NASA CR-130143

STAR

NTIS HC $6.50

(NASA-CR-130143) MAGNETIC CONTROL ASSEMBLY REPORTS (Ithaco, Inc.) 90 p HC $6.50 CSCL 14B

N73-15478

Unclas

G3/14 52582

ITHACO

ITHACA, N.Y.

REPORTS

MAGNETIC CONTROL ASSEMBLY

CONTRACT No. NAS 5-21867

90420

I

REPORTS

MAGNETIC CONTROL ASSEMBLY

CONTRACT NAS 5-21867

1. Performance of Nimbus/ERTS MCA
2. Control Laws for Proposed MCA for Nimbus
3. Electromagnet S/N 15026 Test Results
4. MCA Design Data
5. Operational Amplifiers, High Impedance with Small Resistors
6. Mounting Orientation of ITHACO's MCA and Schonstedt's Magnetometers. MCA Magnet Polarities
7. MCA Preliminary Design Review Meeting - GSFC(9-12-72)
8. Thermal Vacuum Test Plan for the Qual Model MCA and Thermal Test Plan for Magnetometers (Schonstedt's)
9. RMP Polarities
10. Qualification Test Report of Magnetic Control Assembly S/N PR1

II

April 25, 1972
File: 10-2724
Report No. 90420
Approval RZF

TO: R. Z. Fowler

FROM: A. C. Stickler

SUBJECT: Performance of Nimbus/ERTS MCA

This report contains preliminary results of the MCA performance under the conditions stated on the attached curves. In all instances an initial condition in pitch is inserted to show the transient and damping performance.

Figure 1

Unloading performance with the attitude control system operating normally. Peak excursions of the wheels are:

Roll - 35 RPM
Pitch - 5 RPM
Yaw - 50 RPM

This assumes perfect attitude control via the wheels and does not include second order effects such as tach imperfections.

Figure 2

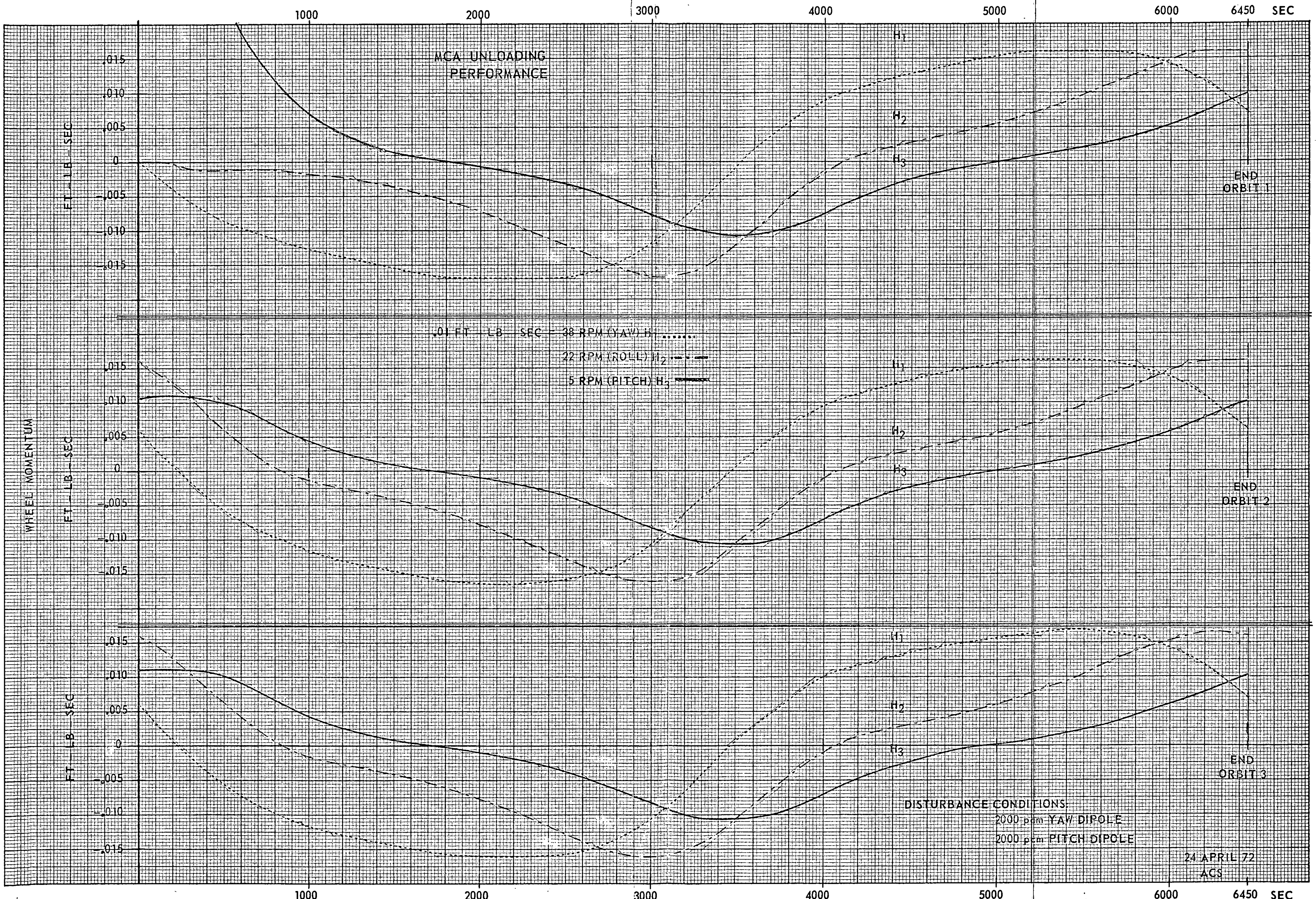
Pitch control performance when the pitch wheel has failed. The peak steady state pitch error is shown to be negligible.

Figure 3

Yaw control performance when the yaw wheel has failed. The performance shown should be regarded as the best possible under the stated conditions because of the simplifying assumption that yaw information is perfect. This curve says that, insofar as corrective torque availability is concerned, the yaw error can be limited to 1°. Additional runs will be made with the real yaw sensor (RMP) simulated.

