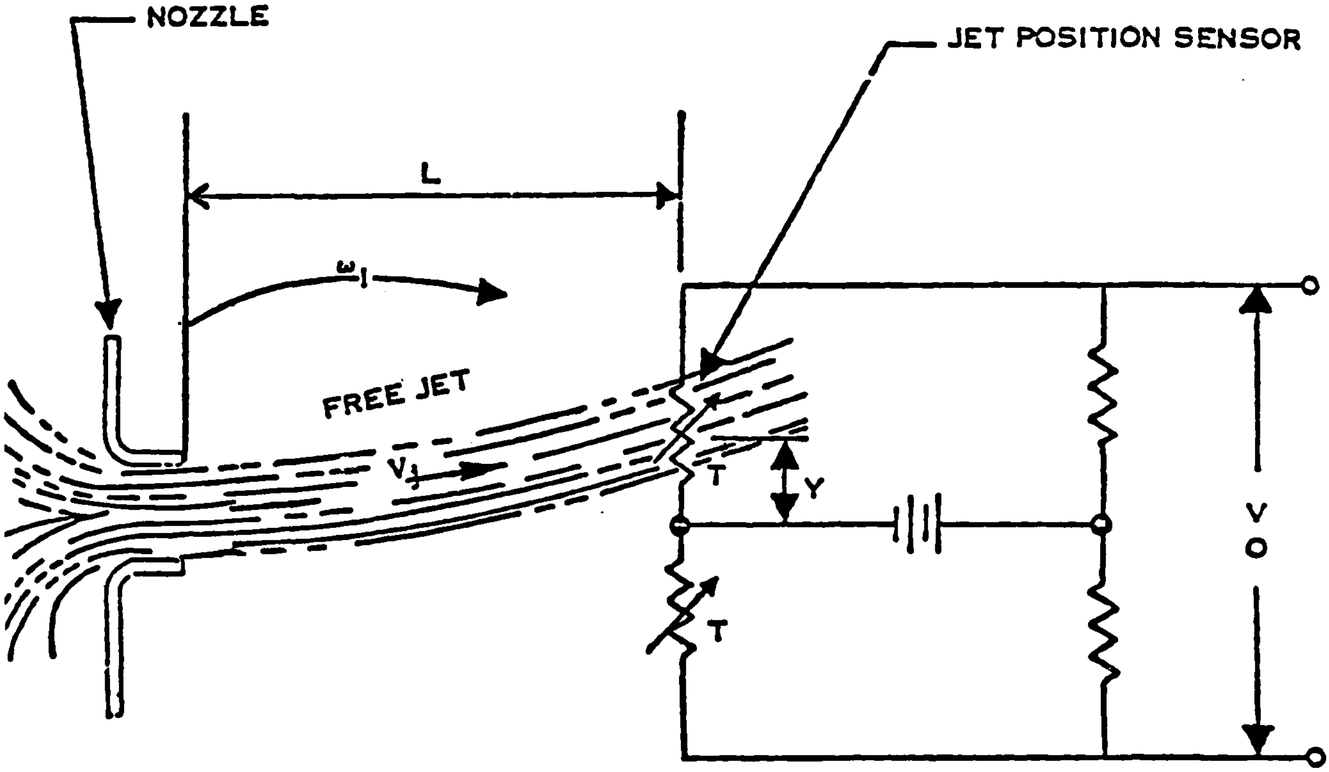


FIGURE 1 SUPERJET ANGULAR RATE SENSOR SCHEMATIC

sensitivity" or cross-axis effects be conducted. Furthermore, that test program did not include dynamic performance evaluation. The dynamic performance of candidate sensors is required for the computer simulation of seat dynamics currently underway for the Maximum Performance Ejection System (MPES) at NADC. Consequently, it was decided to measure the cross-axis effects and the dynamic performance of these sensors in the Advanced Concepts Laboratory (6013). The three angular rate sensors used during this evaluation were serial numbers 0100355, 0100373, and 0100381, which will be referred to as serial numbers 355, 373, and 381 respectively. This reports presents the results of these tests and evaluations.

TEST PLAN

The tests were organized by a chain block plan as described in chapter 13 of NBS Handbook 91(2). This is an incomplete factorial experimental design in which each sensor is subjected to some of the tests, randomly selected and paired. The pairing allows measurement replication in order to detect unexpected variance in performance. The tests (treatments) conducted on the sample of 3 single axis angular rate sensors were:

1. Frequency response
2. Step response
3. Transverse Velocity Sensitivity
4. Centripetal Acceleration Sensitivity

These tests are described in detail in later sections. Here it suffices to state that frequency and step response are standard techniques for measuring the dynamic behavior of a system. Subsequent analysis of this data results in a real time mathematical model of the system for use in computer simulation.

The cross-axis sensitivity measurements (tests 3 and 4 above) are designed to detect misinformation. The sensor is mounted on the rate table so that there is in fact no rotation of the sensitive axis. Any output under these test conditions becomes part of the overall error of the device.

In test 3 the sensor is mounted with the jet flow parallel to the axis of rotation and with the sensitive plane tangent to the cylinder of rotation as shown in Figure 2.

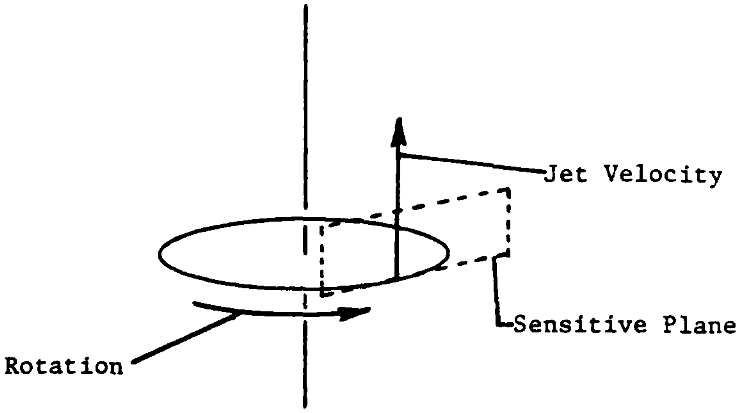


Figure 2 Jet Alignment for Lateral Velocity Sensitivity Test

In test 4, the sensor is mounted with the jet flow parallel to the axis of rotation, perpendicular to the rate table surface with the sensitive plane oriented radially so that it is subjected to centripetal acceleration as shown in Figure 3.

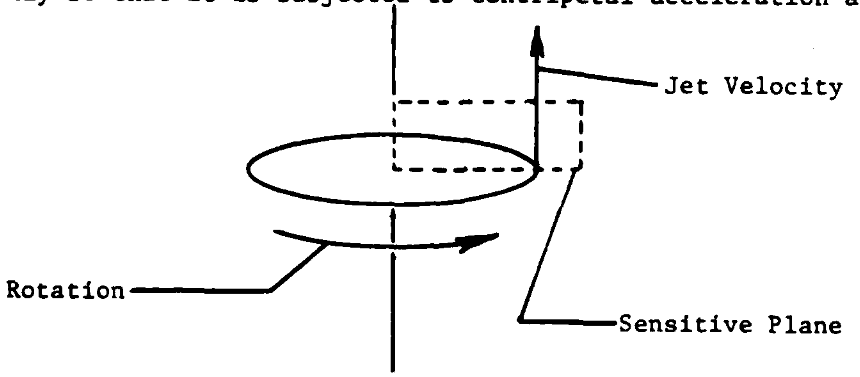


Figure 3 Jet Alignment for Centripetal Acceleration Sensitivity Test

These tests may indicate a sensitivity to linear transverse velocity and linear transverse acceleration as well. However, it is the manufacturer's opinion that any observed effects probably result from secondary steady flow patterns established inside the helium vessel. This question could be resolved if necessary by using the ejection tower facility at NADC to conduct linear acceleration tests.

The distribution of the aforementioned tests among the sensors is shown in Table 2.

TABLE 2 Chain Block Test Plan

Test Number			
Sensor S/N	355	373	381
	1	1	1
	2	2	2
	3		3
		4	4

The tests denoted in Table 2 are:

1. Frequency response
2. Step response
3. Transverse Velocity Sensitivity
4. Centripetal Acceleration Sensitivity

DYNAMIC PERFORMANCE TESTS

Frequency Response Tests

The frequency response tests were conducted in accordance with ANSI B93.14-1971 (3), using the equipment arrangement shown in Figure 4.

This figure also indicates the data reduction procedures. The sensors were mounted with the centerline of the jet at the center of the table and with the jet flow radially outward.

The SM 2001 frequency response analyser consists of two main sections, a generator and a correlator. The generator section provides the excitation signal to the system-under-test and the correlator section measures the output of the system-under-test and displays the result, as shown in Figure 5. The excitation signal is a voltage sinusoid, digitally synthesized and converted to a continuous signal (1024 points are generated for each sine wave period). The correlator section accepts the analog output from the system under test, converts it to digital form, and multiplies it by in-phase and quadrature references established relative to the generator excitation signal. These products are integrated over a selected number of cycles to produce the Cartesian components of the output signal with respect to the references. Further digital processing is available for conversion to polar form (gain and phase angle) or to log arithmic polar form. The phase angle is always referenced to the nearest principal axis.

The Genisco 1100 series rate-of-turn table (turntable) responds to the analyser generator signal. A built-in tachometer generates a voltage proportional to table speed.

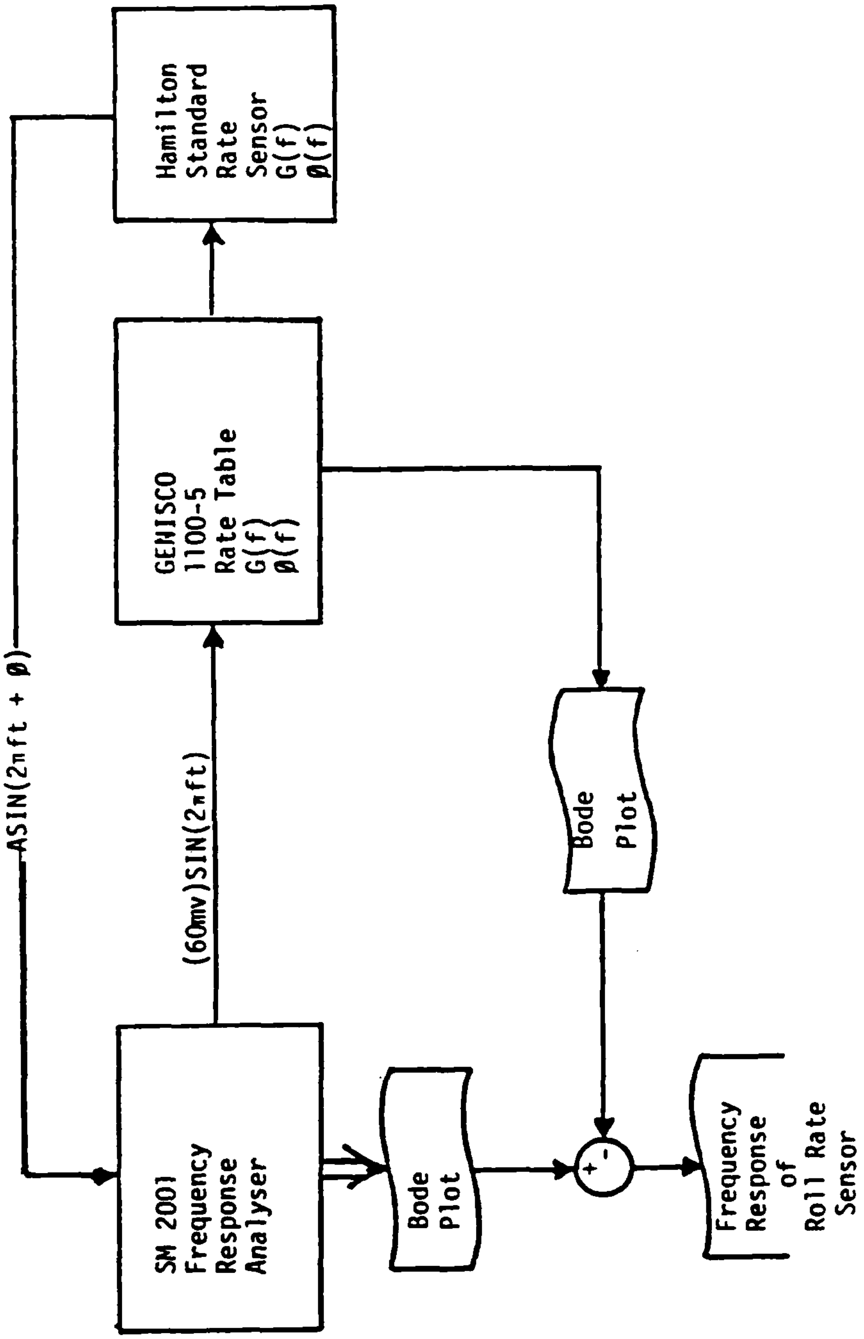


FIGURE 4 Frequency Response Test Arrangement

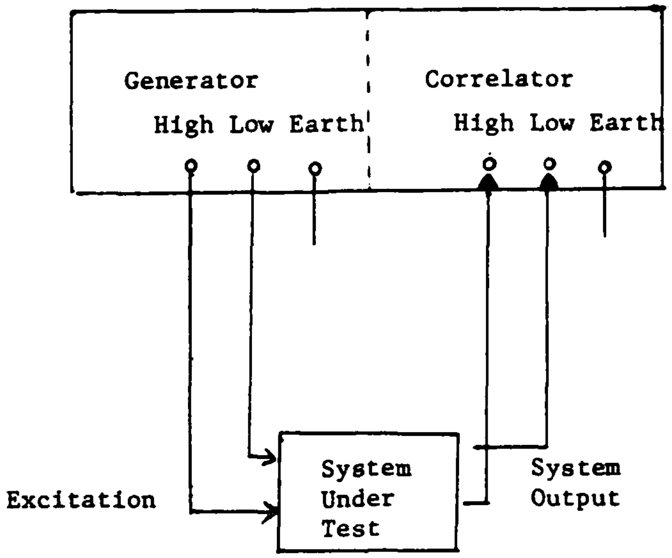


Figure 5 Frequency Response Analyzer Operational Diagram

Data Reduction

Measurements were observed at randomly selected frequencies between 0.5 and 32.0 Hz. The process of extracting sensor gain response and phase lag from the data of the aggregate system is described below.

Gain Response

1. Each measurement was normalized with respect to an average of several readings taken at very low frequency (essentially steady speed).

2. Each of the gain ratios of the aggregate system (turntable <u>and</u> sensor) was divided by the normalized turntable gain ratio at that frequency.

3. These quotients each were divided by the ratio: rate sensor output scale factor to input scale factor of the rate table (both constant). The re-

sulting gains are plotted in Figure 6.