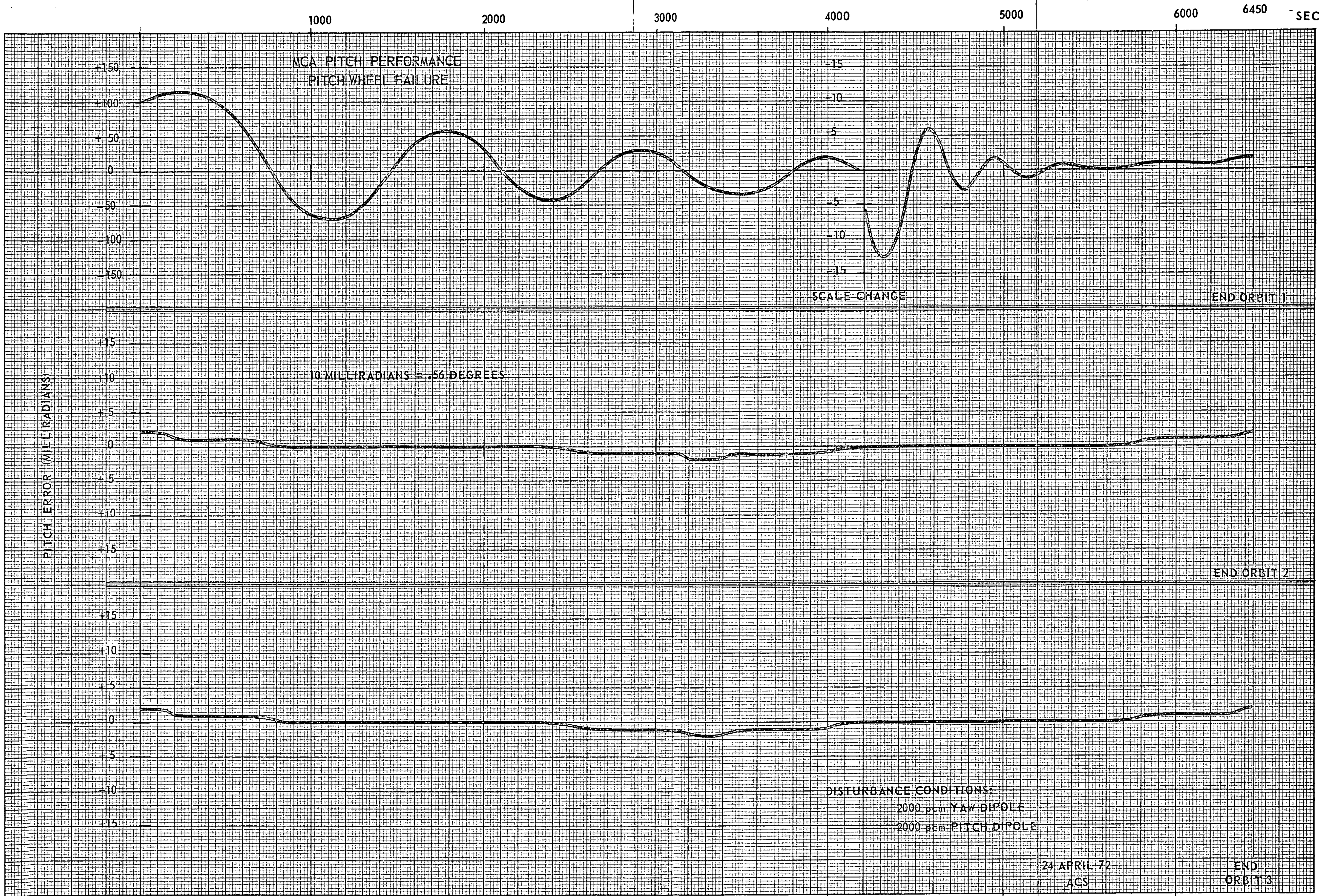
III

acs



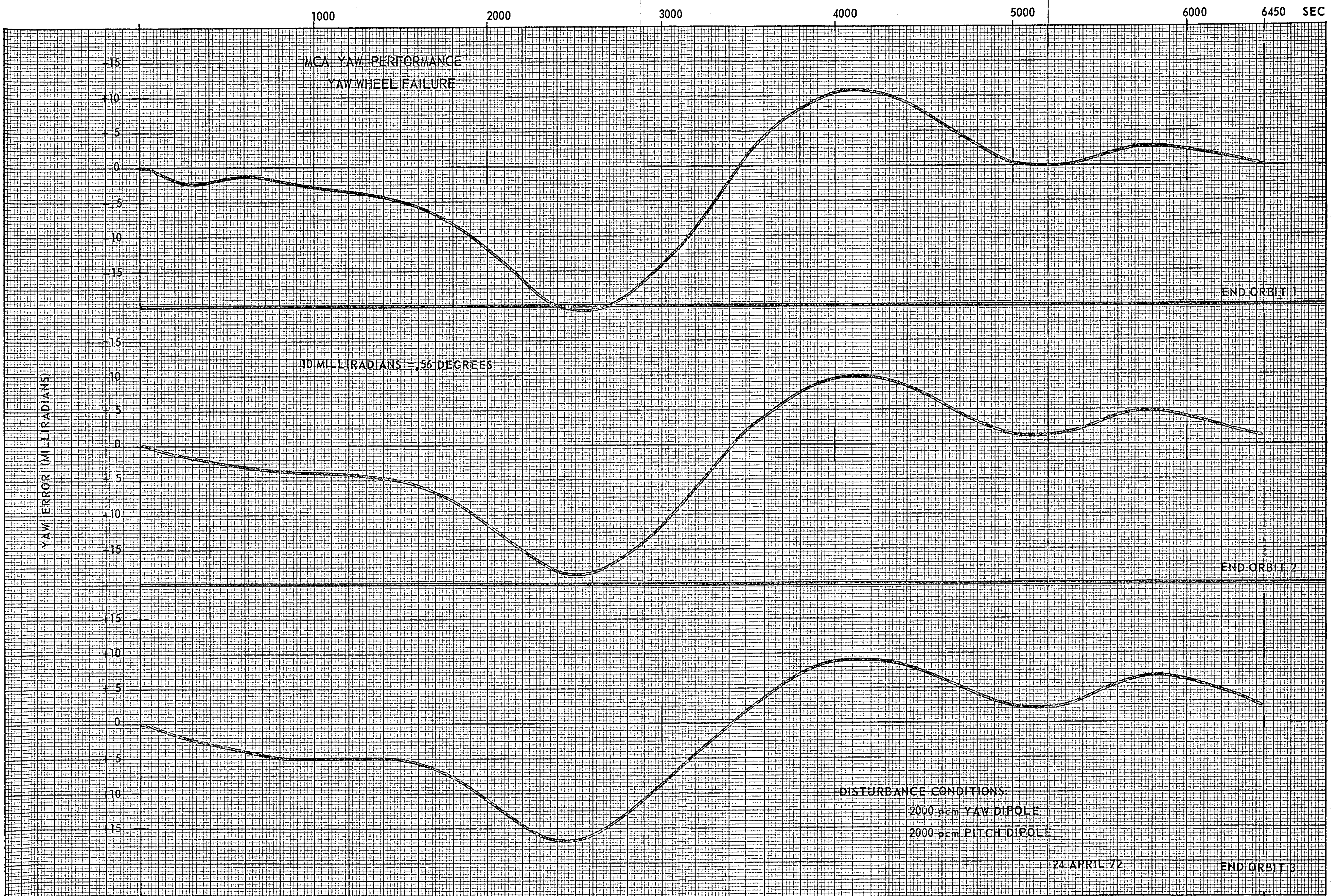
MCA UNLOADING
PERFORMANCE
WHEEL MOMENTUM
FT - LB - SEC
.015
.010
.005
0
-.005
-.010
-.015
1000
2000
3000
4000
5000
6000
6450
SEC
H_1
H_2
H_3
END
ORBIT 1
END
ORBIT 2
END
ORBIT 3
.01 FT - LB - SEC = 38 RPM (YAW) H_1
22 RPM (ROLL) H_2
5 RPM (PITCH) H_3
DISTURBANCE CONDITIONS
2000 pcm YAW DIPOLE
2000 pcm PITCH DIPOLE
24 APRIL 72
ACS

FIGURE 1



MCA PITCH PERFORMANCE
PITCH WHEEL FAILURE
SCALE CHANGE
END ORBIT 1
10 MILLIRADIANS = .56 DEGREES
PITCH ERROR (MILLIRADIANS)
END ORBIT 2
DISTURBANCE CONDITIONS:
2000 pcm YAW DIPOLE
2000 pcm PITCH DIPOLE
24 APRIL 72
ACS
END ORBIT 3
1000
2000
3000
4000
5000
6000
6450
SEC

FIGURE 2



MCA YAW PERFORMANCE
YAW WHEEL FAILURE
10 MILLIRADIANS = .56 DEGREES
YAW ERROR (MILLIRADIANS)
END ORBIT 1
END ORBIT 2
END ORBIT 3
DISTURBANCE CONDITIONS:
2000 pcm YAW DIPOLE
2000 pcm PITCH DIPOLE
24 APRIL 72
1000
2000
3000
4000
5000
6000
6450
SEC

FIGURE 3

May 9, 1972
File: 10-2724
Report No. 90433
Approval RZF

Page 1

TO: R. Z. Fowler

FROM: R. L. Graham

SUBJECT: ELECTROMAGNET S/N 15026 TEST RESULTS

A 7-inch electromagnet was tested in the MMCA Test Fixture by measuring coil voltage vs coil current vs magnetic moment.

This magnet gives a moment/coil voltage slope of 388p-cm/V and a moment/coil current slope of 87.6p-cm/mA with linear operation extending to about 7000 p-cm. The residual moment after applying 24V d.c. to the coil was about 15 p-cm.

The test setup consisted of a 10 ohm, 0.1% meter shunt in series with the magnetizing coil and connected to a d.c. supply. A DVM (GP47) was connected directly across the magnetizing coil and a digital multimeter (VM30) across the 10 ohm shunt. A Sperry Magnetometer (GP20) was held at 44.5cm spacing from the magnet under test by the MMCA Test Fixture.

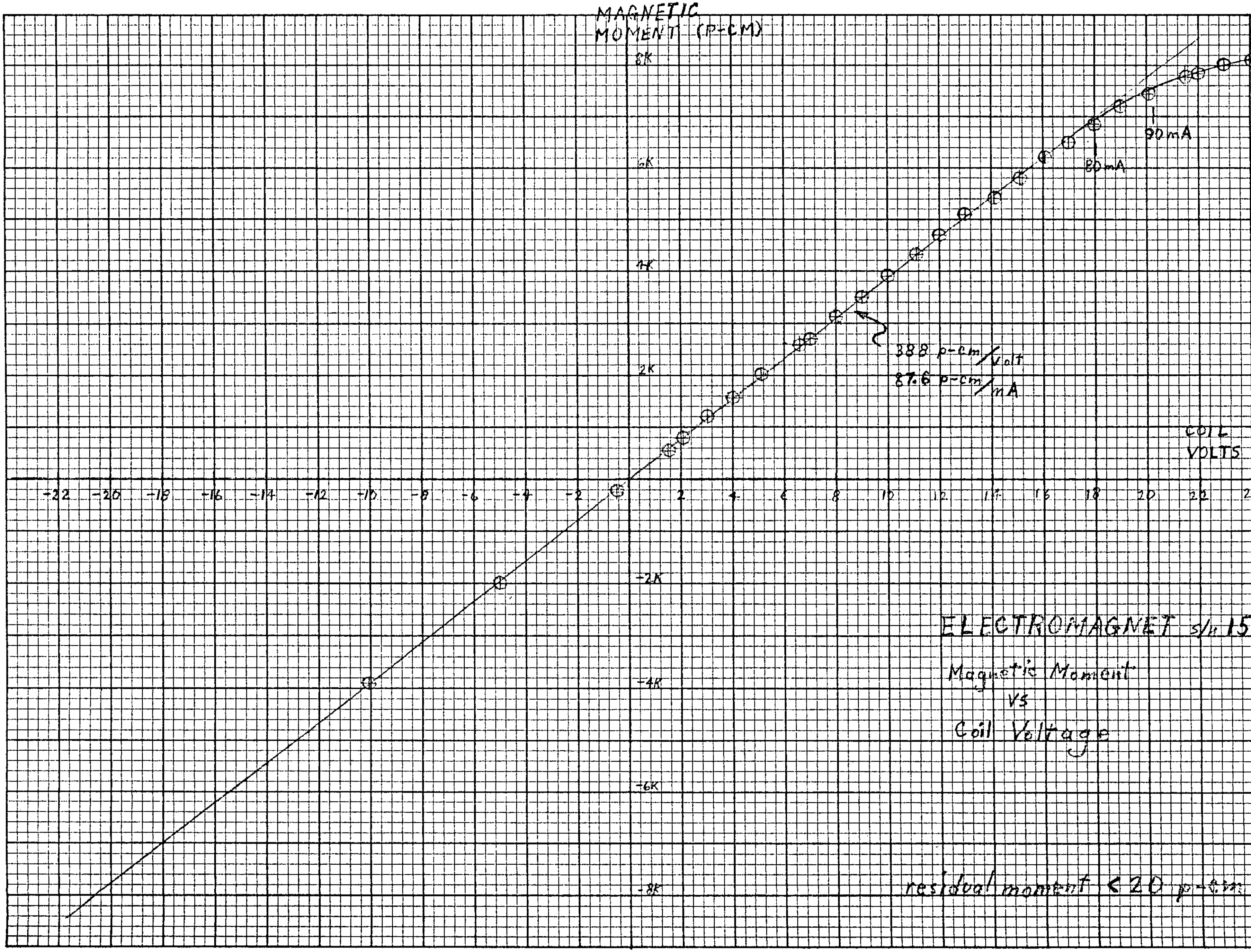
The electromagnet core was 0.28" x 0.28" x 7" alloy 48 with a magnetizing coil consisting of 10,519 turns of #32 AWG double formvar copper wire in 15 turns.