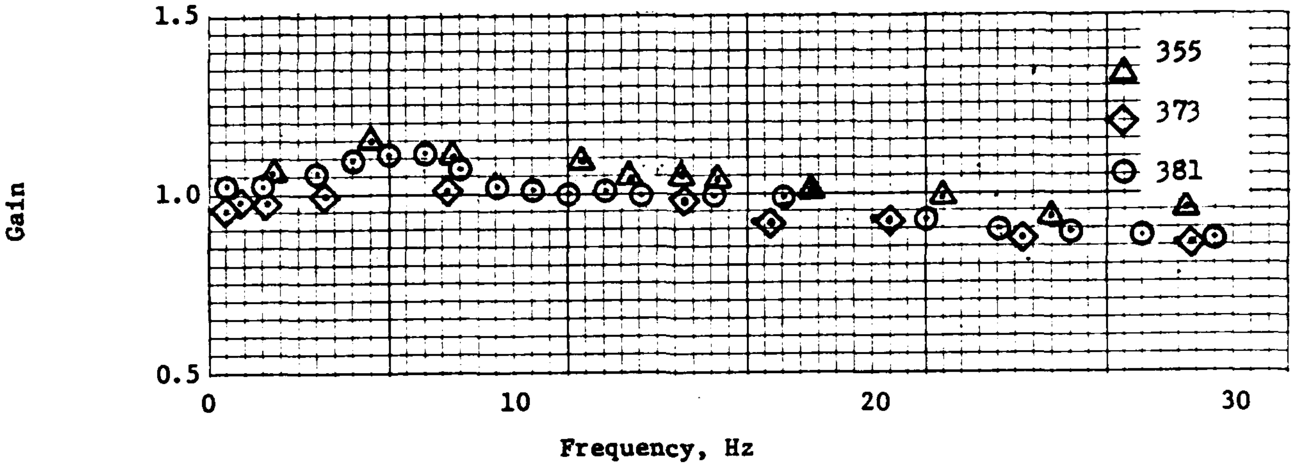


Figure 6 Gain Responses vs. Frequency of the Three Rate Sensors

Phase Lag (°)

1. The phase lag of the aggregate system shown in Figure 4 was observed at each of the test frequencies.

2. From these values the phase lag of the turntable alone was subtracted at each test frequency.

3. The resulting angular difference is the phase response of the sensor.

The phase response of all three sensors is shown in Figure 7.

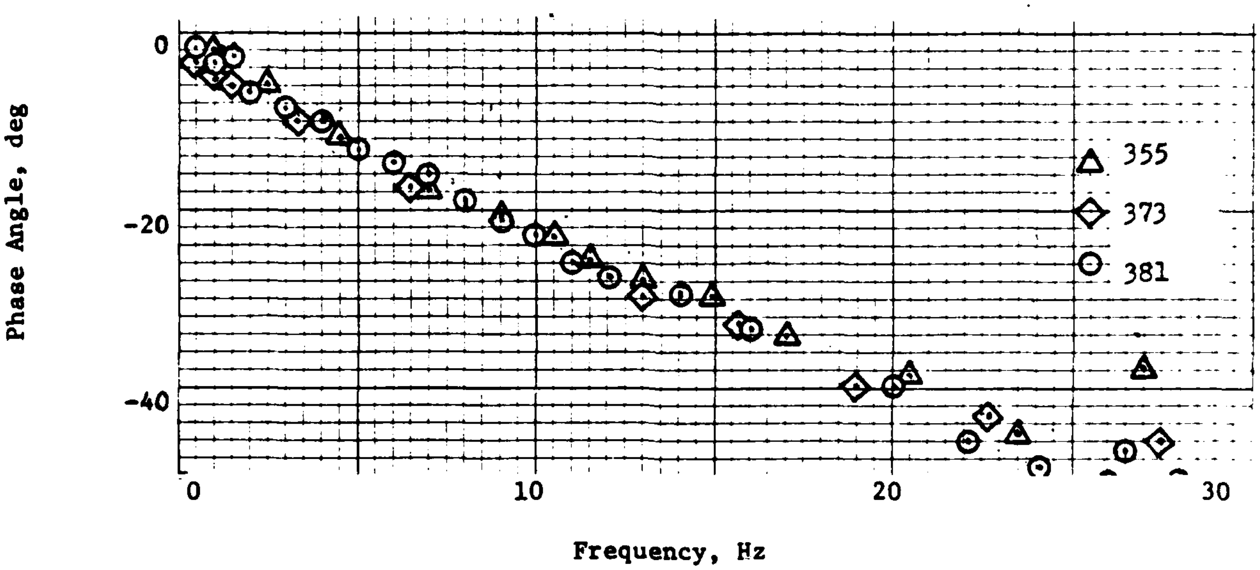


Figure 7 Phase Response vs. Frequency of the Three Sensors

It can be seen in Figure 6 that the gain is nearly constant. The average gain of all three sensors over the frequency range is 1.0. It can be seen in Figure 7 that the phase lag increases linearly with frequency. Such a phase response is characteristic of a transport delay, and the delay time can be determined from the slope of this curve by using equation 1.

$$t_s(\mathrm{sec}) = \frac{\text{Phase Lag (deg)}}{f(\mathrm{Hz})360(\mathrm{deg/rev})} \qquad (1)$$

The turntable gain and phase responses used in the data reduction procedures are shown in Figures 8 and 9.

Transport Delay Test

To verify that the major characteristic of this sensor is a transport delay, this interval was measured directly. The sensor was mounted the same way as in the frequency response tests above.

The test method is simply to cause a sudden change in table speed, observe the change in the sensor output, and measure the time between the two events. For this reason it is called a step response. In fact the sensor responds so rapidly that it appears as a response to a ramp input on the oscilloscope. Nonetheless the time difference between the beginning of the table speed ramp and the sensor output is a valid measure of the transport delay. The sensor output also appeared to be a linear ramp. This test was conducted in accordance with ANSI B93.41-1971 (3) using published procedures and instruments (4). Both increasing and decreasing speed ramps were used, and there was no detectable difference in the observed transport delays between them.

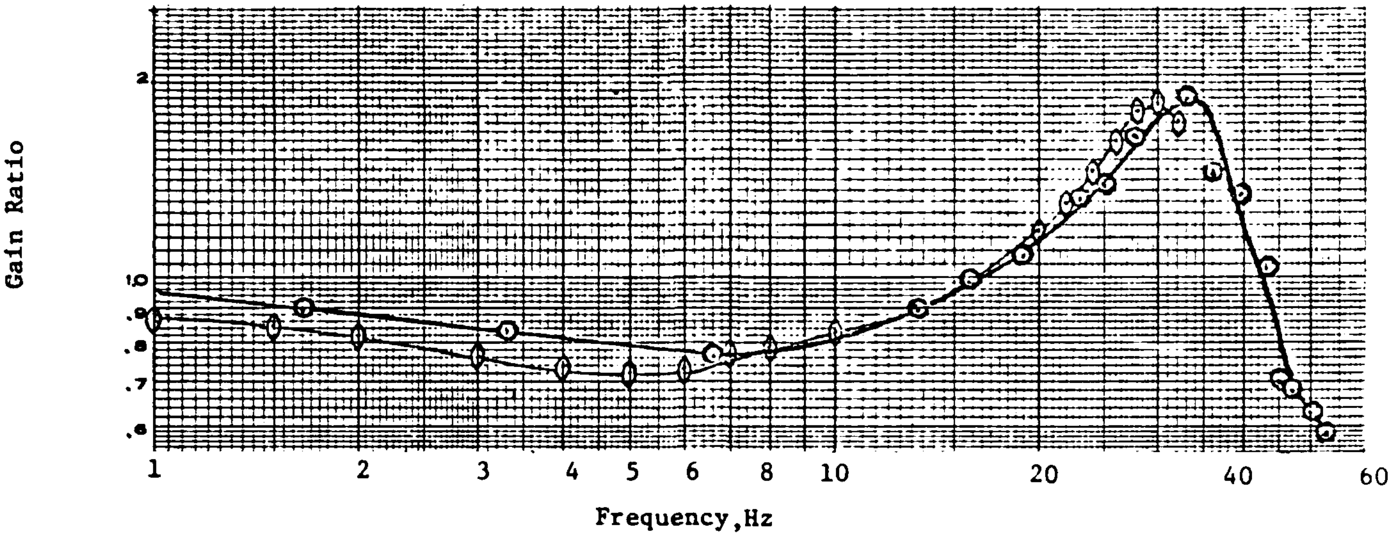


Figure 8 Gain Response vs. Frequency of the GENISCO Rate Table

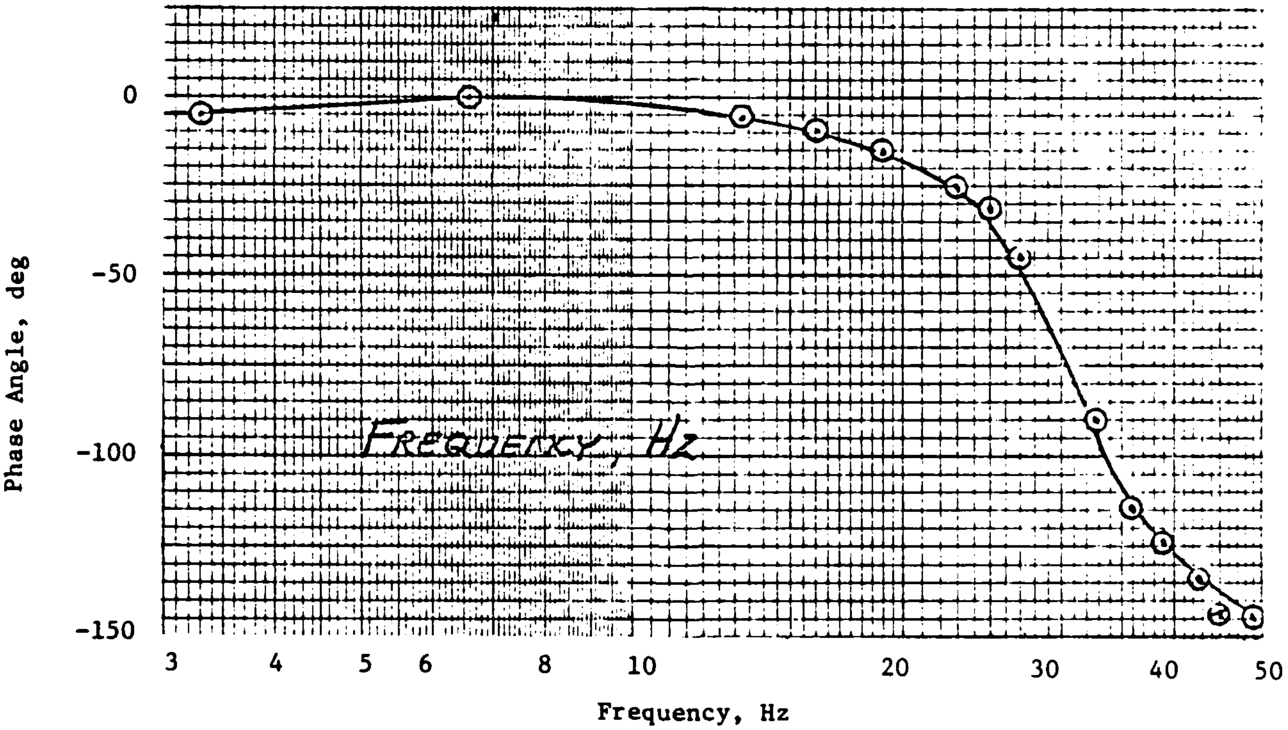


Figure 9 Phase Response vs. Frequency of the GENISCO Rate Table

Table 3 summarizes the mean transport delay time data observed for each sensor using both tests methods.

TABLE 3 Dynamic Performance Test Data

Sensor SN	Freq. Resp. Delay(msec)	Direct Transport Delay(msec)	Variation at 95% Confidence(msec)
355	4.23	4.28	±0.55
373	4.87	5.13	±1.6
381	5.85	5.34	±0.95

The complete set of dynamic performance data is presented in Appendix A.

The mathematic description of the average roll rate sensor performance recommended for use in computer simulation of ejection seat dynamics is:

$$\omega_o(t) = \omega_i\ (t - .00495)\ \frac{\text{deg}}{\text{sec}} \tag{2}$$

The LaPlace transform of which is:

$$\omega_o(s) = \omega_i\ (s)e^{-.00495(s)} \tag{3}$$

CROSS-AXIS SENSITIVITY TESTS

These tests are designed to measure misinformation. In these tests the sensor is rotated about an axis orthogonal to its sensitive axis. The ideal sensor would not produce an output under these conditions. Any observed output then worsens the overall accuracy of the sensor. The reason for conducting these tests derives from the intention to combine three of these sensors into a

3-axis configuration for use in the Maximum Performance Ejection System (MPES). In this configuration, these sensors will be subjected to precisely these conditions.

Centripetal Acceleration Sensitivity Test

In this test the sensor is aligned as shown in Figure 3. This may be visualized also from Figure 1 wherein its right-hand side becomes the upper surface of the sensor and the page is aligned along a radius of the table. Figure 10 shows a pair of sensors installed on the angular rate table for this test.

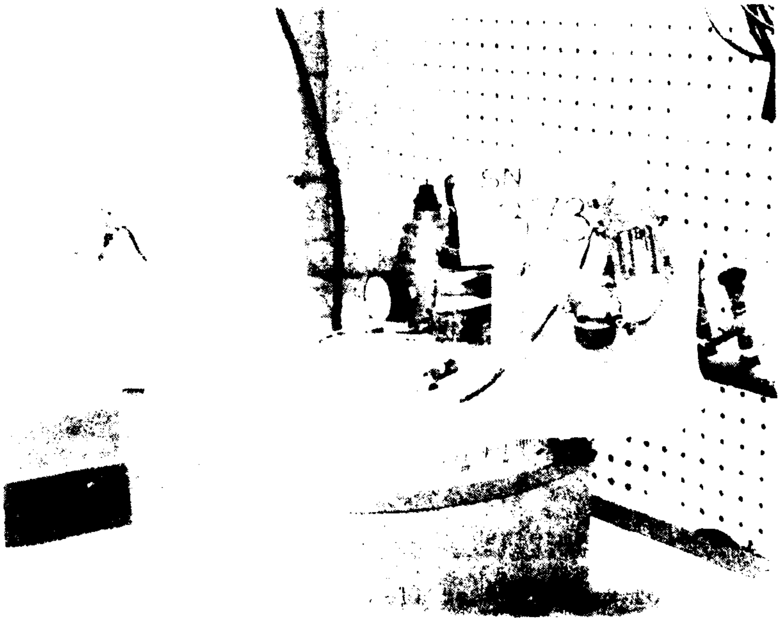


Figure 10 Test Installation to Observe Centripetal Acceleration Sensitivity

This test also may disclose unsatisfactory performance during the high linear accelerations of an ejection.

Testing and Data Reduction

Observations were made up to 2200 deg/sec at intervals of 100 deg/sec in both clockwise (CW) and counterclockwise (CCW) rotation. The table speed and direction were randomly selected for each observation. Sensor outputs were measured with a Fluke model 8600A digital voltmeter, first during rotation and then at rest. The implied angular rate was computed by comparing the two outputs (equation 4).

$$\text{Implied Angular Rate (deg/sec)} = \frac{\text{(Rotating Output - Rest Output) mv}}{\text{(Scale Factor, mv . sec/deg)}}$$

The scale factors were approximately 6.0 mv.sec/deg.

This calculation removes the effect of bias error and electronic drift. A selector switch permitted measuring the output of both sensors sequentially without changing turntable speed.

Centripetal accelerations up to 25 "g" were obtained with the installation shown in Figure 10 and with speeds up to 2200 deg/sec. This "g" level covers the range expected in the MPES application.

Centripetal Sensitivity

The test results for SN373 are shown in Figure 11; Figure 12 presents the same for SN381. There are two distinct curves of error as a function of orthogonal speed for each sensor: one for CW and another CCW rotation.

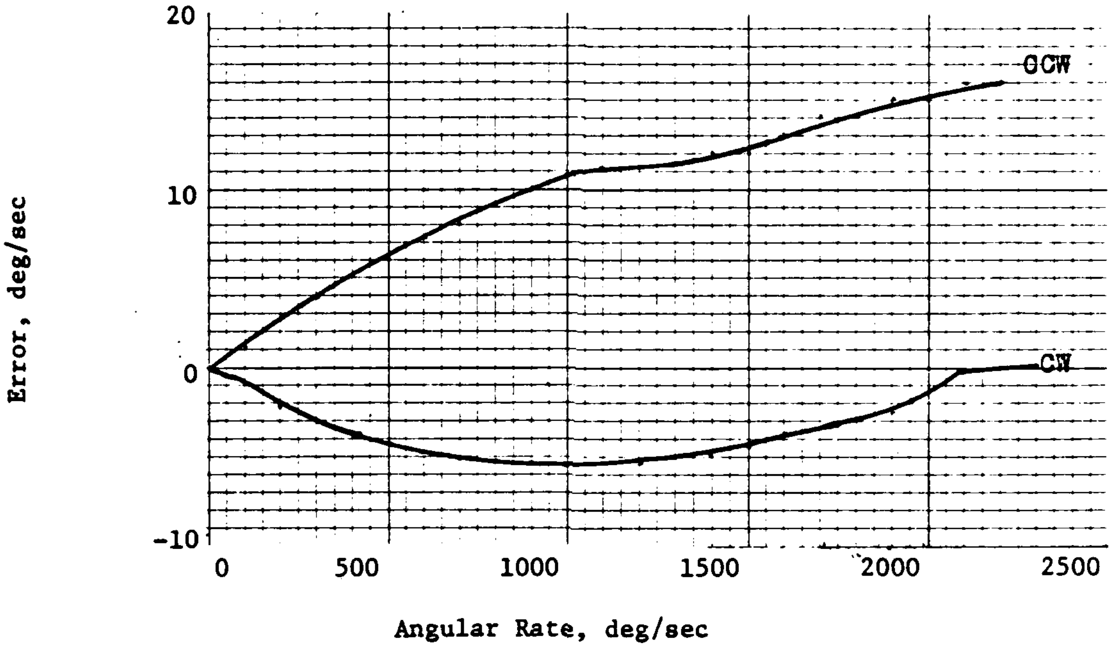


Figure 11 Centripetal Acceleration Sensitivity of SN373

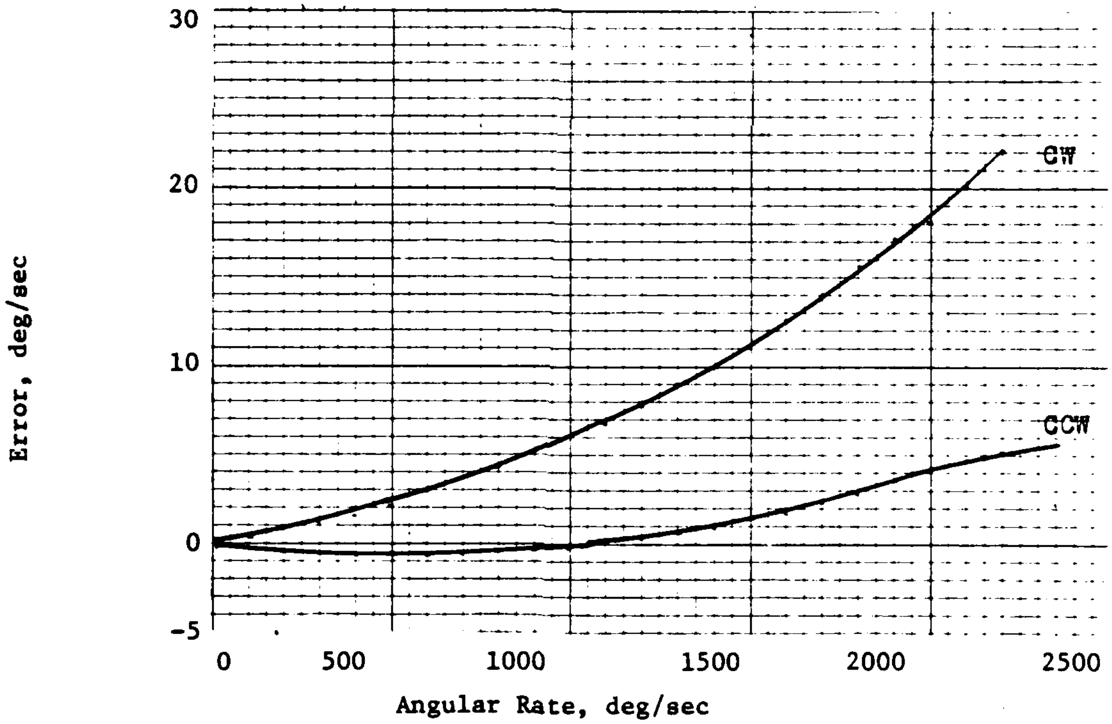


Figure 12 Centripetal Acceleration Sensitivity of SN381

Comparing the upper curves of the two sensors, it is noted that the one results from CCW rotation while the other results from CW rotation. This might imply that there is a "heads or tails" orientation probability of the fluidic subassembly when it is installed in the angular rate sensor. Since different sensitivities were observed depending on direction of rotation, nothing conclusive can be said about "g" sensitivity. The same centripetal accelerations are obtained at the same speed regardless of which way the table is turning. The larger error curves of the two shown in Figures 11 & 12 are replotted as a function of "g" level in Figure 13. These results lend some credence to the manufacturer's assertion that such sensitivity results from circulating steady flow inside the helium vessel. The maximum centripetal sensitivity observed was 1.2% of orthogonal rate in the range of 100 to 500 deg/sec, which is the range of interest for the MPES.

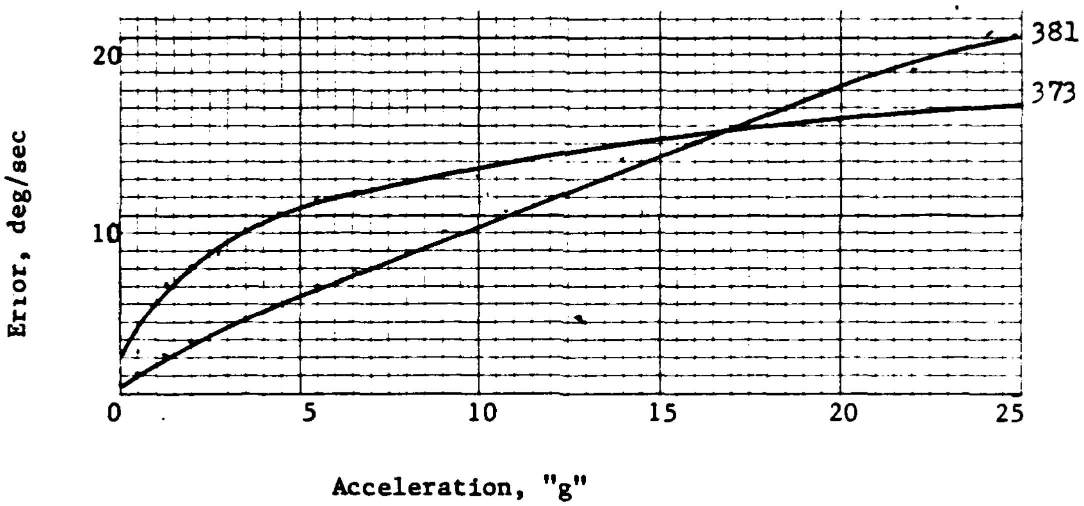


Figure 13 Error from Centripetal Acceleration vs. "g" Level

Lateral Velocity Sensitivity Test

In this test the sensor is aligned as shown in Figure 2. This may be visualized also from Figure 1 wherein its right-hand side [illegible] surface of the sensor, the jet flow is upward, and the page is [illegible] perpendicular to the radius of the table. Figure 14 shows the pair installed on the angular rate table for this test. The test [illegible]

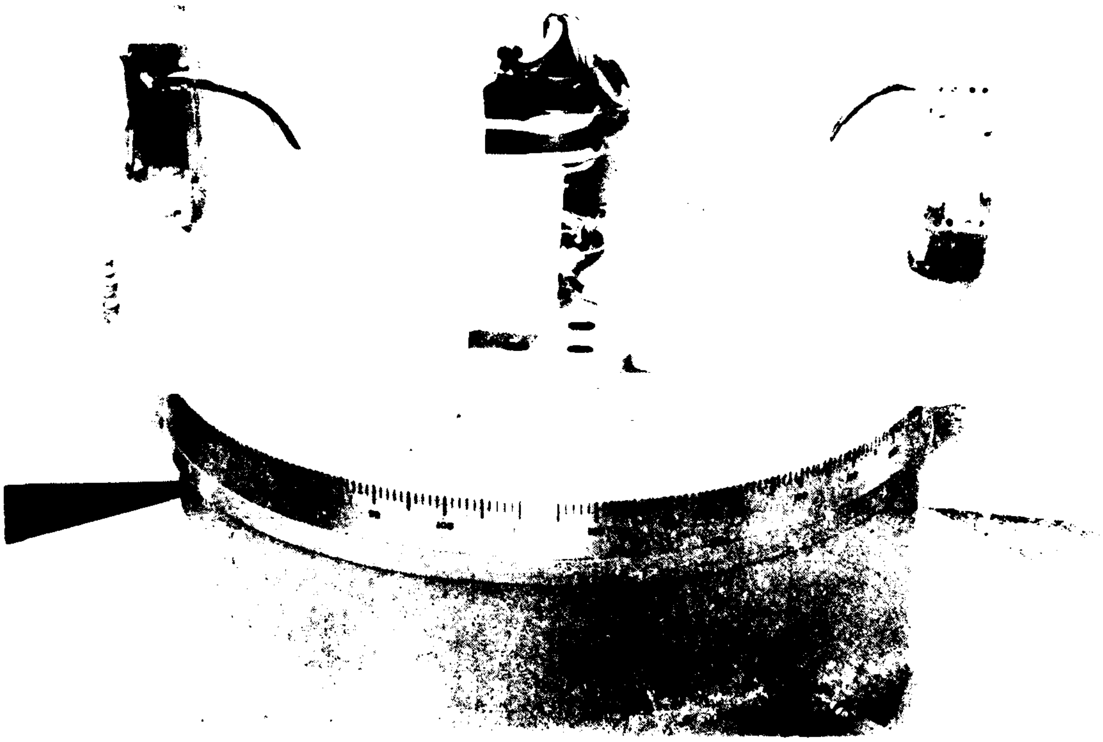


Figure 14 Test Installation to Observe Lateral Velocity Sensitivity

[illegible]ation were identical to those used in the centripetal sensitivity [illegible] Equation 4 was used again to reduce the data.

Lateral Velocity Sensitivity

The test results for SN355 are shown in Figure 15, and those of [illegible] given in Figure 16. As in the centripetal sensitivity data, there are two distinct curves-one for CW and one for CCW rotation. As before, the upper curve of SN355 describes the data in CCW rotation while that of SN381 portrays the CW direction. Even more interesting, the two sets of curves seem to be mirror images of each other. This observation further bolsters the hypothesis that there may be a "heads on tails" manufacturing or assembly of these sensors. The

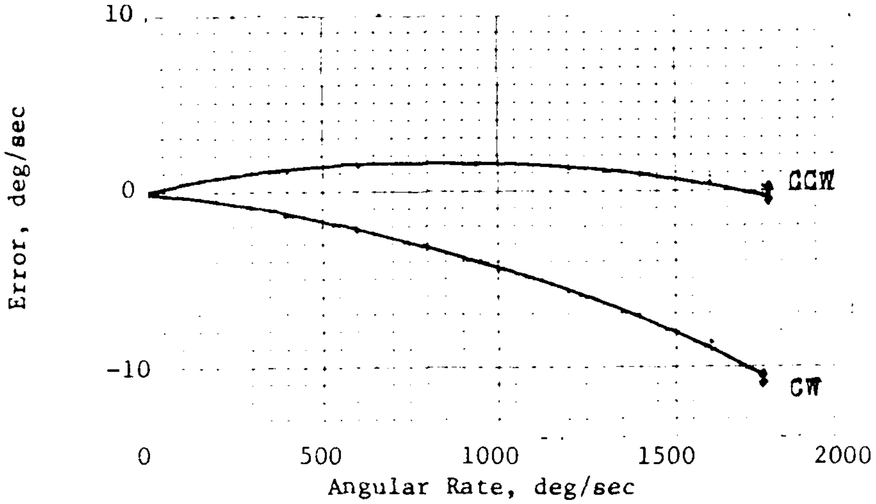


Figure 15 Lateral Velocity Sensitivity of SN355

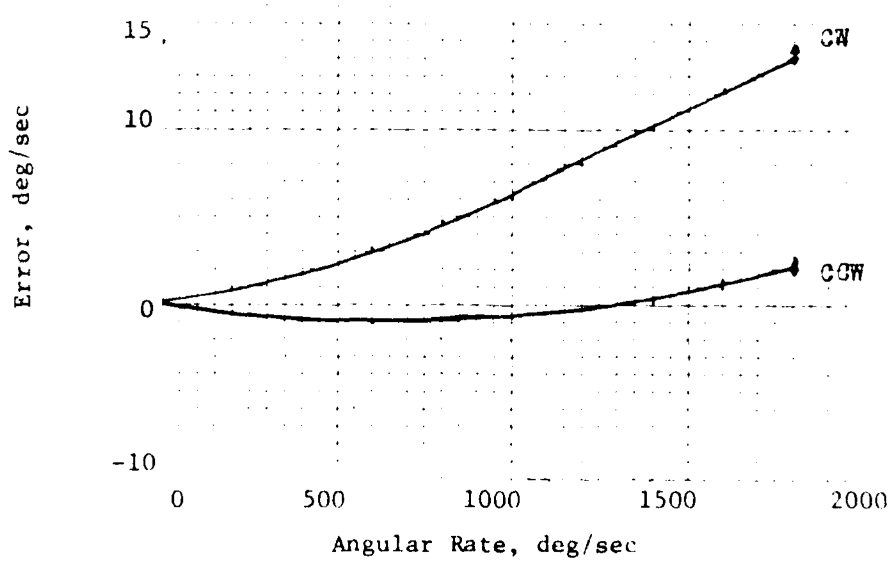


Figure 16 Lateral Velocity Sensitivity of SN381

lateral sensitivity observed in the speed range of 100 to 500 deg/sec was 0.5% of orthogonal angular rate.

The cross-axis sensitivity data are presented in Appendix B.