Bridge measurements gave 224 ohm coil resistance and 5.725 Henry inductance.

Ronald L. Graham

cc: V. Selby

Coil Voltage (V)	Coil Current (mA)	Magnetic Moment (p-cm)
0	0	-3
-0.519	-2.3	-225
+1.459	+6.5	+550
+2.079	+9.4	+800
+3.033	+13.7	+1200
+4.016	+18.1	+1580
+5.152	+23.2	+2000
+6.625	+29.8	+2600
+7.045	+31.7	+2720
+8.007	+36.0	+3120
+9.061	+40.8	+3500
+10.025	+45.1	+3900
+11.08	+49.7	+4300
+12.03	+53.9	+4700
+13.06	+58.3	+5100
+14.11	+62.9	+5400
+15.15	+67.5	+5800
+16.13	+72.1	+6200
+17.01	+75.7	+6500
+18.05	+80.3	+6850
+19.00	+84.8	+7200
+20.16	+89.8	+7430
+21.48	+95.5	+7780
+22.05	+97.9	+7820
+23.00	+102.0	+8000
+24.11	+106.7	+8100
+9.056	+40.1	+3500
0	0	+15
-5.031	-22.3	-2000
-10.085	-44.7	-3900


MAGNETIC MOMENT (P-CM)
8K
6K
4K
2K
-2K
-4K
-6K
-8K
-22 -20 -18 -16 -14 -12 -10 -8 -6 -4 -2 2 4 6 8 10 12 14 16 18 20 22 24
COIL VOLTS
90mA
80mA
388 p-cm/volt
87.6 p-cm/mA
ELECTROMAGNET s/n 15026
Magnetic Moment
vs
Coil Voltage
residual moment < 20 p-cm

May 8, 1972
File: 10-2724
Report No. 90429
Approval RZF

Page 1

TO: Peter Hui

FROM: A. Craig Stickler

SUBJECT: Control Laws for Proposed MCA for Nimbus

In a recent memo (ITHACO Report No. 90417, 4-20-72) I discussed a simulation model suitable for investigation of the small angle attitude dynamics (and associated control system dynamics) of a satellite in a circular orbit. In this memo I will discuss some recent development work on a proposed auxiliary attitude control system suitable for the Nimbus/ERTS series satellites. This work uses that model.

The proposed system (termed a Magnetic Control Assembly, MCA) consists of three 5000p-cm electromagnets, a three-axis Schonstedt magnetometer and associated control electronics. The system performs two separate functions. In the course of normal operation of the primary attitude control system, the auxiliary system serves to unload excess momentum from the momentum reaction wheels by torquing against the Earth's magnetic field. In this way the reaction wheel speeds are constrained to a narrow range about some operating points. This eliminates the consumption of gas and provides better attitude control.

In the event of a failure of either or both of the pitch or yaw reaction wheels, the proposed system simultaneously performs another function - that of attitude control itself. This it does again by magnetic torquing against the Earth's field in response to attitude error signals from the roll scanner pair. Both of the above functions are accomplished without the need for mode switching or external commands. Just how this is done will be developed shortly. On the basis of some initial simulation work we have some performance predictions for this system. These predictions are recorded in ITHACO Report No. 90420, (4-25-72), a copy of which accompanies this report.

In summary we can say the following. During normal operation the peak excursions of the primary control system reaction wheels were: Roll - 35RPM, Pitch - 5RPM, Yaw - 50RPM. When the pitch wheel was deleted (simulating pitch wheel failure) we found that the maximum steady state pitch error was of the order of 0.1 degrees. When the yaw wheel was deleted the peak yaw error was about 1 degree. The parameters and details upon which this simulation and these results are based were as follows:

(1) Disturbances were 2000p-cm magnetic unbalance on the pitch and yaw axes.

(2) Perfect yaw, roll, and pitch information is assumed.

(3) A tilted dipole model of the Earth's field is used.

(4) A 600 nautical mile circular orbit is assumed.

(5) Nimbus "E" parameters are incorporated in the simulation model.

The plots accompanying the referenced report (ITHACO Report No. 90420) offer a more complete picture of system performance. Of particular note is the excellent pitch performance. The pitch excursions are of the same order as our ability to measure pitch. Further, they are about equal to the deadbands in the pitch pulse modulator. This means it is possible (likely, for the greater part of the time) that the pitch wheel will not be driven. We could then expect a prolongation of the life of the wheel and a savings of the power it normally uses. It is quite possible that the measured pitch error could be reduced somewhat; we have simulated the control scheme with only one set of gains, parameters, etc. and have by no means settled on the best combination.

MCA CONTROL SCHEME

Let us consider a possible wheel unloading scheme. The coordinate notation used in this discussion is

yaw - axis 1 - ψ - radially outward

roll - axis 2 - ϕ - forward into orbit

pitch - axis 3 - θ - along the orbit normal.

This astrodynamic coordinate system is of course right handed (yaw x roll = pitch).

Now, the excess momentum to be unloaded is

$$\bar{h}_e = \delta h_1 \bar{e}_1 + \delta h_2 \bar{e}_2 + \delta h_3 \bar{e}_3 \qquad (1)$$

where the δh_i are the individual wheel momentum offsets ($\delta\omega_i I_W$), and the $\bar{e}_i$ are unit vectors. The torque available to unload this momentum is given by

$$\bar{\tau} = \bar{M} \times \bar{B} = \tau_1 \bar{e}_1 + \tau_2 \bar{e}_2 + \tau_3 \bar{e}_3 \qquad (2)$$

$$\tau_1 = M_2 B_3 - M_3 B_2$$

$$\tau_2 = M_3 B_1 - M_1 B_3$$

$$\tau_3 = M_1 B_2 - M_2 B_1$$

3

These torque components should be opposite in sign to the excess momentum components given by (1). Note, however, that two M_i are involved in determining each τ_i, and conversely, each M_i enters into two τ_i. What this means is that any particular M_i, say M_2, may help by unloading on one axis while at the same time acting detrimentally on the other axis. In order to minimize the ratio of such undesirable effects to desired action, the following scheme is employed. Each M_i is scaled so that it becomes greater as the amount of desirable effect increases over the undesirable effect. There are many ways to implement such a general concept, and the one which we have chosen is

$$M_1 = \delta h_2 B_3 - \delta h_3 B_2 \qquad (3)$$

$$M_2 = \delta h_3 B_1 - \delta h_1 B_3$$

$$M_3 = \delta h_1 B_2 - \delta h_2 B_1$$

This scheme was chosen with both ease of implementation and suitability in mind. The "net good" (or harm) that each M_i will cause is evaluated as the sum of two terms, corresponding to the two axes about which it yields a torque. Each term is proportional to the product of the momentum correction required (δh_i) and the field component (B_i) available to make that correction. The sign for each term is appropriately chosen. Note that the "net good" or effect of each M_i must be greater than or equal to zero. If the amount of desirable over undesirable effect is small, then the M_i is small. Equations (3) may be substituted in (2) to yield

$$\tau_1 = -(\delta h_1)(B_2^2 + B_3^2) + B_1 B_2 \delta h_2 + B_1 B_3 \delta h_3 \qquad (4)$$

$$\tau_2 = -(\delta h_2)(B_1^2 + B_3^2) + B_2 B_3 \delta h_3 + B_1 B_2 \delta h_1$$

$$\tau_3 = -(\delta h_3)(B_1^2 + B_2^2) + B_2 B_3 \delta h_2 + B_1 B_3 \delta h_1$$

In each of (4), the first term on the right is the desired one; the other two are of the "noise" category. Each equation is of the form (since $\tau_i = d(\delta h_i)/dt$)

$$\dot{x} = -Kx \qquad K = (B_i^2 + B_j^2) \geq 0 \qquad (5)$$

which indicates exponential decay of the excess momenta. Note that there is undesirable coupling as indicated by the second and third terms in each of (4), but its sign varies and it should not prove to be a problem.

We have so far discussed how momentum unloading is to be accomplished; now we turn to position control. Instead of going through a long discussion of how we came upon the present scheme, we will merely exhibit it and discuss its operation. The scheme is as follows. Everywhere in (3) where δh_1 and δh_3 appear, we substitute $(\delta h_1 + \alpha_1\psi + \beta_1\dot{\psi})$ and $(\delta h_3 + \alpha_3\theta + \beta_3\dot{\theta})$, respectively. The α and β are appropriately chosen constants. These terms then obviously replace the δh_i in (4).