UNCERTAINTY ESTIMATES

Estimates of experimental uncertainties were formulated using the methods of ISO 5168 (5). The elemental uncertainty estimates of each component in the measuring system are presented in Table 4. The measurement uncertainties of each of the results reported herein are:

Measured Gain

$$U=[U^2(2001) + (2.09\sigma^2(1100-5)]^{\frac{1}{2}} \\ =\pm 2.7\% \tag{4}$$

Phase Lag

$$U=[U^2(2001) + (2.09\sigma)^2]^{\frac{1}{2}} \\ =\pm 0.1^\circ \ \%2.7\% \tag{5}$$

Transport Delay

$$U = \pm 0.2\text{ms} \pm 3\% \\ = \pm 5.8\% \tag{6}$$

Cross-axis Sensitivity

$$U=\pm 0.2\text{mv} \\ \approx\pm 5.5\% \text{ at } 100 \text{ deg/sec} \tag{7}$$

Projected Accuracy of a Three-Axis Angular Rate Sensor

An estimate of the overall accuracy was calculated for three of these sensors combined into a three-axis device operating in general three dimensional rotation. This estimate uses the empirical results of the calibration and cross-axis sensitivity tests substituted into equation 8.

$$U= B(\text{null bias}) + d[U^2(\text{primary}) + \\ U^2(\text{centripetal}) + U^2(\text{lateral})]^{\frac{1}{2}} \tag{8}$$

$$U=\pm 2 \text{ deg/sec} \pm 3.11[3.22\%^2 + 1.2\%^2 + 0.5\%^2]^{\frac{1}{2}} \\ =\pm 2 \text{ deg/sec} \pm 10.8\% \tag{9}$$

TABLE 4 UNCERTAINTY ESTIMATES

Elemental Error Source (Name)	Bias from this Source b_j (ratio)	Quality of Bias--Does it Result from: Measurement(M) Theoretical Calculation(C) Reference Handbook (R) Estimate (E)	Sensitivity Coefficient of this Source θ_j	Number of Observations during Test N	Value of Student's t for (N-1) Degrees of Freedom $t_j = t_{95}(N-1)$	Variance of Observations $s_j^2 = \frac{\sum_{i=1}^{N}(x_i - \bar{x})^2}{N-1}$	Estimate of the (Least) Upper Bound of this Elemental Error $u_j = \theta_j (b_j + t_j \sqrt{s_j^2})$
SM2001	GAIN-0.27%	M	1	20	2.093	.05522%^{2}	±.76%
SM2001	GAIN dB+.176	M	1	20	2.093	.05522%^{2}	+.176dB±0.5%
SM2001	Phase ±.1°	R,	1	20	2.093	1.0%^{2}	±.1° ±2.09%
GENISCO 1100	+3.06%	M	1	20	2.093	1.562%^{2}	±5,67%
RRS #373	±6.25%	M	1	13	2.179	7.836%^{2}	±12.4%
TEK 3B3 Time Base	±3% ±.2DIV	R	1	40	1.95	.134DIV^2	±0.9Div
GENISCO 1100-5	Above 20 Hz Scatter	M	1	10	2.262	11.64%^{2}	±10.77%
TEKTRONIX 3B3 Time Base	±0.2 msec	R	1	30	1.96	±9%^{2}	±0.2 msec ±3.0%

This is the overall accuracy that may be expected from 95% of a very large sample of uncalibrated three-axis rate sensors. The factor, d, is a statistical correction for the fact that this projection is based on a sample size of only 3 units. This estimate is probably conservative because these three sensors had been shot from cannon previously and had been subjected to numerous environmental tests which tend to degrade the accuracy relative to their "new" condition.

Sensor Specifications

A design and performance specification for the three-axis MPES angular rate sensor was developed based on the data analysis of the test results and on interface and performance requirements desired by the Life Support Engineering Division. This specification is given in Appendix C. It is subject to revision as the MPES requirements become better defined by future testing.

CONCLUSIONS

Three Hamilton Standard electrofluidic single axis angular rate sensors were tested to measure their steady speed and dynamic performance. This sensor design is a strong candidate for use in ejection seat steering control primarily because of its short "readytime", sufficient accuracy, apparently adequate dynamic response, and compatible electrical input/electronic output interface.

Dynamic Performance

The major characteristic time response of these sensors is a transport delay of 4.95 msec ±1.0 msec, which is to say that a change in the seat angular rate is not transmitted until 4.95 milliseconds later. The gain of the sensors is nearly unity.

The second important time consideration bearing on the application of this sensor to an ejection seat is its "readytime", the elapsed time between the application of power to the sensor and the delivery of an adequate signal. The "readytime" data were reported (1) for each of the three sensors throughout the expected range of roll rates. The mean "readytime" was 45 ±14 milliseconds.

Cross-Axis Sensitivity

This measure of error in a three-axis configuration of these sensors is ±1.2% of the orthogonal angular rate in the centripetal orientation and ±0.5% in the lateral velocity orientation.

RECOMMENDATIONS

It is recommended that further research be conducted to develop a three-axis angular rate sensor based on fluidic or fluid dynamic principles. Several such sensors should be fabricated to achieve the performance goals outlined in Appendix C. These would be delivered to NADC for test and evaluation of their suitability for use in the maximum performance ejection system. The test program would include laboratory calibration, dynamic performance tests, ejection seat tower tests, sled tests, and appropriate MIL-STD-810C environmental tests.

REFERENCES

1. "Performance Verification of the "Superjet" Laminar Angular Rate Sensor," Curry, B. W., Rp. NADC-80081-60, May 1980.

2. "Experimental Statistics", National Bureau of Standards Handbook 91, Natrella, M. G., 1963, USGPO, Washington, DC.

3. "Methods of Presenting Basic Performance Data for Fluidic Devices, American National Standard, ANSI B93.14-1971, reaffirmed 1979.

4. NADC Technical Memorandum No. ACSTD-TM-2066, "Transport Delay Test Method for Angular Rate Sensors"; Keyser, D. and Dietz, P.; 18 February 1981.

5. International Standard 5168: "Measurement of Fluid Flow-Estimation of Uncertainty of a Flow-Rate Measurement", 1978.

APPENDIX A

DYNAMIC PERFORMANCE DATA

LABORATORY TEST SHEET
4ND-NADC-3960/45 (3-71)

LABORATORY ADVANCED CONCEPTS 60134

TEST OF HAMILTON STANDARD RATE SENSOR 9304100-099 SN 0100355

TEST ENGINEER McGIBONEY/KEYSER

OBSERVERS ZERO RATE FREQ. RESP

DATE 21 OCT 1980

TEST EQUIPMENT GENISCO 1100-5 S/N 2014, EMI SM2001A S/N 5003, ~~HP [illegible]~~ POWER SUPPLY ~~BATTERY~~ TEKTRONIX PS503A

FREQ. Hz	MEAS. OUTPUT AMPLIT mV	GAIN RATIO OR ABS. POS	# ∫ CYCLES	GAIN RATIO MEAS	GAIN MEAS dB	PHASE ANGLE °	RATE TABLE PHASE °	SN355 PHASE ∠ °	MEAS G / SS GAIN (6.23)	10^{-3} GEN GAIN
.0728	60.	R1	10	.607	-4.3	-3.2	-.80	-2.4	.974	1.08
1.78	60.	R1	10	.567	-4.8	-12.4	-6.275	-6.125	.910	1.06
4.54				.515	-5.7	-16.2	-3.825	-12.38	.827	1.15
6.79				.514	-5.7	-18.5	-1.10	-17.4	.825	1.09
8.65				.536	-5.3 ~~-21.6~~	-21.6	-1.10	-20.5	.860	1.09
10.4				.549	-5.1	-25.6	-2.275	-23.33	.881	1.09
11.8				.569	-4.8	-29.3	-3.625	-25.68	.913	1.04
13.3				.593	-4.5	-33.9	-5.45	-28.45	.952	1.05
? 14.3				.612	-4.2	-37.2	-7.20	-30.0	.982	1.04
16.9				.651	-3.6	-45.4	-11.425	-33.98	1.045	1.01
20.4				.740	-2.5	-57.7	-18.875	-38.83	1.188	.99
23.5				.856	-1.3	-73.4	-28.475	-44.93	1.374	.94
27.2				1.009	+0.2	-82.8	-45.375	-37.43	1.620	.95
30.6	60	R2	10	1.19	+1.5	-120.8	-65.80	-55.0	1.910	.91
30.6			100	1.14	+1.2	-122.1	65.80	-56.3	1.830	
30.6				1.15	+1.3	-120.5	-65.80	-54.7	1.862 1.846	
34.4				1.10	+.9	-153.8	-93.97	-59.83	1.765	.83
? 37.5				.90	-.9	-179.1	-115.3	-63.8		
~~37.5~~ ~~41.0~~	~~40~~	~~R2~~	~~100~~	~~.84~~ ~~.80~~	~~-.15~~	~~-179.3~~	-115.3	-64.0		
41.0	40			.60	-4.4	-199.3	-130.95	-68.35		
44.0	"			.60	-4.4	-212.7	-138.48	-74.2		
48	"			.41	-7.8	-226.0	-146.92	-79.1		

PLATE NO. 20894

Table Al-Frequency Response Data

LABORATORY TEST SHEET
4ND-NADC-3960/45 (3-71)

LABORATORY: ADVANCED CONCEPTS 60134

TEST OF: HAMILTON STANDARD RATE SENSOR 9304100-099 SN 373

TEST ENGINEER: KEYSER

OBSERVERS: ZERO RATE FREQUENCY RESP

DATE: 23 SEP 80

TEST EQUIPMENT: GENISCO 1100-5 S/N 2014, EMI SN 2001A S/N 5003, HP ±15V Power Supply 8A1842 8A1343, DVM

FREQ. Hz	MEAS. OUTPUT AMPLIT mV	GAIN RATIO OR ABS. POS	# ∫ CYCLES	GAIN RATIO MEAS (P)	GAIN MEAS dB	PHASE ANGLE °	FACTOR TRUE PHASE °	MEAS G / SS GAIN (mean)	FACTOR GAIN / TABLE GAIN
0.1	60.	R1	1	.599	-4.4	-4.5	(mean)		
0.1				.594	-4.5	-4.0		.9490	
0.1	60	R1	1	.592	-4.5	-3.7	-3.14		
0.412	60	R1	10	.599	-4.4	-5.7			
0.412				.604	-4.3	-6.0	-3.35	.9593	.9563
0.824				.592	-4.5	-8.2			
0.824				.588	-4.5	-8.6	-4.05	.9410	.9746
1.65				.546	-5.2	-12.7			
1.65				.553	-5.1	-12.4	-6.20	.8604	.9722
3.30	60	R1	100	.515	-5.7	-15.7			
3.30				.518	-5.6	-15.5	-9.80	.8238	.9979
6.60				.490	-6.1	-19.4			
6.60				.485	-6.2	-19.0	-17.6	.7775	1.020
13.2				.542	-5.2	-36.0			
13.2				.545	-5.2	-35.0	-29.4	.8668	.9756
15.8				.564	-4.9	-43.5	-33.6	.9000	.9197
19.0				.629	-4.0	-54.9	-39.6	1.0032	.9303
22.8				.718	-2.8	-68.6	-43.15	1.1451	.8795
27.4				.887	-1.0	-88.6	-43.08	1.405	.8651
27.4				.875	-1.1	-86.9			
32.8				1.034	+0.4	-139.0	-63.25		.8903
32.8				1.012	+0.2	-148		1.632	
39.4				.709	-2.9	194.2	-71.8		

PLATE NO. 20894

Table A1-Frequency Response Data

.903

LABORATORY TEST SHEET
4ND-NADC-3960/45 (3-71)

LABORATORY ADVANCED CONCEPTS 60134

TEST OF HAMILTON STANDARD RATE SENSOR 9304100-099 SN 373

TEST ENGINEER KEYSER

OBSERVERS ZERO RATE FREQ RESPONSE

DATE 23 SEP 80

TEST EQUIPMENT GENISCO 1100-5 S/N 2014, EMI SM2001A S/N 5003, HP ±15V POWER SUPPLY 8A1342 8A1343, DVM

FREQ. Hz	MEAS. OUTPUT AMPLIT mV	GAIN RATIO OR ABS. POS	# ∫ CYCLES	GAIN RATIO MEAS	GAIN MEAS dB	PHASE ANGLE °	FACTOR TRUE PHASE °	$\frac{\text{MEAS G}}{\text{SS GAIN}}$	$\frac{\text{FACTOR GAIN}}{\text{TABLE GAIN}}$
39.4	60	R1	100	.676	-3.3	-196.5		1.104	.8364
43.0				.494	-6.1	-215.	-80.0	.7879	.7602
37				.802	-1.8	-180.2			
37				.869	-1.1	-178.7			
37				.759	-2.3	-183.7		1.279	.8251
37.				.778	-2.1	-181.8	-60.4		
35				.953	-.30	-161.	(@ 36Hz)		
35				.896	-0.9	-166.8		1.446	.8034
35				.871		-169.0			
33.0				1.027	+0.3	-191.2			
↑ RANGE for 10 readings ↓				.992	0	-143.5		1.559	.8427
33.0				.928	-0.6	-152.4			
27.4				.884	-1.0	-96.6		1.410	
26.0				.794	-1.9	-86.6			
26.4				.827	-1.6	-89.1			

(.00627 $\frac{V\,SEC}{°}$ $\dot{\theta}$ $\frac{°}{SEC}$ × $\frac{1}{60\,mV}$

PLATE NO. 20894

Table A1-Frequency Response Data

LABORATORY TEST SHEET
4ND-NADC-3960/45 (3-71)

LABORATORY: ADVANCED CONCEPTS 60134

TEST OF: HAMILTON STANDARD RATE SENSOR 9304100-099 SN 381

TEST ENGINEER: McGIBONEY

OBSERVERS: FREQ RESPONSE

DATE: 28 OCT, 1980

TEST EQUIPMENT: GENISCO 1100-5 S/N 2014, EMI SM2001A S/N 5003, HP ±15V POWER SUPPLY 8A1342 8A1343, DVM

FREQ. Hz	MEAS. OUTPUT AMPLIT mV	GAIN RATIO OR ABS. POS	#∫ CYCLES	GAIN RATIO MEAS	GAIN MEAS dB	PHASE ANGLE °					
.10	2000	R3	1	.610		-2.0					
				.603		-1.8					
				.611		-.8					
.15	2000	R3	1	.610		-.8					
				.612	-4.2	-1.0					
				.611	-4.2	-1.0					
.25	2000	R3	10	.609	-4.2	-2.0					
.50				.606	-4.3	-1.9					
.75				.607	-4.3	-3.0					
1.00				.606	-4.3	-3.7					
1.50				.609	-4.2	-5.1					
2.00	1500			.609	-4.2	-6.7			-.7		
3.00	1200			.610	-4.2	-10.0			-5.0		
4.30	900			.612	-4.2	-14.2			-11.2		
6.10	720			.610	-4.2	-21.0			-20.0		
8.50	400			.608	-4.3	-28.4			-27.4		
12.00	290			.593	-4.5	-418			-37.8		
18.00	200	R4	100	.60	-4.4	-60.7			-46.7		
23.00	140			.70	-3.0	-74.4			-48.4		
~~30.00~~	~~50~~			1							
29.00	70			1.17	+1.4	-118.9			-28.9		
34.00	70			1.00	+.1	-169.5			-66.5		

PLATE NO. 20894

Table A1-Frequency Response Data

LABORATORY TEST SHEET
4ND-NADC-3960/45 (3-71)

LABORATORY
ADVANCED CONCEPTS 60134

TEST OF
HAMILTON STANDARD RATE SENSOR 9304100-099 SN 381

TEST ENGINEER
MCGIBONEY

OBSERVERS
FREQ. RESP

DATE
28 OCT, 1980

TEST EQUIPMENT
GENISCO 1100-5 S/N 2014, EMI SM2001A S/N 5003, HP±15V POWER SUPPLY 8A1842 8A1343, DVM

FREQ. Hz	MEAS. OUTPUT AMPLIT mV	GAIN RATIO OR ABS. POS	# ∫ CYCLES	GAIN RATIO MEAS	GAIN MEAS dB	PHASE ANGLE °					
.1	400	R3	1	.597	-4.4	-1.6					
				.597	-4.4	-1.6					
.2	400	R3	1	.594	-4.5	-1.8					
				.597	-4.4	-1.4					
				.598	-4.4	-1.9					
.4	400	R3	10	.595	-4.4	-2.6					
				.593	-4.5	-2.7					
.7		R3	10	.593	-4.5	-3.5					
				.593	-4.5	-3.5					
1.0				.594	-4.4	-4.7					
				.595	-4.4	-4.4					
1.5				.592	-4.5	-6.3					
				.593	-4.5	-6.1					
2.0				.598	-4.4	-7.8					
				.596	-4.4	-7.8					
3.0				.595	-4.4	-11.5					
				.596	-4.4	-11.0					
5.0				.598	-4.4	-17.5					
				.599	-4.4	-17.8					
9.0				.607	-4.3	-30.6					
				.608	-4.2	-30.6					
13.0			100	.635	-3.9	-44.2					
				.630	-3.9	-44.0					

PLATE NO. 20894

Table A1-Frequency Response Data

LABORATORY TEST SHEET | LABORATORY ADVANCED CONCEPTS 60134 | Pge 1 OF 3

AND-GEN-1128

TEST OF: HAMILTON STANDARD RATE SENSOR 9304100-099 SN 381

TEST ENGINEER: McGIBONEY

OBSERVERS: FREQ RESP, 18-35 Hz

DATE: 29 OCT, 1980

TEST EQUIPMENT:

FREQ	AMPL. mV	GAIN POSITION	#∫ CYCLES	GAIN RATIO RDNG	GAIN dB	φ, °			MEAN φ, °	GENISCO φ, °	φ DIFF
18	95	R2	100	.66		-50.6			-50.9	-13.5	-37.3
				.67	-3.4	-51.7					-37.3
				.67	-3.5	-50.2					
				.66	-3.5	-50.8					
19	90	R2	100	.69	-3.2	-54.4			-53.8	-16	-37.8
				.68	-3.3	-54.4					-37.8
				.69	-3.2	-54.4					
				.69	-3.2	-52.1					
20	90	R2	100	.72	-2.8	-56.8			-57.0	-18	-39.0
				.71	-2.9	-56.5					39.0
				.71	-2.9	-57.5					
				.72	-2.9	-57.2					
21	85	R2	100	.75	-2.4	-61.2			-60.8	-21	-39.8
				.75	-2.4	-60.8					-40.4
				.74	-2.5	-60.8					
				.76	-2.3	-60.4					
22	85	R2	100	.77	-2.3	-65.3			-65.3	-23.5	-41.8
				.77	-2.2	-64.6					-42.0
				.78	-2.1	-65.1					
				.78	-2.2	-66.1					
23	85	R2	100	.80	-1.9	-69.1			-69.5	-26	-43.5
				.80	-1.9	-69.1					-43.5
				.80	-1.9	-69.5					

.82 -1.7 -70.4

Table A1-Frequency Response Data

Pg. 2 of 3

LABORATORY TEST SHEET
4ND-GEN-1128

LABORATORY: ADVANCED CONCEPTS 60134

TEST OF: HAMILTON STANDARD RATE SENSOR 9304100-099 SN 381

TEST ENGINEER: MCGIBONEY

OBSERVERS: FREQ RESP, 18-35 HZ

DATE: 29 OCT, 1980

TEST EQUIPMENT

									MEAN ϕ, °		
24	85	R2	100	.83	-1.6	-74.6			-74.9	-30	-44.9
				.84	-1.5	-74.2				-29	-45.9
				.86	-1.3	-76.9					
				.85	-1.4	-74.1					
25	80	R2	100	.87	-1.1	-77.3			-81.1	-32	-49.1
				.88	-1.0	-80.7				-32.5	-48.6
				.91	-.7	-84.8					
				.89	-1.0	-81.7					
26	80	R2	100	.94	-.5	-88.6			-88.0	-42	-46.0
				.93	-.6	-85.1				-36.5	-51.5
				.94	-.5	-89.5					
				.97	-.2	-88.8					
27	80	R2	100	.97	-.2	-92.0			-93.2	-45	-48.2
				.96	-.3	-92.1				-42	-51.2
				.97	-.1	-92.8					
				.97	-.2	-95.9					
28	80	R2	100	1.00	+.1	-101.9			-101.8	-57	-44.8
				1.00	+.1	-99.5				-475	-54.3
				1.02	+.2	-102.0					
				1.02	+.2	-103.9					
29	80	R2	100	1.03	+.3	-110.4			-112.3	-65	-47.3
				1.07	+.7	-114.8				-54.5	-58.8
				1.05	+.5	-112.4					
				1.09	+.8	-111.4					

Table A1-Frequency Response Data

Pg 3 of 3

LABORATORY TEST SHEET
AND-GEN-1128

LABORATORY
ADVANCED CONCEPTS 60134

TEST OF
HAMILTON STANDARD RATE SENSOR 9304100-099 SN 381

TEST ENGINEER
McGIBONEY

OBSERVERS
FREQ RESP, 18-35 Hz

DATE
29 OCT 80

TEST EQUIPMENT

									MEAN φ °		
30	75	R2	100	1.15	+1.3	-116.2			-115.3	-72	-43.3
				1.08	+.8	-116.2				-63	-52.3
				1.14	+1.2	-115.6					
				1.13	+1.1	-113.1					
31	70	R2	100	1.16	+1.4	-128.3			-127.8	-80	-47.8
				1.14	+1.2	-133.9				-69.5	58.3
				1.18	+1.5	-126.6					
				1.20	+1.6	-122.5					
32	70	R2	100	1.16	+1.3	-141.1			-141.9	-82	-59.9
				1.18	+1.5	-143.5				-77.5	64.4
				1.12	+1.0	-144.4					
				1.19	+1.5	-138.8					
33	70	R2	100	1.17	+1.5	-145.3			-147.3	-93	-54.3
				1.16	+1.4	-145.3				-85	62.3
				1.15	+1.3	-149.6					
				1.14	+1.2	-148.9					
34	70	R2	100	1.09	+.8	-161.3			-159.9	-103	-56.9
				.98	-.1	-166.2				-93	-66.9
				1.09	+.8	-158.3					
				1.12	+1.0	-153.8					
35	60	R2	100	.88	-1.1	-175.8			-170.5	-110	-60.5
				.88	-1.0	-171.9				-107	67.5
				1.07	+.7	-164.1					
				.97	-.3	-171.1					
				1.00	+.1	-169.8					

Table A1-Frequency Response Data

LABORATORY TEST SHEET
4ND-GEN-1128

LABORATORY
ADVANCED CONCEPTS 60134

TEST OF
HAMILTON STANDARD RATE SENSOR 9304100-099 SN 381

TEST ENGINEER
McGIBONEY

OBSERVERS

DATE
1 DEC 80

TEST EQUIPMENT

FREQ HZ.	MEAS. AMPL. mV	GAIN SETTING	# ∫ CYCLES	GAIN RATIO	GAIN dB	Φ_0	$(\Phi_3-\Phi_6)$ $=\Phi_5$				
.5	1000	R4	10	.54	-5.3	-4.1	-3.9				
1.0	1000	R4	10	.53	-5.5	-3.1	-2.7				
1.5	1000	R4	10	.54	-5.3	-5.7	-3.5				
2.0	1000	R4	10	.54	-5.3	-5.7	-4.6				
3.0	1000	R4	10	.56	-5.0	-9.2	-6.7				
4.0	1000		10	.57	-4.8	-12.0	-8.7				
~~5.0~~	~~700~~	~~R4~~	~~100~~	~~.53~~	~~-5.4~~	~~-9.1~~					
5.0	700	R4	100	.55	-5.2	-16.9	-11.8				
6.0	600	R4	100	.57	-4.8	-19.8	-13.8				
7.0	500	R4	100	.59	-4.5 ~~-23.~~	-23.2	-15.7				
8.0	500	R4	100	.61	-4.2	-27.4	-17.5				
9.0	460	R4	100	.60	-4.4	-29.3	-18.9				
10.0	400	R4	100	.60	-4.4	-32.2	-21.4				
~~11.0~~	~~370~~	~~R4~~	~~100~~	~~.58~~	~~-4.7~~	~~-36.6~~					
11.0	300	R4	100	.55	-5.2	-34.9	-22.5				
~~12.00~~	~~250~~	~~R4~~	~~100~~	~~.74~~	~~-2.5~~	~~-38.8~~					
~~13.00~~	~~250~~	~~R4~~	~~100~~	~~.75~~	~~-2.4~~	~~-44.6~~					
14.00	200	R4	100	.50	-6.0	-44.7	-30.0				
				.48	-6.3	-45.3					
16.00	200	R4	100	.52	-5.6	-49.9	-31.4				
19.00	150	R4	100	.58	-4.7	-61.5	-41.3				
22.00	150	R4	100	.64	-3.8	-74.6	-46.7				
25.00	120	R4	100	1.01		-95.8	-61.7				

Table A1-Frequency Response Data

LABORATORY TEST SHEET
4ND-GEN-1128

LABORATORY
ADVANCED CONCEPTS 6013~~4~~

TEST OF
HAMILTON STANDARD RATE SENSOR 9304100-099 S/N 381

TEST ENGINEER
McGIBONEY

OBSERVERS

DATE
1 DEC 80

TEST EQUIPMENT

FREQ Hz.	MEAS. AMPL. mV	GAIN SETTING	$\#\int$ CYCLES	GAIN RATIO	GAIN dB	Φ_o	$(\Phi_T - \Phi_C) = \Phi_s$
27	90	R4	100	1.0	0	-110.9	-69.6
28	80	R4	100	1.2	+1.4	-110.2	-60.2
~~29~~	~~75~~	~~R4~~	~~100~~	~~1.1~~	~~+.7~~	~~-109.4~~	
30	75	R4	100	1.3	+23	-120.3	-55.1
32	70	R4	100	1.4	+2.7	-143.3	-69.6

Table A1-Frequency Response Data

.1.3

LABORATORY TEST SHEET
AND-GEN-1128

LABORATORY
ADVANCED CONCEPTS 60134

TEST OF
HAMILTON STANDARD RATE SENSOR # 9304100 -099 S/N 381

TEST ENGINEER
McGIBONEY

OBSERVERS

DATE
DEC 1, 1980

TEST EQUIPMENT

FREQ Hz	MEAS. OUTPUT AMPL mV	GAIN SETTING	# ∫ CYCLES	GAIN RATIO	GAIN dB	ϕ_0	$\overline{\phi_T}$	$\phi_T - \phi_G = \phi_S$	$\overline{\text{GAIN RATIO}}$	$\frac{\overline{\text{GAIN}_S}}{\overline{\text{GAIN}_G}}$	$\cancel{.6375}$
.5	70	R3	10	.59	-4.5	-4.3	-4.2	-.9	.580	.648	1.016
				.57	-4.8	-4.4					
				.58	-4.7	-3.9					
1.0				.59	-4.6	-8.7	-8.26	-3.21	.587	.673	1.056
				.58	-4.8	-7.4					
				.58	-4.7	-8.7					
1.5.				.54	-5.3	-9.4	-8.6	-2.3	.553	.649	1.018
				.55	-5.1	-8.2					
				.57	-4.8	-8.2					
2.0				.61	-4.2	-13.1	-11.6	-6.3	.557	.678	1.064
				.53	-5.5	-10.9					
				.53	-5.5	-10.9					
3.0				.51	-5.7	-14.5	-14.03	-8.0	.510	.670	1.051
				.51	-5.7	-14.0					
				.51	-5.8	-13.6					
4.0			100	.51	-5.8	-14.7	-13.3	-9.05	.513	.693	1.087
				.50	-6.1	-13.8					
				.53	-5.5	-11.4					
5.0				.52	-5.7	-13.8	-14.9	-12.9	.517	.714	1.12
				.51	-5.8	-14.7					
				.52	-5.6	-16.2					

Table A1-Frequency Response Data

993

LABORATORY TEST SHEET
AND-GEN-1128

LABORATORY
ADVANCED CONCEPTS 60134

TEST OF
HAMILTON STANDARD RATE SENSOR #9304100-099 S/N 381

TEST ENGINEER
McGIBONEY

OBSERVERS

DATE
DEC 1, 1980

TEST EQUIPMENT

FREQ Hz	AMPL mV	GAIN RATIO SETTING	# $\int$ CYCLES	GAIN RATIO	GAIN dB	ϕ, °	$\bar{\phi}_T$	$(\phi_T-\phi_G)=\phi_S$, °	$\overline{\text{GAIN RATIO}}$	$\overline{\text{GAINS}}/\overline{\text{GAIN}}_G$	$\overline{\ }$/.6375
6.0	70[illegible]	R3	100	.50	-6.0	-15.0	-16.2	-14.2	.523	.707	1.109
				.55	-5.2	-16.9					
				.52	-5.5	-16.6					
7.0				.53	-5.5	-16.9	-17.5	-15.67	.517	.676	1.060
				.53	-5.5	-18.5					
				.51	-5.8	-17.0					
8.0				.51	-5.8	-18.8	-20.3	-18.3	.513	.651	1.021
				.52	-5.7	-20.9					
				.51	-5.7	-21.1					
9.0				.51	-5.7	-22.2	-22.5	-20.5	.513	.642	1.007
				.52	-5.6	-23.0					
				.51	-5.7	-22.2					
10.0				.52	-5.6	-24.8	-24.6	-22.1	.523	.635	.996
				.52	-5.6	-26.2					
				.53	-5.4	-26.8					
11.0				.53	-5.5	-28.0	-28.9	-25.3	.543	.641	1.005
				.55	-5.0	-29.2					
				.55	-5.1	-29.5					
12.0				.54	-5.3	-32.6	-31.7	-26.75	.550	.628	.985
				.56	-5.0	-30.7					
14.0				.59	-4.5	-36.5	-36.7	-29.1	.575	.623	.977
				.56	-5.0	-36.8					

Table A1-Frequency Response Data

LABORATORY TEST SHEET
4ND-GEN-1128

LABORATORY
ADVANCED CONCEPTS 60134

TEST OF
HAMILTON STANDARD RATE SENSOR # 9304100-099 S/N 381

TEST ENGINEER
MCGIBONEY

OBSERVERS

DATE
DEC 1, 1980

TEST EQUIPMENT

							Φ_T	$(\Phi_T - \Phi_\theta)$ $= \Phi_S$	$\overline{\text{GAIN}}$ RATIO	$\frac{\overline{\text{GAINS}}}{\overline{\text{GAIN}}_\theta}$	
16.0	70	R3	100	.60	-4.4	-42.5	-43.7	-33.1	.605	.624	.979
				.61	-4.2	-44.9					
18.0	-			.63	-3.9	-50.6	-50.3		.635		
				.64	-3.7	-49.9					
20.0				.68	-3.3	-57.4	-57.7	-39.3	.680	.581	.911
				.68	-3.3	-58.0					
22.0				.75	-2.4	-68.5	-67.9	-45.5	.740	.572	.897
				.73	-2.6	-67.4					
24.0				.80	-1.9	-78.9	-78.0	-48.65	.810	.559	.877
				.82	-1.7	-77.2					
26.0				.91	-.7	-87.4	-86.6	-50.0	.895	.556	.872
				.88	-1.0	-85.8					
28.0				.98	-.1	-100.4	-98.8	-49.8	.975	.551	.864
				.97	-.3	-97.3					
30.0				1.07	+.7	-119.1	+116.8	-54.0	1.065	.589	.923
				1.06	+.5	-114.5					
32.0				1.09	+.8	-153.5	-148.6	-74.9	1.033	.607	.952
				1.03	+.3	-147.0					
				.98	-.1	-145.4					

Table A1-Frequency Response Data

LABORATORY TEST SHEET
4ND-NADC-3960/45 (3-71)

LABORATORY
ADVANCED CONCEPTS 60134

TEST OF
HAMILTON STANDARD RATE SENSOR 9304100-099 SN355

TEST ENGINEER
KEYSER

OBSERVERS
TRANSPORT DELAY TIME 23 OCT, 1980

TEST EQUIPMENT
GENISCO 1100-5 S/N 2014, ~~[illegible]~~ TEKTRONIX 383 SCOPE SN5927 ~~H.P. POWER SUPPLY ±15 8A1343, 8A1342~~