Ignoring the cross coupling terms in (4), the equations for ψ and θ are

$$(\tau_1 = I_1\ddot{\psi}) + K\delta h_1 + K\beta_1\dot{\psi} + K\alpha_1\psi = 0 \qquad (6)$$

$$(\tau_2 = I_2\ddot{\theta}) + K\delta h_3 + K\beta_3\dot{\theta} + K\alpha_3\theta = 0$$

$$K = (B_i^2 + B_j^2) \geq 0$$

Now, these equations are those of a damped second order system. In the event of a yaw and/or pitch wheel failure, δh_1 and/or δh_3 goes to zero and the corresponding attitude angle comes under magnetic control. Under normal operating conditions ψ, $\dot{\psi}$, θ, and $\dot{\theta}$ are quite small and their presence in the magnet control law (3) does not affect the unloading scheme. The control law now appears as

$$M_1 = G[(\delta h_2)B_3 - (\delta h_3 + \beta_3\dot{\theta} + \alpha_3\theta)B_2] \qquad (7)$$

$$M_2 = G[(\delta h_3 + \beta_3\dot{\theta} + \alpha_3\theta)B_1 - (\delta h_1 + \beta_1\dot{\psi} + \alpha_1\psi)B_3]$$

$$M_3 = G[(\delta h_1 + \beta_1\dot{\psi} + \alpha_1\psi)B_2 - (\delta h_2)B_1]$$

G is an overall gain factor. In some initial simulation work we have set G = 70 (M_{Max}), so as to drive the magnets full on for a $\delta h_i = 0.05$ (lb-ft-sec) and $B_i = 0.3$ (Gauss). That is of course, assuming only one term in each of (7) is active. Also, in this simulation we have obtained reasonable performance for $\alpha_1 = \alpha_3 = 10$, corresponding to full on magnets for ψ or $\theta = 0.005$ (radians), and $\beta_1 = \beta_3 = 270$, corresponding to full magnets at $\dot{\psi}$ or $\dot{\theta} = 0.0107$ (deg/sec). These parameters are those which were used for the simulation work reported in ITHACO Report No. 90420, referenced earlier in this report.

The above description, in conjunction with the referenced simulation study, indicates how a satisfactory momentum unloading scheme and auxiliary yaw and pitch attitude control scheme may be easily implemented, without mode switching, and with a minimum of hardware. In all of the above the type of operation is that which we term "Mode 1". This is the normal operating mode. We note in passing that a second mode, utilizing momentum bias, is available should the yaw gyros (RMP's) fail. In that case, we must rely on quarter orbit coupling for yaw control, hence the need for a momentum bias (dual spin) system. Ground commands are necessary to initiate this mode, because the control laws are somewhat different, etc.

The details of Mode 2 operation will be the subject of a subsequent memo.

A. Craig Stickler

Distribution:
M. Lidston, NASA
S. Kant, NASA
R. Fowler
M. Rutkowski
J. Kenney
D. Sonnabend

August 4, 1972
Report No. 90483
File: 10-2724
Approval ~~ICZ~~

Page 6

TO: Seymor Kant
Peter Hui

FROM: A. C. Stickler

SUBJECT: MCA Design Data

Here are some copies of my notes detailing the MCA configuration and gains. Also included is the rational for setting these gains from the points of view of performance, noise, offsets, etc.

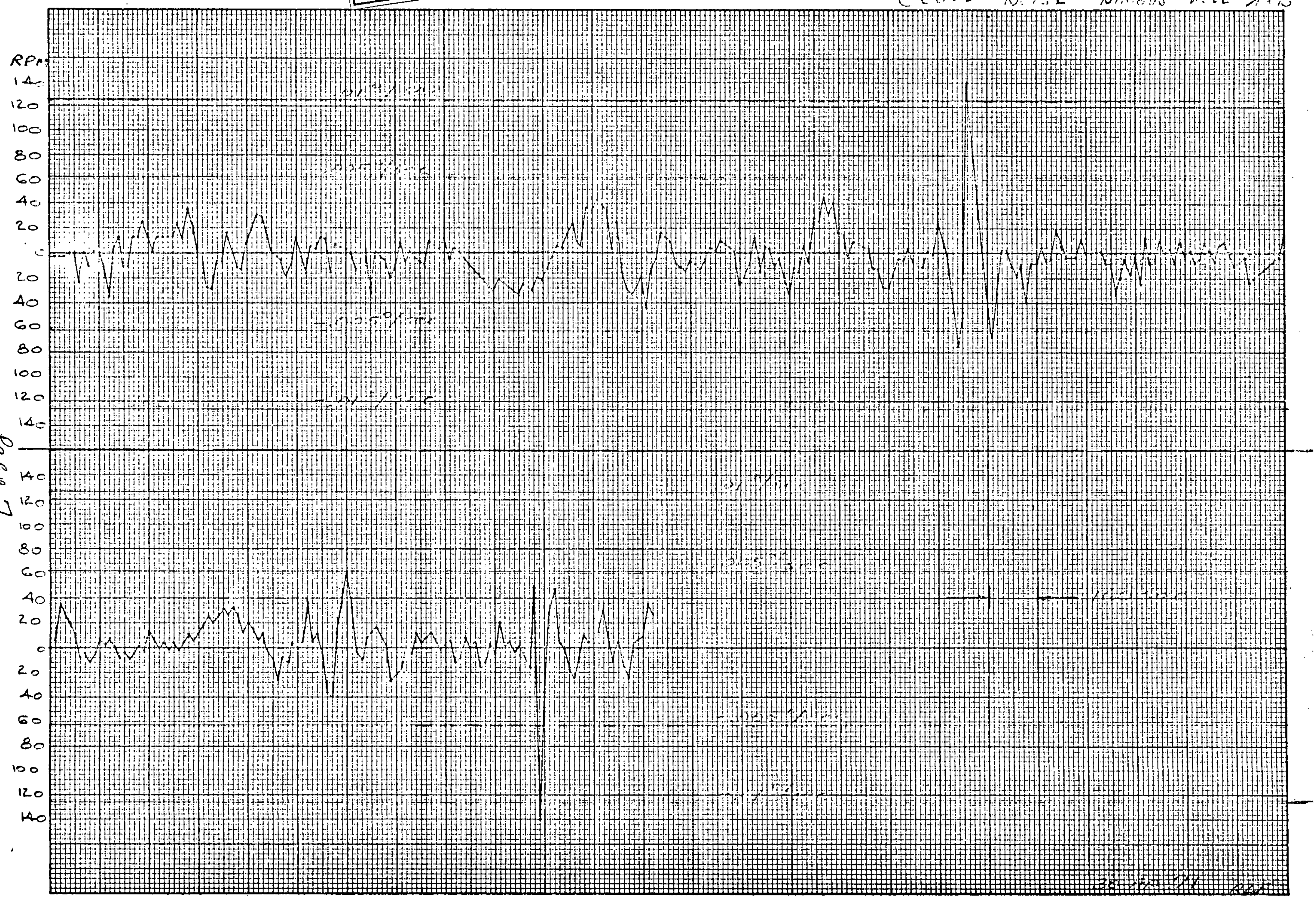
Most of the above we discussed and agreed on in general form last Monday (7/31/72) in conference with you.

Included with these notes are my feeling as to the simulation work required. This should commence next week.

I apologize for the hand written design calculations, but our secretary is leaving and I thought you would prefer to have this information now, rather than having them typed later.

A. C. Stickler

CLOUD NOISE - NIMBUS ROLL AXIS



Page 7

GAINS ON MCA

ACS / 8-3-72

GAINS:

Δh_3 : 1) Pitch offset voltage: If this voltage is offset, then for $M_1 = 0 \Rightarrow$ & B_2 term $= 0$, we have $\Delta h_3 = \dfrac{3.33\Delta\Theta}{0.22}$

if $\Delta\Theta = 0.1$ deg

$$\Delta h_3 = \frac{3.33}{0.22}\,\frac{0.1}{57.3} = 0.0262 \text{ ft-lbf-sec}$$

$$\& \quad J_3 = 0.0127 \Rightarrow \Delta\omega_3 = 2.06\,\frac{\text{rad}}{\text{sec}} = 20 \text{ RPM}$$

since this is acceptable, we could decrease the unloading on Δh_3 by as much as a factor of 5. We could increase it as much as we desire.

2) *Noise*:

Look at eqn. (1a) & (1b). The average value of $\bar{B}_1$ & B_2 together is about 0.3. The noise level - see attached sheet - is about 0.0063 ft-lbf-sec

RMS is about 1/2 of this →

Then the average M commanded will be

$$(0.22)(0.3)(.678 \times 10^6)(0.0063) = 265 \quad \text{P-Cm}$$

Total for two magnets together → average power consumption due to Δh_3. This seem

We probably would not want to raise

(1a)

the gain by anymore than a factor of five from the noise point of view.

3) Performance: how much Δh_3 for 2K-P-cm Disturbance (0.1 ft-lbf-sec)

ans: with 0.2/$\sqrt{z}$ field, on the order of 80 RPM (Cf. A2)

B) GAIN on θ

1) Pitch offset voltage:

We can not raise the gain here more than say, by a factor of 5 and still have an acceptable Δh_3 offset.