SPEED CHANGE	SCOPE TIME DIV	SCALE 'X' TABLE	SCALE 'X' RRS	ΔX	SCALE 'X' TABLE	SCALE 'X' RRS	ΔX̄
UP	1mS	2.7	6.8	4.1			
UP		1.2	5.1	3.9			
UP		2.4	6.8	4.4			
UP		1.3	5.6	4.3			
UP		3.0	7.3	4.3			
DN		0.8	5.0	4.2			
UP		3.5	7.8	4.3			
DN		1.9	6.3	4.4			
UP		0.0	4.5	4.5			
DN		6.4	10.0	3.6			
DN		3.5	8.0	4.5			
DN		2.6	6.8	4.2			
DN		3.5	8.0	4.5			
UP		0.1	4.3	4.2			
UP		1.6	6.2	4.6			
UP		5.0	9.6	4.6			
DN		1.0	4.8	3.8			
UP		4.4	8.6	4.2			
UP		4.9	9.2	4.3			
DN		1.5	6.6	4.1			
DN		5.2	9.6	4.4			
DN		1.8	6.6	4.8			

300-400 (beside row 1 in margin)

400-300 (beside DN row 6 in margin)

300-312 TT SIGNAL

Δ TT TACH SPEED
2.8 DIVISIONS
300°-400°/sec
(2 V/DIV)

Δ SENSOR SIGNAL
3.2 DIVISIONS
300-400°/sec
(.2V/DIV)

$\overline{\Delta X}$ = 4.283

$\bar{\sigma}$ = .2754 (n-1)

σ = .269 (n)

V = .0724

transport delay = 4.283 ±.55 msec
95% conf
±13%

n = 22

PLATE NO. 20894

Table A2-Transport Delay Data

LABORATORY TEST SHEET
4ND-NADC-3960/45 (3-71)

LABORATORY
ADVANCED CONCEPTS 60134

TEST OF
HAMILTON STANDARD RATE SENSOR 9304100-099 SN 373

TEST ENGINEER
KEYSER

OBSERVERS
TRANSPORT DELAY TIME OCT. 1980

TEST EQUIPMENT
GENISCO 1100-5 S/N 2014, ~~[illegible]~~ TEKTRONIX SCOPE 383 SN5927 ±15 H.P. POWER SUPPLY BA1342, BA1343

	SCOPE TIME / DIV	SCALE 'X' TABLE	SCALE 'X' RRS	ΔX	SCALE 'X' TABLE	SCALE 'X' RRS	ΔX
1	1ms	3.6	8.5	4.9			
2		1.5	6.0	4.5			
3		3.8	7.4	3.6			
4		1.2	5.8	4.6			
5		4.6	8.5	3.9			
6		5.0	9.3	4.3			
7		4.8	9.1	4.3			
8		0.7	5.8	5.1			
9		1.5	6.1	4.6			
10		4.3	8.5	4.2			
11		3.6	8.0	4.4			
12		4.5	8.7	4.2			
13		2.2	6.8	4.6			
14		3.8	8.2	4.4			
15		1.7	7.0	5.3			
16		3.5	9.0	5.5			
17		1.4	6.5	5.1			
18		1.2	6.7	5.5			
19		3.4	9.5	6.1			
20		2.8	9.0	6.2			
21		3.6	9.8	5.2			
22		3.7	8.9	5.2			
23		1.5	7.2	5.7		n =	1.96

TACH SIGNAL
1.8 DIVISIONS
0-400°/SEC
5 VOLTS/DIV

SENSOR SIGNAL
5 DIVISIONS
0-400 °/SEC
1 VOLT/DIV.

$\overline{\Delta X}$ = 5.13 mSEC
σ = .802
V = .643

TRANSPORT DELAY = 5.13 ± 1.57 mSEC

PLATE NO. 20894

Table A2-Transport Delay Data

LABORATORY TEST SHEET
4ND-NADC-3960/45 (3-71)

LABORATORY
ADVANCED CONCEPTS 60134

TEST OF
HAMILTON STANDARD RATE SENSOR 9304100-099 SN 373

TEST ENGINEER
KEYSER

OBSERVERS
TRANSPORT DELAY TIME OCT. 1980

TEST EQUIPMENT
GENISCO 1100-5 S/N 2014, ~~EAI~~ TEKTRONIX SCOPE 383 SN 5927 H.P. POWER SUPPLY ±15 BA1342, BA1343

	SCOPE TIME/DIV	SCALE 'X' TABLE	SCALE 'X' RRS	ΔX	SCALE 'X' TABLE	SCALE 'X' RRS	ΔX				
24	1 ms	0.0	6.1	6.1							
25	↓	2.3	8.2	5.9							
26		1.5	7.3	5.8							
27		2.1	8.4	6.3							
28		0.8	6.5	5.7							
29		2.9	9.5	6.6							
30		1.4	7.4	6.0							

PLATE NO. 20894

Table A2-Transport Delay Data

LABORATORY TEST SHEET
4ND-NADC-3960/45 (3-71)

LABORATORY
ADVANCED CONCEPTS 60134

TEST OF
HAMILTON STANDARD RATE SENSOR 9304100-099 SN 381

TEST ENGINEER
KEYSER

OBSERVERS
TRANSPORT DELAY TIME 24OCT, 1980

TEST EQUIPMENT
GENISCO 1100-5 S/N 2014, TEKTRONIX SCOPE 383 SN5927 H.P. POWER SUPPLY ±15 BA1342, BA1343

0- 300°/sec

	SCOPE TIME / DIV	SCALE 'X' TABLE	SCALE 'X' RRS	ΔX	SCALE 'X' TABLE	SCALE 'X' RRS	ΔX
UP	1ms	1.6	7.6	5.0			
UP		1.4	6.2	4.8			
DN		2.0	7.0	5.0			
DN		4.5	9.2	4.7			
UP		3.5	8.8	5.3			
DN		4.0	8.8	4.8			
UP		3.0	9.0	6.0			
DN		1.5	6.0	4.5			
UP		2.0	8.0	6.0			
DN		.5	6.0	5.5			
UP		3.0	8.5	5.5			
DN		0.0	5.5	5.5			
DN		0.0	5.0	5.0			
UP		2.0	8.0	6.0			
DN		0.0	5.0	5.0			
DN		2.0	7.5	5.5			
UP		3.5	9.0	5.5			
UP		3.0	9.5	6.5			
UP		2.0	7.5	5.5			
DN		0.0	6.0	6.0			
DN		0.0	6.0	6.0			

TACH SIGNAL
4 DIVISIONS
0 - 300°/sec
5V/DIV

SENSOR SIGNAL
3.6 DIVISIONS
0- 300°/sec
0.5V/DIV

$\overline{\Delta X}$ = 5.35, 5.33
σ = .4797, .467
σ = .517, .504
v = .2186

transport delay = 5.34 ± .95 msec

n= 20

PLATE NO. 20894

Table A2-Transport Delay Data

APPENDIX B

CROSS-AXIS SENSITIVITY DATA

CCW

LABORATORY TEST SHEET
4ND-NADC-3960/45 (3-71)

LABORATORY
ADVANCED CONCEPTS

TEST OF
JET CENTRIFUGAL CROSS EFFECT

TEST ENGINEER
PHIL DIETZ

OBSERVERS
SN 1 - 373 SN 2 - 381

DATE
1-21-81

TEST EQUIPMENT
GENISCO 1101-5 SN 2014 / TECHTRONIX PS 503 A / FLUKE 8600A SN 97146

SENSOR 1						SENSOR 2					
RATE OF ROTATION °/SEC	INDUCED ACCELER Ft/SEC²	SIGNAL mV	SIGNAL AT REST mV	IMPLIED ROLL RATE °/SEC	CROSS AXIS EFFECT %	RATE OF ROTATION °/SEC	INDUCED ACCELER Ft/SEC²	SIGNAL mV	SIGNAL AT REST	IMPLIED ROLL RATE °/SEC	CROSS AXIS EFFECT %
100	1.78	-4.9	2.2	0.99	0.99	100	1.78	3.0	1.3	-0.28	0.28
200	7.10	-11.6	2.5	2.3	1.1	200	7.10	4.1	1.0	-0.50	0.25
300	16.0	-18.8	2.6	3.5	1.2	300	16.0	5.0	0.9	-0.67	0.22
400	284	-25.9	2.6	4.6	1.2	400	28.4	5.3	0.9	-0.72	0.18
500	44.0	-32.3	2.8	5.7	1.1	500	44.0	4.8	0.7	-0.67	0.13
600	63.9	-38	3.0	6.7	1.1	600	63.9	4.5	0.4	-0.67	0.11
700	87.0	-44	3.0	7.6	1.1	700	87.0	4.1	0.4	-0.60	0.09
800	114	-49	2.9	8 5	1.1	800	114	3.7	0.5	-0.40	0.05
900	144	-55	3.0	9.4	1.0	900	144	2.6	0.4	-0.36	0.04
1000	178	-59	2.7	10.1	1.0	1000	178	1.3	0.3	-0.16	0.02
1100	215	-64	2.8	10.9	0.99	1100	215	0.1	0.4	0.05	0 00
1200	256	-65	2.6	11.1	0.92	1200	256	-2.3	0.3	0.42	0.04
1300	300	-66	2.7	11.2	0.86	1300	300	-4.1	0.3	0.72	0.06
1400	348	-69	2.6	11.7	0.84	1400	348	-6.4	0.3	1.1	0.08
1500	400	-72	2.3	12.2	0.81	1500	400	-8.6	0.4	1.5	0.10
1600	455	-76	2.2	12.7	0.79	1600	455	-11.0	0.5	1.9	0.12
1700	513	-79	2.3	13	0.77	1700	513	-13.9	0.4	2.3	0.14
1800	575	-82	2.0	14	0.76	1800	575	-17.1	0.4	2.8	0.16
1900	641	-86	2.0	14	0.75	1900	641	-20.2	0.6	3.4	0.18
2000	710	-89	2.0	15	0.74	2000	710	-23.9	0.6	4.0	0.20
2100	783	-92	2.0	15	0.73	2100	783	-27	0.7	4.6	0.22
2200	860	-96	1.5	16	0.72	2200	860	-31	1.0	5.2	0.24

PLATE NO. 20894

Table B1-Centripetal Acceleration Sensitivity Test Data

CW

LABORATORY TEST SHEET
4ND-NADC-3960/45 (3-71)

LABORATORY
ADVANCED CONCEPTS

TEST OF
JET CENTRIFUGAL CROSS EFFECT

TEST ENGINEER
PHIL DIETZ

OBSERVERS
SN 1 - 373 SN 2 - 381

DATE
1-22-81

TEST EQUIPMENT
GENISCO 1101-5 SN 2014 / TECHTRONIX PS 503 A / FLUKE 8600A SN 97146

SENSOR 1						SENSOR 2					
RATE OF ROTATION °/SEC	INDUCED ACCELER Ft/SEC²	SIGNAL mV	SIGNAL AT REST mV	IMPLIED ROLL RATE °/SEC	CROSS AXIS EFFECT %	RATE OF ROTATION °/SEC	INDUCED ACCELER Ft/SEC²	SIGNAL mV	SIGNAL AT REST	IMPLIED ROLL RATE °/SEC	CROSS AXIS EFFECT %
100	1.78	2.6	-4.2	-1.1	1.1	100	1.78	10.7	12.7	0.34	0.34
200	7.10	8.9	-4.3	-2.1	1.1	200	710	7.6	12.0	0.72	0.36
300	16.0	14.0	-4.2	-3.0	0.99	300	16.0	5.9	12.7	1.1	0.37
400	28.4	18.6	-4.1	-3.7	0.92	400	28.4	2.0	12.1	1.6	0.41
500	44.0	23.1	-4.7	-4.5	0.90	500	44.0	-2.6	11.2	2.2	0.45
600	63.9	25.7	-4.4	-4.9	0.82	600	63.9	-6.5	11.3	2.9	0.48
700	87.0	26.9	-4.2	-5.1	0.72	700	87.0	-9.3	12.2	3.5	0.50
800	114	28.3	-4.1	-5.3	0.66	800	114	-14.3	12.0	4.3	0.53
900	144	29.1	-4.1	-5.4	0.60	900	144	-18.4	12.5	5.0	0.56
1000	178	29.5	-4.1	-5.5	0.55	1000	178	-24.2	12.3	5.9	0.59
1100	215	28.9	-4.1	-5.4	0.49	1100	215	-30	12.1	6.8	0.62
1200	256	29.0	-4.2	-5.4	0.45	1200	256	-38	11.8	8.1	0.63
1300	300	28.4	-4.6	-5.4	0.41	1300	300	-45	11.2	8.9	0.69
1400	348	25.4	-4.0	-4.8	0.34	1400	348	-50	11.9	10.1	0.72
1500	400	23.3	-4.0	-4.5	0.29	1500	400	-57	12.6	11	0.76
1600	455	22.7	-4.7	-4.5	0.29	1600	455	-67	11.4	13	0.79
1700	513	17.6	-4.0	-3.5	0.21	1700	513	-72	12.7	14	0.81
1800	575	14.5	-4.0	-3.0	0.17	1800	575	-82	12.3	15	0.85
1900	641	12	-4.9	-2.7	0.14	1900	641	-94	11.6	17	0.91
2000	710	6	-4.0	-1.6	0.08	2000	710	-100	12.2	18	0.91
2100	783	0	-4.1	-0.67	0.03	2100	783	-111	12.2	20	0.95
2200	860	5	-4.5	-1.5	0.07	2200	860	-125	11.8	22	1.0

PLATE NO. 2089

Table B1-Centripetal Acceleration Sensitivity Test Data

CCW

LABORATORY TEST SHEET
4ND-NADC-3960/45 (3-71)

LABORATORY
ADVANCED CONCEPTS

TEST OF
JET CENTRIFUGAL CROSS EFFECT

TEST ENGINEER
PHIL DIETZ

OBSERVERS
SN 1-373 SN 2-381

DATE
1-22-81

TEST EQUIPMENT
GENISCO 1101-5 SN 2014 / TECHTRONIX PS 503 A / FLUKE 8600A SN 97146

SENSOR 1						SENSOR 2					
RATE OF ROTATION °/SEC	INDUCED ACCELER Ft/SEC²	SIGNAL mV	SIGNAL AT REST mV	IMPLIED ROLL RATE °/SEC	CROSS AXIS EFFECT %	RATE OF ROTATION °/SEC	INDUCED ACCELER Ft/SEC²	SIGNAL mV	SIGNAL AT REST	IMPLIED ROLL RATE °/SEC	CROSS AXIS EFFECT %
100	1.78	-8.7	-1.2	1.2	1.2	100	1.78	5.4	3.7	-0.28	0.28
200	7.10	-15.9	-1.0	2.4	1.2	200	7.10	6.3	3.4	-0.47	0.24
300	16.0	-23.6	-0.8	3.7	1.2	300	16.0	7.7	3.8	-0.63	0.21
400	28.4	-31.2	-1.0	4.9	1.2	400	28.4	7.5	2.9	-0.75	0.19
500	44.4	-37.3	-0.3	6.0	1.2	500	44.4	8.5	3.5	-0.81	0.16
600	63.9	-44	-0.7	7.0	1.2	600	63.9	7 4	2.6	-0.78	0.13
700	87.0	-49	-0.5	7.8	1.1	700	87.0	6.8	2.2	-0.75	0.11
800	114	-54	-0.2	8.8	1.1	800	114	7.0	3.2	-0.60	0.08
900	144	-60	-0.6	9.6	1.1	900	144	6.1	2.9	-0.52	0.06
1000	178	-65	-0.5	10.4	1.0	1000	178	4.5	2.8	-0.28	0.03
1100	215	-69	-0.8	11	0.99	1100	215	2.7	2.6	-0.02	0.00
1200	256	-69	-0.5	11	0.92	1200	256	1.4	2.7	0.21	0.02
1300	300	-70	-0.7	11	0.86	1300	300	-0.5	2.8	0.54	0.04
1400	348	-73	-0.3	12	0.85	1400	348	-3.2	2.1	0.86	0.06
1500	400	-76	-0.3	12	0.82	1500	400	-5.1	3.0	1.3	0.09
1600	455	-80	-0.4	13	0.81	1600	455	-8.3	2.3	1.7	0.11
1700	513	-84	-0.3	14	0.80	1700	513	-11.0	1.8	2.1	0.12
1800	575	-87	-0.3	14	0.79	1800	575	-14.0	1.9	2.6	0.14
1900	641	-89	-0.3	15	0.76	1900	641	-17	2.7	3.3	0.17
2000	710	-92	-0.5	15	0.75	2000	710	-21	2.5	3.9	0.20
2100	783	-95	-0.1	16	0.74	2100	783	-24	2.5	4.4	0.21
2200	860	-99	-0.2	16	0.73	2200	860	-27	2.3	4.7	0.21