$\theta \simeq 0.1° \Rightarrow$
$M = 1125$ P-cm
(due to 0.36 field)

2) Performance: runs with 1.67 gain showed errors of about 0.5° in the pitch backup mode. These errors should be reduced somewhat by raising the gain to 3.33. In any case I would not want to reduce the gain

USE GAIN OF 3.33

3) Noise:

Pitch signal noise is about 0.1 degree, rms. This will drive a dipole of

for two magnets together

$$M_{noise} = 3.33\left(\frac{0.1}{57.3}\right) 0.3 \times 6.75\times10^5 = 1180 \text{ P-cm}$$

(B_1 & B_2 both)

this is acceptable power consumption but we should not raise the gain by more than 2X.

f) GAIN ON $\dot{\theta}$

1) Performance: We desire at least a ten second lag in the lead-lag filter giving us $\theta + K\dot{\theta}$. We also desire a decade of lead over lag. Thus we need at least $\frac{100s+1}{10s+1}$.

2) Noise: — The same graph that indicated Δh_3 noise also indicates $\dot{\theta}$ noise - since we have momentum conservation for the short term at least. The relation

$$\delta h_3 = I_3 \delta\dot{\theta} \quad \text{applies}$$

$$\delta\dot{\theta} = \frac{\delta h_3}{I_3} = \frac{\delta h_3}{250}$$

cf. $0.22\, \delta h_3$ with $450\,\delta\dot{\theta} = \overset{1.8}{\frac{450}{250}}\, \delta h_3$

Two magnet noise due to $\dot{\theta}$

ie, we have about 10X the noise from Δh_3. $\frac{1.8}{0.22} \times 265\text{-P-Cm} = 2160\,\text{P-C}$

E) GAINS ON ψ_R .. Backup mode

1. Performance: Optimal performance with present gain seems to be about 4° error (w/ 2K P-cm disturbances). Gain might be raised, but not lowered, from this point of view.

2. Noise: We have a very tight loop around the yaw wheel, which tends to null out the ψ_R noise. This noise is primarily roll cloud noise coupled in thru the inclined gyro axis. $\psi_R \simeq xx + 1000\dot{\phi}$; $\dot{\phi}$ noise $= 2.5 \times 10^{-5}$ r/s, so if none of this were nulled out, we would have 2K P-cm of noise. However, it is nulled out. also, the lag $\frac{5s+1}{100s+1}$, at $\omega = 1$ r/s attenuates by around 15-20, so power consumption <200 P-cm

good number for cloud noise

3. Offsets

there are no significant offsets to worry about on ψ_R

Recommendations gain on ψ_R should be raised by a factor of three for better performance.

(3a)

Final Equations to be evaluated:

ASTRODYNAMIC COORDINATES; 1-YAW; 2-ROLL; 3-PITCH

$$M_1 = 0.678 \times 10^6 \left[0.33\,\Delta h_2 B_3 - (0.22\,\Delta h_3 + 3.33\theta + 450\dot{\theta}) B_2 \right]$$

$$M_2 = 0.678 \times 10^6 \left[(0.22\,\Delta h_3 + 3.33\theta + 450\dot{\theta}) B_1 - (0.57\,\Delta h_1 + 34\psi_R) B_3 \right]$$

$$M_3 = 0.678 \times 10^6 \left[(0.57\,\Delta h_1 + 34\psi_R) B_2 - 0.33\,\Delta h_2 B_1 \right]$$

Note: $3.33\theta + 450\dot{\theta}$ is intended to represent: $3.33 \left(\frac{135+1}{155+1} \right) \theta$

the Δh_i are in ft-lb-sec, $J_1 = 0.0025$ slug-ft^2

θ, ψ_R are in radians, $J_2 = 0.0044$ slug-ft^2

$\dot{\theta}$ in rad/sec, $J_3 = 0.0127$ slug-ft^2

B_i in Gauss

Estimated Power Consumption

@ 150 mw/1000 P-Cm

		M_1 P-Cm
1. Δh_3 on M_1 & M_2 → together → Worst Case →		265
2. θ offset ⇒ M_1 & M_2 →	RMS	1125
3. θ noise ⇒ M_1 & M_2 ⇒	⇒ 2750 P-Cm	1180
4. $\dot{\theta}$ noise ⇒ M_1 & M_2 ⇒		2160

5. Effect of Δh_1, Δh_2 & Ψ_R on M_3 ⇒ $\Delta h_1 = 420$

$\Delta h_2 = 650$

RMS'ing these ⇒ 980 P-Cm. $\Psi_R = 600$

6. Effect of Δh_2 on M_1 ; Δh_1 on M_2 & Ψ_R on BOTH SHOULD BE SMALL DUE TO SMALL PITCH FIEL[D]

TOTAL POWER CONSUMPTION DUE TO NOISE IN THE WORST CASE SHOULD BE

980 + 2750 ≃ 3750 P-Cm

& @ 150 mw/1000 P-Cm ⇒ < 0.6 watts

MAX. POWER DRAIN AT SATURATION 2.25 watts

Acquisition Circuitry

There will be very sharp deadzones with limits as follows

(1) Roll & Yaw axes circuits

We will have half saturated magnets for $|\dot{B}| = 1.25\ \omega_0\ B_{MAX}\Big|_{\substack{\text{worst temp} \\ \text{\& part tolerances} \\ \text{cases}}}$

$$= 1.25 \times 10^{-3} \times 0.4 = 0.5 \times 10^{-3}\ \text{GAUSS/sec.}$$

(2) Pitch circuits

1/4 the deadzone of Roll & Yaw

$$\Rightarrow |\dot{B}| = 0.125 \times 10^{-3}\ \text{GAUSS/sec.}$$

It would be desireable to be able to halve the deadzones via ground command (& go back up) if necessary.
RZF & SK will work this out

SIMULATION WILL BEGIN NEXT WEEK
THE INVESTIGATION WILL PROCEED IN THIS ORDER

(1) WE WILL USE THE GAINS OUTLINED ON P. 4

(2) WE WILL USE THE DISTURBANCE TORQUES OUTLINED ON PAGE A.

(3) WE WILL INCLUDE AS MANY OF THE ACTUAL CONTROL CIRCUIT NON-LINEARITIES AS POSSIBLE (ESP. THE MULTIPLYERS) IN COMPUTING THE DIPOLE MOMENTS M_i ON P. 4.

(4) NO "NOISE SIGNALS" WILL BE CONSIDERED.

(5) THE FIRST DETAILS TO BE INVESTIGATED WILL CONCERN THE NORMAL UNLOADING MODE. I WILL TRY TO ESTABLISH WHEEL SPEEDS FOR VARIOUS DISTURBANCES & VARIOUS INACCURACIES IN FIELD DETERMINATION.

SECONDLY, I WILL INVESTIGATE PERFORMANCE IN THE CASES OF YAW & PITCH WHEEL FAILURE. (ALSO WITH FIELD MEASUREMENT ERRORS)

WE MAY WANT TO SPECIFY TOLERANCES ON OUR FIELD DETERMINATION CAPABILITY.

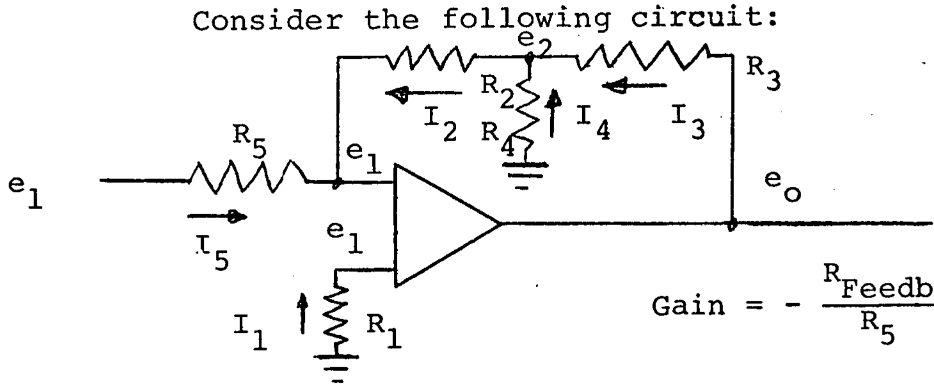
August 22, 1972

Report No. 90492

Operational Amplifiers
High Impedance With Small Resistors

Occasionally, when using operational amplifiers in high impedance circuits, the need arises for impractically large values of resistors in the feedback circuit. By using a T-network in the feedback circuit, the desired effective feedback resistor may be achieved without using super large resistors.

Consider the following circuit:



$$\text{Gain} = -\frac{R_{Feedback}}{R_5}$$

It may be shown, using the usual operational amplifier approximations, that $R_{Feedback}$ is given by:

$$R_{Feedback} = R_2 + R_3 + \frac{R_2 R_3}{R_4}$$

For instance, if R_2 and R_3 are 500k and R_4 = 1k, then $R_{Feedback}$ is 251 Megohms. Of course, care must be exercised to be sure not to run out of open loop gain.

An important question is:

What is the effect of offset and bias currents?