PLATE NO. 20894

Table B1-Centripetal Acceleration Sensitivity Test Data

LABORATORY TEST SHEET
4ND-NADC-3960/45 (3-71)

LABORATORY ADVANCED CONCEPTS

TEST OF JET CENTRIFUGAL CROSS EFFECT

TEST ENGINEER KEYSER

OBSERVERS SN 373 SN 381

DATE 1-22-81 & 1-23

TEST EQUIPMENT DATA REDUCTION

Rate of Rotation deg/sec			←CCW—373—CW→				CCW 381 CW			
	Normal Accel. ft/sec²	Normal Accel. "g"	ERROR deg/sec	g Sens. deg/sec·g	ERROR deg/sec	g sens deg/sec·g	ERROR deg/sec		ERROR deg/sec	
100	1.78	.055	1.2	21.8	-1.1	-20.0	-0.26		.36	
200	7.10	.221	2.5	11.31	-2.2	-9.95	-.49		.73	
300	16.0	.497	3.8	7.64	-3.0	-5.03	-.65		1.1	
400	28.4	.882	4.9	5.55	-3.7	-4.19	-.80		1.6	
500	44.0	1.37	6.0	4.38	-4.3	-3.13	-.80		2.2	
600	63.9	1.99	7.2	3.6	-4.8	-2.4	-.81		2.8	
700	87.0	2.70	8.1	3.0	-5.1	-1.88	-.73		3.5	
800	114.	3.54	8.9	2.5	-5.3	-1.49	-.61		4.2	
900	144.	4.48	9.9	2.2	-5.4	-1.20	-.49		5.0	
1000	178.	5.53	10.7	1.93	-5.5	-1.0	-.29		5.9	
1100	215.	6.68	11.2	1.67	-5.4	-.808	-.05		6.8	
1200	256.	7.96	11.2	1.40	-5.4	-.67	+.18		7.8	
1300	300.	9.32	11.4	1.22	-5.2	-.56	+.59		8.9	
1400	348	10.8	12.	1.11	-4.9	-.45	+.88		10.1	
1500	400	12.4	12.	.97	-4.6	-.38	1.3		11.2	
1600	455	14.1	13.	.92	-3.8	-.27	1.7		12.5	
1700	513	15.9	14.	.88	-3.6	-.23	2.2		14.0	
1800	575	17.9	14.	.78	-3.1	-.17	2.7		15.4	
1900	641	19.9	15.	.75	-2.5	-.12	3.3		17.0	
2000	710	22.0	15.	.68	-1.7	-.077	3.9		18.	
2100	783	24.3	16.	.67	-1.0	-.041	4.4		20.	
2200	860	26.7	16.	.66	-0.16	-.005	4.9		22.	

PLATE NO. 20894

Table B1-Centripetal Acceleration Sensitivity Test Data

LABORATORY TEST SHEET
4ND-NADC-3960/45 (3-71)

LABORATORY
ADVANCED CONCEPTS

CW

TEST OF
JET CENTRIFUGAL CROSS EFFECT

TEST ENGINEER
PHIL DIETZ

OBSERVERS
SN 1 - 373 SN 2 - 381

DATE
1-23-81

TEST EQUIPMENT
GENISCO 1101-5 SN 2014 / TECNTRONIX PS 503 A / FLUKE 8600A SN 97146

SENSOR 1						SENSOR 2					
RATE OF ROTATION °/SEC	INDUCED ACCELER Ft/sec^2	SIGNAL mV	SIGNAL AT REST mV	IMPLIED ROLL RATE °/SEC	CROSS AXIS EFFECT %	RATE OF ROTATION °/SEC	INDUCED ACCELER ft/sec^2	SIGNAL mV	SIGNAL AT REST	IMPLIED ROLL RATE °/SEC	CROSS AXIS EFFECT %
100	1.78	4.3	-2.5	-1.1	1.1	100	1.78	6.5	8.7	.36	0.36
200	7.10	10.7	-2.5	-2.2	1.1	200	7.10	3.8	8.3	.73	0.37
300	16.0	16.1	-2.5	-3.0	1.0	300	16.0	1.0	8.0	-1.1	0.38
400	28.4	20.4	-2.2	-3.7	.93	400	28.4	-1.2	8.9	1.6	0.41
500	44.0	24.3	-2.3	-4.3	.86	500	44.0	-5.1	8.3	2.2	0.44
600	63.9	27.3	-2.2	-4.8	.80	600	63.9	-8.7	8.6	2.8	0.47
700	87.0	29.1	-2.4	-5.1	.73	700	87.0	-13.5	8.0	3.5	0.50
800	114	30.1	-2.2	-5.3	.65	800	114	-17.4	8.6	4.2	0.53
900	144	31.0	-2.1	-5.4	.60	900	144	-22	8.7	5.0	0.56
1000	178	31	-2.5	-5.5	.55	1000	178	-28	8.1	5.9	0.59
1100	215	31	-2.1	-5.4	.45	1100	215	-33	8.9	6.8	0.62
1200	256	31	-2.2	-5.4	.45	1200	256	-40	8.0	7.8	0.65
1300	300	30	-2.4	-5.2	.40	1300	300	-47	7.6	8.9	0.69
1400	348	27.6	-2.0	-4.9	.35	1400	348	-53	8.6	10.1	0.72
1500	400	25.6	-2.1	-4.6	.30	1500	400	-61	8.4	11.2	0.75
1600	455	23.4	-2.1	-3.8	.24	1600	455	-69	8.4	12.5	0.78
1700	513	19.9	-2.1	-3.6	.21	1700	513	-77	8.5	14.0	0.82
1800	575	16.8	-2.3	-3.1	.17	1800	575	-87	7.7	15.4	0.86
1900	641	12.8	-2.3	-2.5	.13	1900	641	-96	8.0	17	0.89
2000	710	8.5	-2.2	-1.7	.09	2000	710	-105	7.8	18	0.92
2100	783	4.0	-2.2	-1.0	.05	2100	783	-115	7.7	20	0.95
2200	860	-1.5	-2.5	-.16	.01	2200	860	-126	7.9	22	0.99

PLATE NO. 20894

Table B1-Centripetal Acceleration Sensitivity Test Data

CCW

LABORATORY TEST SHEET
4ND-NADC-3960/45 (3-71)

LABORATORY
ADVANCED CONCEPTS

TEST OF
JET CENTRIFUGAL CROSS EFFECT

TEST ENGINEER	OBSERVERS	DATE
PHIL DIETZ	SN 1 - 373 SN 2 - 381	1-23-81

TEST EQUIPMENT
GENISCO 1101-5 SN 2014 / TECHTRONIX PS 503 A / FLUKE 8600A SN 97146

SENSOR 1						SENSOR 2					
RATE OF ROTATION °/SEC	INCUCED ACCELER Ft/SEC²	SIGNAL mV	SIGNAL AT REST mV	IMPLIED ROLL RATE °/SEC	CROSS AXIS EFFECT %	RATE OF ROTATION °/SEC	INDUCED ACCELER ft/SEC²	SIGNAL mV	SIGNAL AT REST	IMPLIED ROLL RATE °/SEC	CROSS AXIS EFFECT %
100	1.78	-10.2	-2.6	1.2	1.2	100	1.78	8.8	7.2	-0.26	0.26
200	7.10	-18.0	-2.6	2.5	1.3	200	7.10	9.7	6.7	-0.49	0.24
300	16.0	-25.7	-2.3	3.8	1.3	300	16.0	11.3	7.3	-0.65	0.22
400	28.4	-33	-2.7	4.9	1.2	400	28.4	11.3	6.4	-0.80	0.20
500	44.0	-39	-2.1	6.0	1.2	500	44.0	12.1	7.2	-0.80	0.16
600	63.9	-46	-2.2	7.2	1.2	600	63.9	11.5	6.5	-0.81	0.14
700	87.0	-52	-2.1	8.1	1.2	700	87.0	11.3	6.8	-0.73	0.10
800	114	-57	-1.9	8.9	1.1	800	114	10.8	7.0	-0.61	0.08
900	144	-63	-2.4	9.9	1.1	900	144	9.7	6.7	-0.49	0.05
1000	178	-68	-2.1	10.7	1.1	1000	178	8.4	6.6	-0.29	0.03
1100	215	-71	-2.0	11.2	1.0	1100	215	6.4	6.1	-0.05	0.00
1200	256	-71	-2.3	11.2	0.94	1200	256	4.9	6.0	0.18	0.02
1300	300	-72	-1.8	11.4	0.88	1300	300	3.2	6.8	0.59	0.05
1400	348	-76	-2.0	12	0.86	1400	348	0.5	5.9	0.88	0.06
1500	400	-78	-1.8	12	0.82	1500	400	-1.4	6.7	1.3	0.09
1600	455	-81	-1.9	13	0.80	1600	455	-3.9	6.7	1.7	0.11
1700	513	-85	-1.9	14	0.79	1700	513	-7.4	6.4	2.2	0.13
1800	575	-88	-1.9	14	0.79	1800	575	-10.4	6.4	2.7	0.15
1900	641	-91	-2.0	15	0.76	1900	641	-14	6.3	3.3	0.17
2000	710	-94	-1.9	15	0.75	2000	710	-18	6.2	3.9	0.20
2100	783	-98	-1.9	16	0.74	2100	783	-21	6.1	4.4	0.21
2200	860	-101	-21	16	0.73	2200	860	-24	5.9	4.9	0.22

PLATE NO. 20894

Table B1-Centripetal Acceleration Sensitivity Test Data

LABORATORY TEST SHEET
4ND-NADC-3960/45 (3-71)

LABORATORY
ADVANCED CONCEPTS 60134

TEST OF
JET TRANSLATION CROSS EFFECT - HAM STD. RRS 9304100-099

TEST ENGINEER
PHIL DIETZ

OBSERVERS
SN- 0100355

DATE
1-13-81

TEST EQUIPMENT
GENISCO 1100-5 SN 2014 / TECHTRONIX PS503A / FLUKE 8600A SN 97146

DIRECTION OF ROTATION	RATE °/SEC	SIGNAL mV	REST SIGNAL mV	SIGNAL CHANGE mV	IMPLIED ROLL RATE °/SEC	CROSS AXIS EFFECT %	DIRECTION	SIGNAL mV	Δ SIGNAL mV	ROLL RATE °/sec	CROSS AXIS EFFECT %
CW	200	4.50	0.6	3.9	-.64	0.32	CCW	-3.0	-3.6	.59	0.30
↓	400	9.3	0.7	8.6	-1.42	0.36		-5.2	-5.9	.97	0.24
	600	14.7	0.6	14.1	-2.32	0.39		-6.7	-7.3	1.2	0.19
	800	20.7	0.6	20.1	-3.31	0.41		-7.3	-7.9	1.3	0.16
	1000	27.4	0.6	26.8	-4.41	0.44		-7.2	-7.8	1.3	0.13
	1200	35	0.6	34	-5.6	0.47		-6.0	-6.6	1.1	0.09
	1400	44	0.6	43	-7.1	0.51		-4.2	-4.8	.79	0.07
	1600	53	0.7	52	-8.6	0.54		+1.4	-2.1	.35	0.02
	1800	64	0.8	63	-10	0.56		2.1	1.3	.21	0.01

PLATE NO. 20894 Table B2-Lateral Velocity Sensitivity Test Data

SENSOR A

LABORATORY TEST SHEET
4ND-NADC-3960/45 (3-71)

LABORATORY
ADVANCED CONCEPTS 60134

TEST OF
JET TRANSLATION CROSS EFFECT - HAM. STD. RRS 9304100-099

TEST ENGINEER
PHIL DIETZ

OBSERVERS
SN- 0100355

DATE
1-14-81

TEST EQUIPMENT
GENISCO 1100-5 SN 2014 TECHTRONIX PS503A/FLUKE 8600A SN 97146

DIRECTION OF ROTATION	RATE °/SEC	SIGNAL mV	REST SIGNAL mV	SIGNAL CHANGE mV	IMPLIED ROLL RATE °/SEC	CROSS AXIS EFFECT %	DIRECTION	SIGNAL	Δ SIGNAL	ROLL RATE	CROSS AXIS EFFECT %
CW	200	5.6	1.6	4.0	-.66	0.33	CCW	-1.8	-3.4	.54	0.27
↓	400	10.4	1.8	8.6	-1.4	0.35	↓	-4.2	-6.0	.99	0.25
	600	16.0	1.8	14.2	-2.3	0.38		-5.7	-7.5	1.2	0.20
	800	220	1.8	20.2	-3.3	0.41		-6.5	-8.3	1.4	0.18
	1000	29	2.0	27	-4.4	0.44		-6.0	-8.0	1.3	0.13
	1200	37	1.9	35	-5.8	0.48		-4.9	-6.8	1.1	0.09
	1400	45	2.0	43	-7.1	0.51		-3.2	-5.2	.86	0.06
	1600	55	2.0	53	-8.7	0.54		-0.3	-2.3	.38	0.02
	1800	65	2.2	63	-10.4	0.58		3.4	1.2	-.20	0.01

SSN5012A

PLATE NO. 20994

Table B2-Lateral Velocity Sensitivity Test Data

LABORATORY TEST SHEET
4ND-NADC-3960/45 (3-71)

LABORATORY
ADVANCED CONCEPTS 60134

TEST OF
JET TRANSLATION CROSS EFFECT - HAM. STD. RRS 9304100-099

TEST ENGINEER

OBSERVERS
SN- 0100355

DATE
1-15-81

TEST EQUIPMENT
GENISCO 1100-5 SN 2014 / TECHTRONIX PS503A / FLUKE 8600A SN 97146

DIRECTION OF ROTATION	RATE °/SEC	SIGNAL mV	REST SIGNAL mV	SIGNAL CHANGE mV	IMPLIED ROLL RATE °/SEC	CROSS AXIS EFFECT %	DIRECTION	SIGNAL	Δ SIGNAL	ROLL RATE	
CW	200	5.3	1.2	4.1	-.67	0.34	CCW	-2.4	-3.6	.59	0.30
	400	10.3	1.2	9.1	-1.5	0.38		-4.9	-6.1	1.6	0.25
	600	15.9	1.2	14.7	-2.4	0.40		-6.6	-7.8	1.3	0.22
	800	22.0	1.3	20.7	-3.4	0.43		-7.3	-8.6	1.4	0.18
	1000	29.9	1.2	28.7	-4.7	0.47		-7.2	-8.4	1.4	0.14
	1200	36	1.1	35	-5.8	0.48		-6.4	-7.7	1.3	0.11
	1400	45	1.2	44	-7.2	0.51		-4.6	-4.8	.79	0.06
	1600	55	1.2	54	-8.9	0.57		-1.8	-3.0	.49	0.03
	1800	66	1.1	65	-11	0.61		1.5	.4	-.07	0.00

SENSOR A

PLATE NO. 20894 Table B2-Lateral Velocity Sensitivity Test Data

LABORATORY TEST SHEET
4ND-NADC-3960/45 (3-71)

LABORATORY
ADVANCED CONCEPTS 60134

TEST OF
JET TRANSLATION CROSS EFFECT - HAM. STD. RRS 9304100-099

TEST ENGINEER
PHIL DIETZ

OBSERVERS
SN-0100381

DATE
1-13-81

TEST EQUIPMENT
GENISCO 1100-5 SN 2014/TECHTRONIX PS503A/FLUKE 8600A SN 97146

DIRECTION OF ROTATION	RATE °/SEC	SIGNAL mV	REST SIGNAL mV	SIGNAL CHANGE mV	IMPLIED ROLL RATE °/SEC	CROSS AXIS EFFECT %	DIRECTION	SIGNAL mV	Δ SIGNAL mV	ROLL RATE °/SEC	CROSS AXIS EFFECT %
CW	200	3.7	8.6	-4.9	.80	0.40	CCW	12.2	3.6	-.59	0.30
↓	400	-2.5	8.5	-11.0	1.79	0.45	↓	14.5	6.0	-.98	0.25
	600	-10.0	8.4	-18.4	2.99	0.50		15.5	7.1	-1.2	0.20
	800	-18.8	8.3	-26.6	4.33	0.54		15.0	6.7	-1.1	0.14
	1000	-28.6	8.3	-36.9	6.00	0.60		13.7	5.4	-.89	0.09
	1200	-40	8.4	-48	7.8	0.65		10.9	2.5	-.41	0.03
	1400	-52	8.4	-60	9.8	0.70		7.0	-1.4	.23	0.02
	1600	-66	8.7	-75	12.2	0.76		2.2	-6.5	1.1	0.07
	1800	-80	8.6	-89	14.5	0.81		-3.4	-12.0	2.0	0.11

SENSOR B

PLATE NO. 20894 Table B2-Lateral Velocity Sensitivity Test Data

LABORATORY TEST SHEET
4ND-NADC-3960/45 (3-71)

LABORATORY
ADVANCED CONCEPTS 60134

TEST OF
JET TRANSLATION CROSS EFFECT - HAM. STD. RRS 9304100-099

TEST ENGINEER
PHIL DIETZ

OBSERVERS
SN- 0100381

DATE
1-13-81

TEST EQUIPMENT
GENISCO 1100-5 SN 2014 / TECHTRONIX PS503A / FLUKE 8600A SN 97146

DIRECTION OF ROTATION	RATE °/SEC	SIGNAL mV	REST SIGNAL mV	SIGNAL CHANGE mV	IMPLIED ROLL RATE °/SEC	CROSS AXIS EFFECT %	
CW	100	.4	2.5	-2.1	.34	0.34	
	200	-2.0	2.6	-4.6	.76	0.38	SCALE FACTOR - -6.15 mV/°/sec
	300	-4.8	2.5	-7.3	1.19	0.40	
	400	-7.9	2.6	-10.5	1.71	0.43	
	500	-11.1	2.7	-13.8	2.24	0.45	
	600	-14.7	2.9	-17.6	2.86	0.48	
	700	-18.9	2.7	-21.6	3.51	0.50	
	800	-23.3	2.6	-25.9	4.21	0.53	
	900	-28.2	2.5	-30.7	5.05	0.56	
	1000	-33.2	2.7	-35.9	5.90	0.59	
	1100	-38	2.8	-41	6.7	0.61	
	1200	-44	2.8	-47	7.7	0.64	
	1300	-50	2.9	-53	8.7	0.67	
	1400	-56	3.0	-59	9.7	0.70	
	1500	-62	3.1	-65	10.7	0.71	
	1600	-69	2.9	-72	11.8	0.74	
	1700	-76	3.0	-79	13.0	0.76	
	1800	-83	3.1	-86	14.1	0.78	
	1900	-90	3.0	-93	15.3	0.80	
	2000	-98	3.0	-101	16.6	0.83	
	2100	-107	3.0	-110	18.1	0.86	
	2200	-115	3.1	-118	19.4	0.88	
	2300	-123	3.2	-126	20.7	0.90	

PLATE NO. 20894 Table B2-Lateral Velocity Sensitivity Test Data

LABORATORY TEST SHEET

4ND-NADC-3960/45 (3-71)

LABORATORY
ADVANCED CONCEPTS 60134

TEST OF
JET TRANSLATION CROSS EFFECT - HAM. STD. RRS 9304100-099

TEST ENGINEER
PHIL DIETZ

OBSERVERS
SN- 0100381

DATE
1-14-81

TEST EQUIPMENT
GENISCO 1100-5 SN 2014 / TECHTRONIX PS503A / FLUKE 8600A SN 97146

DIRECTION OF ROTATION	RATE °/SEC	SIGNAL mV	REST SIGNAL mV	SIGNAL CHANGE mV	IMPLIED ROLL RATE °/SEC	CROSS AXIS EFFECT %	DIRECTION	SIGNAL	Δ SIGNAL	ROLL RATE	CROSS AXIS EFFECT %
CW	200	-6.8	-1.1	-5.7	.93	0.47	CCW	2.9	4.0	-.65	0.33
↓	400	-13.2	-1.4	-11.8	1.9	0.48	↓	4.7	6.1	-.99	0.25
	600	-21.2	-1.5	-19.5	3.2	0.53		5.4	6.9	-1.1	0.18
	800	-30.2	-1.5	-28.7	4.67	0.58		5.3	6.8	-1.1	0.14
	1000	-40	-1.5	-38	6.2	0.62		3.7	5.2	-.85	0.09
	1200	-50	-1.6	-48	7.8	0.65		1.1	2.7	-.44	0 07
	1400	-62	-1.5	-60	9.8	0.70		-2.5	-1.0	.16	0.01
	1600	-76	-1.6	-74	12	0.75		-7.4	-5.8	.94	0.06
	1800	-90	-1.4	-88	14	0.78		-13.1	-11.7	1.9	0.11

SENSOR B

PLATE NO. 20894

Table B2-Lateral Velocity Sensitivity Test Data

LABORATORY TEST SHEET
4ND-NADC-3960/45 (3-71)

LABORATORY
ADVANCED CONCEPTS 60134

TEST OF
JET TRANSLATION CROSS EFFECT - HAM. STD. RRS 9304100-099

TEST ENGINEER	OBSERVERS	DATE
	SN- 0100381	1-15-81

TEST EQUIPMENT
GENISCO 1100-5 SN 2014 / TECHTRONIX PS503A / FLUKE 8600A SN 97146

DIRECTION OF ROTATION	RATE °/SEC	SIGNAL mV	REST SIGNAL mV	SIGNAL CHANGE mV	IMPLIED ROLL RATE °/SEC	CROSS AXIS EFFECT %	DIRECTION	SIGNAL	Δ SIGNAL	ROLL RATE	CROSS AXIS EFFECT %
CW	200	5.1	9.8	-4.7	.76	0.38	CCW	13.6	3.8	-.62	0.31
↓	400	-1.3	9.7	-11.0	1.79	0.45	↓	15.7	6.0	-.98	0.25
	600	-8.9	9.7	-18.6	3.02	0.50		16.4	6.7	-1.1	0.18
	800	-17.6	9.7	-27.3	4.44	0.56		16.1	6.4	-1.0	0.13
	1000	-27.7	9.5	-37.2	6.05	0.61		14.3	4.8	-.78	0.09
	1200	-39	9.6	-49	8.0	0.67		11.3	1.7	-.28	0.02
	1400	-51	9.5	-61	9.9	0.71		7.4	-2.1	.34	0.02
	1600	-65	9.6	-75	12	0.75		2.1	-7.4	1.2	0.08
	1800	-79	9.7	-89	14	0.78		-3.5	-13.2	2.1	0.12

SENSOR B

PLATE NO. 20894 Table B2-Lateral Velocity Sensitivity Test Data

APPENDIX C

Preliminary Design and Performance Specification of an Electrofluidic Angular Rate Sensor

The following constitute the desired design criteria and performance of the sensor:

1. Size and Mass

1.1 The unit shall be less than 0.85 Kg (30 oz.)
1.2 Dimensions. The shape of the sensor is not defined. The sensor should fit within these maximum envelope constraints: (looking down at the seat)

Height	11 cm
Width	11 cm
Fore and aft Length	8.5 cm

The mounting holes shall be in the 10 x 10 cm side, so that the sensor can be mounted in the seat as shown in Figure C-1.

2. Electrical Interface

2.1 The voltage supply shall be either 5 vdc or 12 vdc.
2.2 Power consumption shall be minimized.
2.3 Voltage output shall be linear ±2% of rate ±2 deg/sec up to ±400 degrees/sec, at which rate the output signal shall be between ±(2.5 to 5.0 volts).

3. Performance

After delivery the three sensors will be tested at NADC to determine whether or not the following criteria have been met:

3.1 Maximum Rate. The maximum angular rate expected in service is ±500 deg/sec.

3.2 Linearity. The output signal shall be linear within ±2% of rate and ±2 deg/sec between -400 and ±400 deg/sec.

3.3 Bias. The sensor shall indicate less than ±2.5 deg/sec on each axis when zero actual rate is applied regardless of seat velocity and accelerations up to 18 "g".

3.4 Cross-Axis Sensitivity shall be less than 1.5% of angular rate. That is, the rate indicated on either axis perpendicular to the axis of rotation shall be less than 1.5% of the rotating speed.

3.5 Frequency Response

a. The gain shall be constant ±3% in the range of 0 to 10 Hz.
b. The phase lag response shall be less than 1.8 deg/Hz.

3.6 Readytime. The sensor shall indicate the actual rate, ± 5%, within 100 milliseconds after switching in the power supply to it.

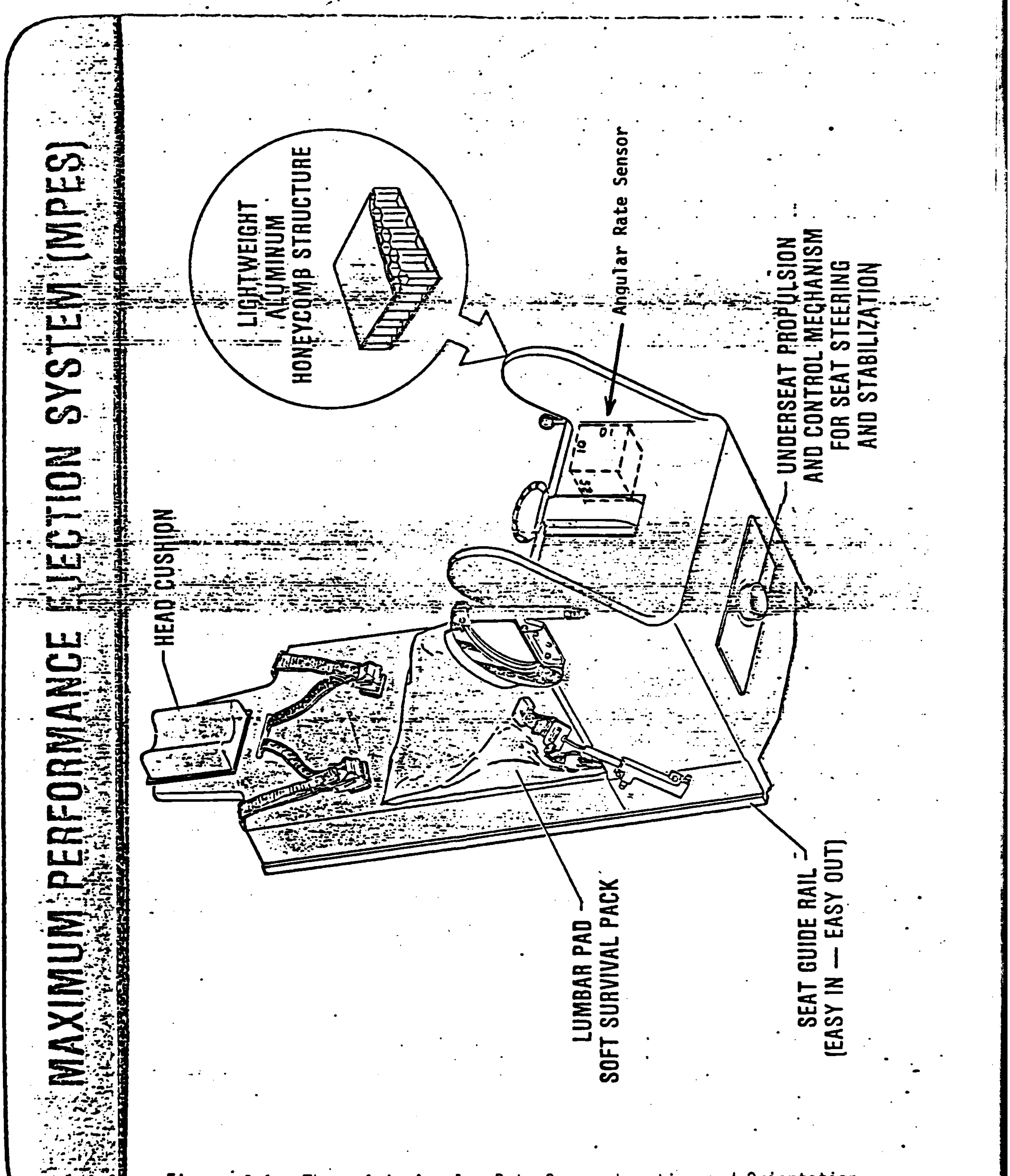


Figure C-1 - Three-Axis Angular Rate Sensor Location and Orientation

4. Environmental Conditions

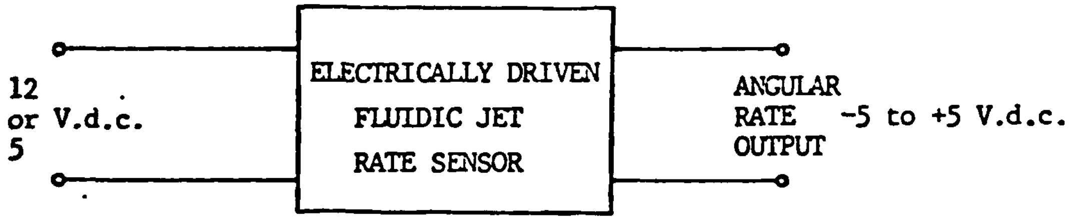
The production model will be subjected to the following tests, decribed in MIL-STD-810C:

500.1
501.1
502.1
507.1
508.1
509.1
510.1
512.1
513.2
514.2
515.2
516.2
518.2

5. Built-in Test Equipment (BITE)

The sensors shall be provided with hardware test points and test procedures to ascertain whether or not the sensor will operate satisfactorily - to provide an "operational check". These test points conveniently can be wired to an external connector on the outside of the seat to facilitate pre-test and post-test checks without removing the sensor from the seat.

6. Sensor Definition



Note: Research conducted by NADC has shown that only a sensor using fluid dynamic principles to measure rotation rate can meet the start-up and operational requirements of this application.

Figure C-2 - Sensor Definition

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PLATE NO. 20894

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