I_1 is a bias current. Then $I_1 = I_2+I_5+A$ where A is an offset current. Let e_i=o.

$$I_1 = \frac{-e_1}{R_1} \qquad I_4 = \frac{-e_2}{R_4}$$

$$I_2 = \frac{e_2-e_1}{R_2} \qquad I_5 = \frac{-e_1}{R_5}$$

$$I_3 = \frac{e_o-e_2}{R_3} \qquad I_2 = I_3+I_4$$

c

Thus

$$\frac{e_2-e_1}{R_2} = \frac{e_o-e_2}{R_3} - \frac{e_2}{R_4}$$

$$\frac{-e_1}{R_1} = \frac{e_2 - e_1}{R_2} - \frac{e_1}{R_5} + A$$

To have e_o=0 for any bias current is desirable. Set e_o=0 and A=o and solve for R_1

The proper choice for R_1 is:

$$R_1 = \frac{R_5(R_2R_4+R_3R_4+R_2R_3)}{R_2R_4+R_3R_4+R_2R_3+R_4R_5+R_3R_5}$$

It may be shown that this result is equivalent to:

$$\frac{1}{R_1} = \frac{1}{R_5} + \frac{1}{R_2+\frac{R_3R_4}{R_3+R_4}}$$

In general, then e_o is given by:

$$e_o = R_3\left[e_1R_2\left(\frac{1}{R_2} + \frac{1}{R_5} - \frac{1}{R_1}\right) - AR_2\right]\left(\frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}\right) - e_1\frac{R_3}{R_2}$$

With the proper choice of R_1, the e_1 terms sum to zero.

$$\therefore e_o = -A\ R_2R_3\left(\frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}\right)$$

$$= -A\left(R_2 + R_3 + \frac{R_2R_3}{R_4}\right)$$

$$= -A\ R_{Feedback}$$

Thus, to adjust gain, the effective feedback resistor is given by

$$R_{fb} = R_2+R_3+\frac{R_2R_3}{R_4}$$

R_1 should be chosen to be equal to the parallel combination of

$$R_5 \quad \text{and} \quad R_2 + \frac{R_3R_4}{R_3+R_4}$$

Obviously $\frac{R_3R_4}{R_3+R_4}$ is the parallel combination of R_3 and R_4

The offset currents flow through the effective feedback resistor, R_{fb}.

V. Selby

cc: R. Shen
R. Graham
J. Langm.
W. Henniger
D. Chandler
O. Kapasi
P. Costantini
H. Jorgensen

ITHACO, Inc. 735 W. Clinton Street Ithaca, New York 14850

Report #90505
Project MCA
File: #10-2724
August 30, 1972
Approval: [signature]

TO: Ennio Scopel (GSFC)

FROM: Robert Shen

SUBJECT: (1) Mounting orientation of ITHACO's MCA and Schonstedt's Magnetometers.

(2) MCA magnet polarities

(1) The ITHACO MCA package and the Schonstedt Magnetometer package should be mounted in an orientation as shown in Figure 1.

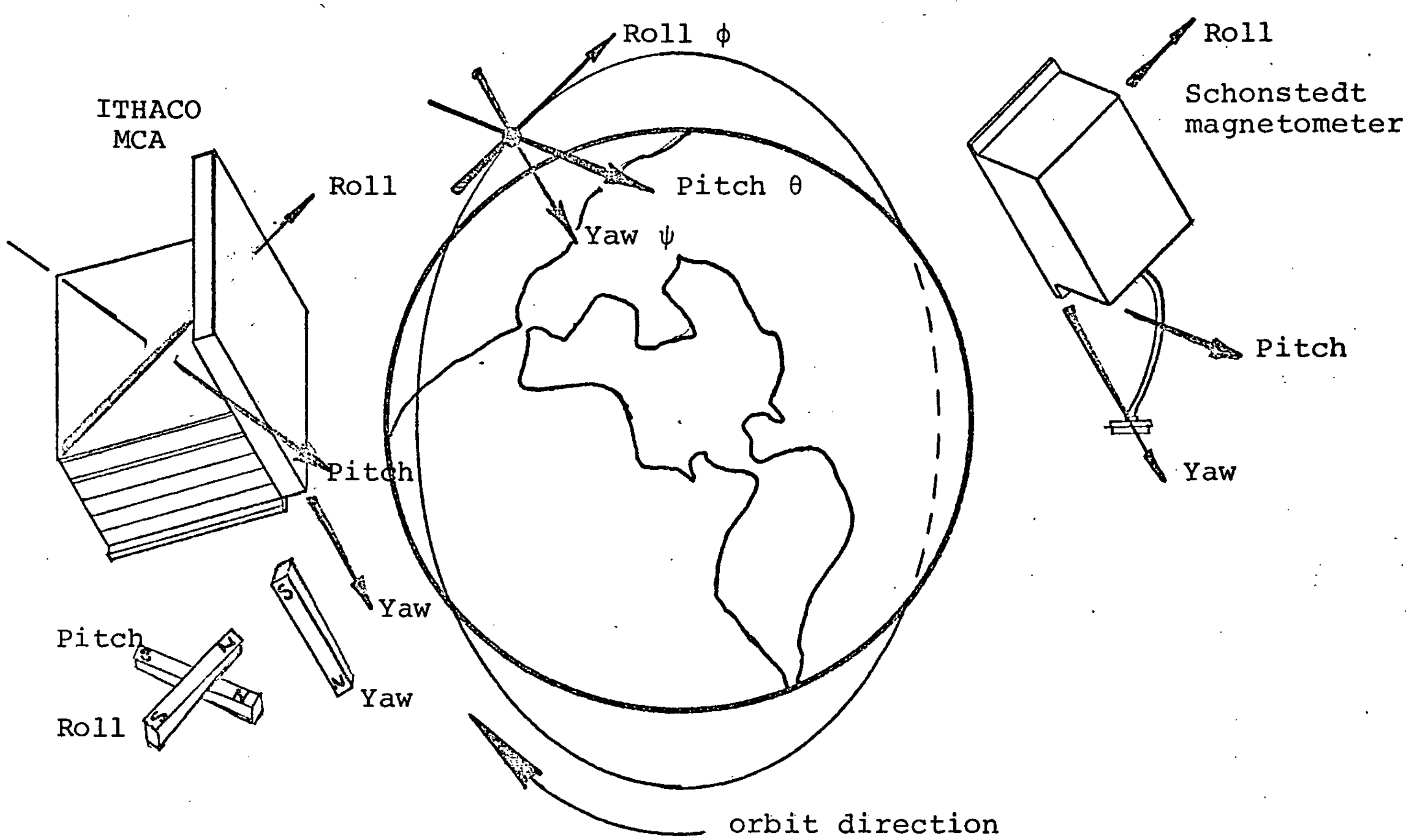


Fig. 1

(2) The MCA magnets will be energized as shown when the following voltages appear across their windings. See "Function Block Diag. MCA F50030"

	Positive	Negative
Roll	A5J1-1	A5J1-2
Yaw	A1J2-23	A1J1-4
Pitch	A5J1-25	A1J2-1

This is the same as when

in Roll, $\dot{B}_\phi$ = negative;

in Pitch, $\dot{B}_\theta$ = negative;

in Yaw, $\dot{B}_\psi$ = negative;

during acquisition.

This is also the same as when

in Roll, $(\delta w_\psi + \psi)B_\theta - (\delta w_\theta + \theta)B_\psi$ = negative;

in Pitch, $\delta w_\phi B_\psi - (\delta w_\psi + \psi)B_\phi$ = negative;

in Yaw, $(\delta w_\theta + \theta)B_\phi - \delta w_\phi B_\theta$ = negative;

during orbit mode.

Distribution:
- Ennio Scopel (GSFC)
- Peter Hui (GSFC)
- Bob Fowler (ITHACO)
- Mike Rutkowski
- Dave Sonnabend
- Bob Shen
- Craig Stickler

To: Distribution

From: M. Rutkowski

Subject: MCA Preliminary Design Review Meeting - GSFC (9-12-72)

Attended By:

NASA
H. Neuman
G. Branchflower
H. Damare
P. Hui
D. Murray

GE
S. Millman
W. Richmond
B. Siegel

ITHACO
C. Stickler
R. Shen
M. Rutkowski

Action Items

1. Prepare a qualification test plan for MCA S/N PR1 to be fully compliant with requirements of GSFC Spec S-320-NI-4.

   Should consist of the following:

   A) Vibration - MCA & Probe

      1. Define levels
      2. Define tests to be performed pre and post vibration
      3. Specify power off during vibration
      4. Specify axes of orientation
      5. Define visual post vibration inspection - solder cracks, loose screws, etc.
      6. Define test fixture to support both MCA & probe
      7. Define which external connectors should be present during vibration and how they should be supported.

B) Thermal vacuum

1. Define time/temperature profile for each box
2. Run MCA in vacuum and probe in thermal chamber.
3. Define tests to be performed prior to, at each plateau, and subsequent to TV test.
4. Define vacuum levels required.

Action: R. Shen Due: 9-15-72

2. Prepare a vibration and a thermal vacuum test procedure.

Responsibility: R. Shen Date Req. 9-19-72

3. Design and fabricate vibration fixture to be compatible with GSFC shaken hole pattern.

Action: R. Fleming, S. Rustyak Due: 9-21-72

4. Design and fabricate TV chamber harnesses and heat sink/ insulator for mounting MCA in chamber.

Action: S. Rustyak Due: 9-22-72

5. Obtain flight and qualification test history on Schonstedt Magnetometer and submit to G. Branchflower.

Action: R. Shen Due: 9-18-72

6. Perform simulation to determine the effect on MCA performance in the presence of fields of 25 and 50 mg. This is required in order to determine how close the MCA can be placed to the RBV shield.

Action: C. Stickler Due: 9-22-72

7. Submit to GSFC a summary of changes contemplated that will make MCA S/N FT 1 different than PR 1, e.g. layout changes, off pad soldering, separate relay grounds, etc.

Action: J. Gosart Due: 9-22-72

8. Update FT 1 parts lists and prepare NASPAR's for all items, Ithaco and Schonstedt, not on GSFC PPL-11.

Action: J. Gosart Due: 9-22-72

9. Add TLM for MCA on/off status. Use separate -24V to be provided on TLM connector.

   Action: R. Shen Due: ASAP

10. Send copies of MOPS and RQPS for soldering potting and conformal coating to GSFC.

    Action: S. Rustyak Due: ASAP

11. Place orders for all parts not already bought for 3 MCA's.

    Action: S. Rustyak Due: 9-15-72

12. Prepare test procedure then perform test on MCA PR1 with Eng Model CLB to demonstrate interface compability.

    Action: R. Shen Due: 10-1-72

13. Ensure that potting of intercard harness connectors and epoxying of large capacitors is included in MOPS and flow chart.

    Action: S. Rustyak Due: 9-15-72

14. Crimp and pot Schonstedt probe connector as well as all other mating interface connectors to be vibrated, e.g. power, TLM, etc.

    Action: S. Rustyak Due: 9-15=72

15. Change Schonstedt Procurement Spec. to specify the new techniques in soldering,conformal coating,and connector crimping and potting.

    Action: S. Rustyak Due: 10-1-72

16. Add to flow plan card photos showing conformal coating and potting.

    Action: S. Rustyak Due: 9-15-72

17. Schedule deliveries of flight units as follows:

    FT 1 -------- 15 Jan 1973
    FT 2 -------- 1 May 1973
    FT 3 -------- 15 Aug 1973

    Action: S. Rustyak Due: 9-22-72

Distribution: Attendees, R. Fowler, R. Fleming, S. Rustyak, J. Gosart, V. Selby

M. Rutkowski

I

Report #90526
File No. 10-2724
Sept. 18, 1972
Page 1
Approval: RZF

To: G. Branchflower

From: R. Shen

Subject: Thermal Vacuum Test Plan for the Qual Model MCA and Thermal Test Plan for Magnetometers (Schonstedt's)

TABLE OF CONTENTS:

1. Brief discussion on test plan

The MCA will be tested inside the Thermal Vac oven throughout the test. The Magnetometers will be tested in an oven or at room temperature outside the Thermal Vac chamber according to the temperature profile shown in Section #3.

2. Vacuum level and pump down time

The Thermal Vac chamber shall be evacuated to the pressure of 10^{-5} mm Hg or less in a period of more than 4 hours. This rate is much slower than the actual flight conditions. This pump down will be done with the oven at 50°C. Then the oven will be brought back to room temperature. The Thermal Vac cycle will start from there.

3. Temperature cycle profile and tolerance for Qual MCA and Magnetometers

See Figure 1.

The Thermal Vac Temperature profile is from S-320-NI-4 Nov. 1, 1968, Attitude Control Subsystem. The temperature tolerance is ± 3°C. The temperature cycle for the Magnetometers is agreed upon with GSFC. MCA subsystem tests ATPS 1105 for high and low temp will be run at the high and low temperature plateaus as specified in the test procedure. At the intervals where *'s are marked, the magnetometers will be excited and their output recorded. See detailed test plan in Paragraph 4.

During the period not covered by the tests mentioned above, Telemetry outputs will be monitored on an eight channel recorder as specified in Para. 5.

4. Explanation of tests indicated on the temperature cycle.

a) ATPS 1105. This is the system level test. It involves plotting the magnetic moment (actually voltages applied to magnets) varying one of the following and holding the others constant B yaw, B pitch, B roll, pitch error, yaw error, pitch yaw and roll tach.

b) The following paragraph of ATPS 1105 will be performed at the beginning of the cycle (Vacuum at room temp). (Para. 6.1, 6.4, 6.5.11, 6.5.13, 6.5.21, 6.5.25, 6.5.36, and 6.5.37).

c)* For this test, the Schonstedt magnetometers will be placed in a zero magnetic field enclosure (nested shield). And electric coil will be placed alongside with the magnetometer in a fixed orientation such that when it is energized, all three magnetometers will receive magnetic fields. This whole package will be placed inside an oven(for temperature test).

When the desired temperature is reached and stabilized for three hours the coiled will be energized with a fixed current 1) in one direction, 2) then the opposite direction and 3) then turned off. In all three cases, the B fields and their polarities will be recorded. The -24 volt current will also be recorded.

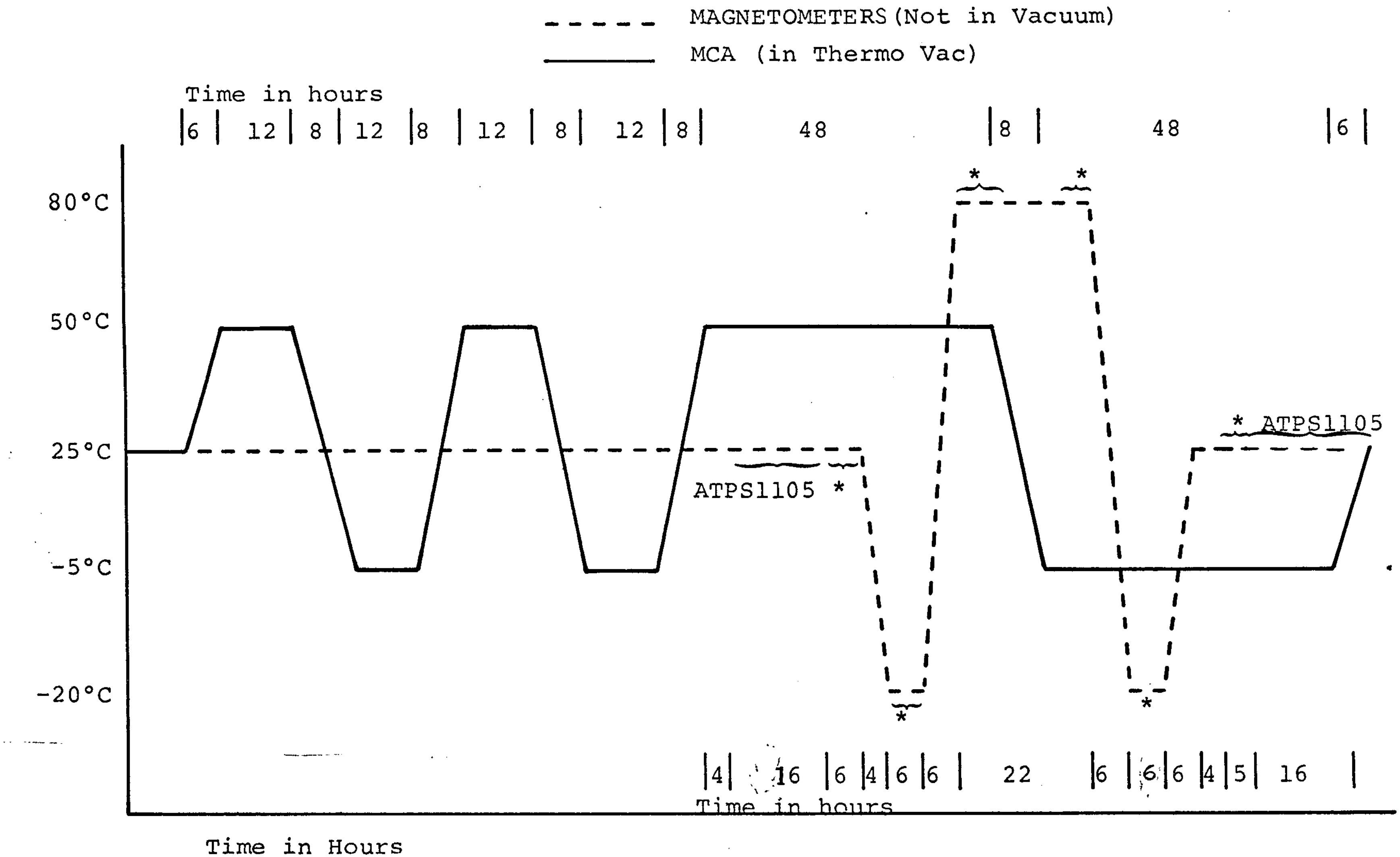
d) If for any reason the tests in 4 a) or c) cannot be finished during the 48 hours Thermal Vac plateaus of the cycle of the MCA test, the 48 hour period will be lengthened.

5. Output of MCA monitored on an eight channel chart recorder when electronic tests are not performed.

The following points will be monitored:

1. Temp TLM
2. $M\theta$ Pitch moment
3. $M\phi$ Roll moment
4. $M\psi$ Yaw moment
5. Power "On off" relay TLM
6. $B\theta$ Pitch magnetic field
7. $B\phi$ Roll magnetic field
8. $B\psi$ Yaw magnetic field

Distribution: G. Branchflower
H. Neumann
D. Murray
E. Scopel
W. Richmond
MCA Dist., Ithaco



MCA & MAGNETOMETERS TEMPERATURE TEST
PROFILE

*See Sec 4

Fig. 1

Report #90538
File No. 10-2724
26 September 1972

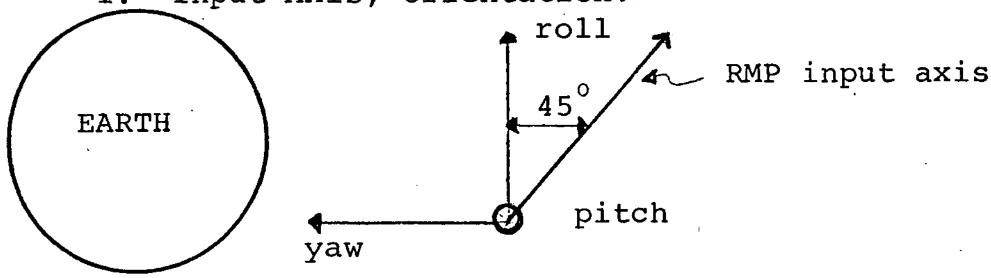
TO: R.Z. Fowler, W. Henniger, V. Selby, R. Shen, D. Sonnabend

FROM: √ A. C. Stickler

SUBJECT: RMP polarities

After looking up (with Bill Henniger's assistance) once too many times the polarities of the RMP inputs and output, the author records here in black and white what he knows about the RMP's on Nimbus and ERTS.

I. Input Axis, Orientation:



II. Equations:

A. In Aerodynamic Coordinates

$$\psi_{RMP} = -\dot{\psi} \sin 45^{o} - \psi\omega_0 \cos 45^{o} + \dot{\phi} \cos 45^{o} - \phi\omega_0 \sin 45^{o} =$$

$$= -\frac{\omega_0}{\sqrt{2}} \left(\frac{\dot{\psi} - \dot{\phi}}{\omega_0} + \psi + \phi \right) \qquad (1)$$

B. In Astrodynamic Coordinates

substituting $-\psi$ for ψ

$$\psi_{RMP} = \frac{\omega_0}{\sqrt{2}} \left(\frac{\dot{\psi} + \dot{\phi}}{\omega_0} + \psi - \phi \right) \qquad (2)$$

here ω_0 = Orbital angular rate ($\approx 10^{-3}$ rad/sec)

ψ_{RMP} = Output (without voltage scale factors) of RMP

C. In ERTS a signal = twice the roll error ϕ and opposite in sense to the input for a positive yaw error ψ is added to the RMP's inputs. Then (1) becomes

$$\psi_{RMP} = -\frac{\omega_0}{\sqrt{2}}\left(\frac{\dot{\psi} - \dot{\phi}}{\omega_0} + \psi - \phi \right) \qquad (3)$$

If the yaw reaction wheel is doing its job properly

$\psi_{RMP} \simeq 0$ and (3) becomes

$$\left(\frac{s}{\omega_0} + 1 \right) \psi = \left(\frac{s}{\omega_0} + 1 \right) \phi \qquad (4)$$

and ψ follows (i.e., is equal to) ϕ

D. When working in Astrodynamic Coordinates, we should add $+2\phi$ to (2), making (for $\psi_{RMP} \simeq 0$)

$$\left(\frac{s}{\omega_0} + 1 \right) \psi = -\left(\frac{s}{\omega_0} + 1 \right) \phi \quad \text{and} \qquad (5)$$

$$\psi \simeq -\phi$$

ACS:erk

cc: RZF
W.H
V.S.
R.S
D.S.
File

QUALIFICATION TEST REPORT

OF

MAGNET CONTROL ASSEMBLY

S/N PR-1

Prepared by: R. R. Fleming

R. R. Fleming
R & QA Engineer

Prepared by: R. Shen

R. Shen
Project Engineer
MCA

Report No. 90548
File No. 10-2724
October 5, 1972
Approval

QUALIFICATION TEST REPORT

of

MAGNET CONTROL ASSEMBLY

CONTRACT NUMBER
NAS5-21867

PREPARED FOR:

Goddard Space
Flight Center
Greenbelt, Maryland

PREPARED BY:

ITHACO INC.
735 W. Clinton St.
Ithaca, New York 14850

2

TABLE OF CONTENTS

3

1.0 QUALIFICATION VIBRATION

Purpose

This report summarizes the results of the Qualification level vibration tests performed on the Magnet Control Assembly, PRl. The vibration levels were in accordance with GSFC Environmental Test Specification S-320-EN-1 dated November 1971. The vibration was performed according to the Vibration Test Plan, ITHACO Report No. 90522 Rev. A (attached) with functional testing and visual inspection as noted.

2.0 VIBRATION TESTING

The MCA was subjected to vibration at GSFC facilities on September 26, 27, 1972. The units, MCA D41105G1 S/N15063 and Triaxial Magnetometer probe C31512 S/N 15062 (Schonstedt SAM-63B-7 S/N4493) were attached to a universal vibration fixture by measn of adapter plates, see photographs on Page 3. Mounting of each unit was by means of four #8-32 socket head screws.

An increase in the level of mechanical noise of the MCA unit indicated an apparent resonance at about 700 Hertx in all three axes. This is typical of other units undergoing similar testing.

After both sinusoidal and random vibration were completed in each axes, a functional test was performed. The test consisted of the following:

Telemetry Outputs Measured

1. B field amplitude (3 axes)
2. B field polarity (3 axes)
3. Magnetic moment (3 axes)
4. Power on/off status
5. Acquisition on/off status
6. Temperature

The functional test of the Magnetometer Probe consisted of steps 1 through 3. The units were also visually inspected for any change in torque striping on the assembly screws and proper securing of the connectors and cables.

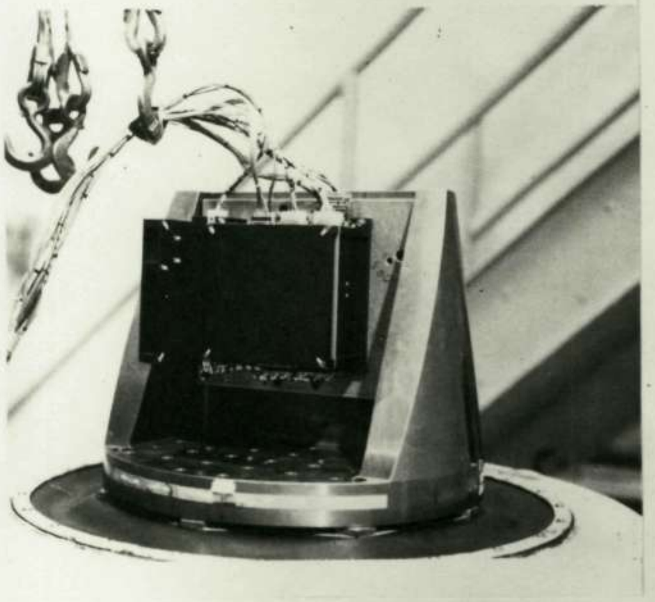
3.0 RESULTS

The MCA electronics and probe units have demonstrated the capability to survive Qualification sinusoidal and random vibration levels. The functional testing indicated normal operation.

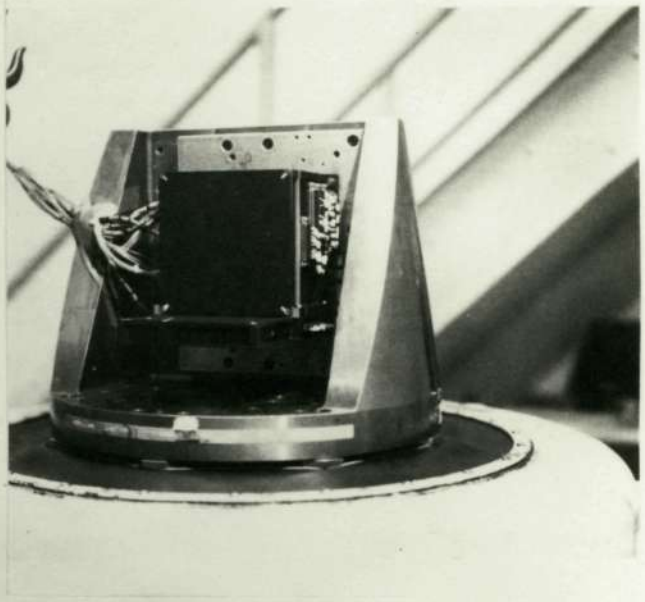
3.0 Continued

of the units after each axis of vibration. Visual inspection indicated no evidence of degradation. Post vibration acceptance testing again verified normal operation of the MCA.

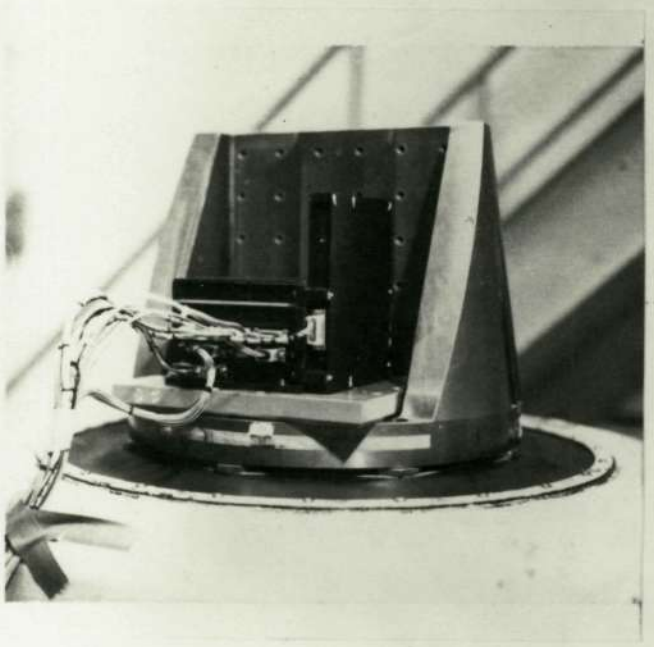
VIBRATION MOUNTING



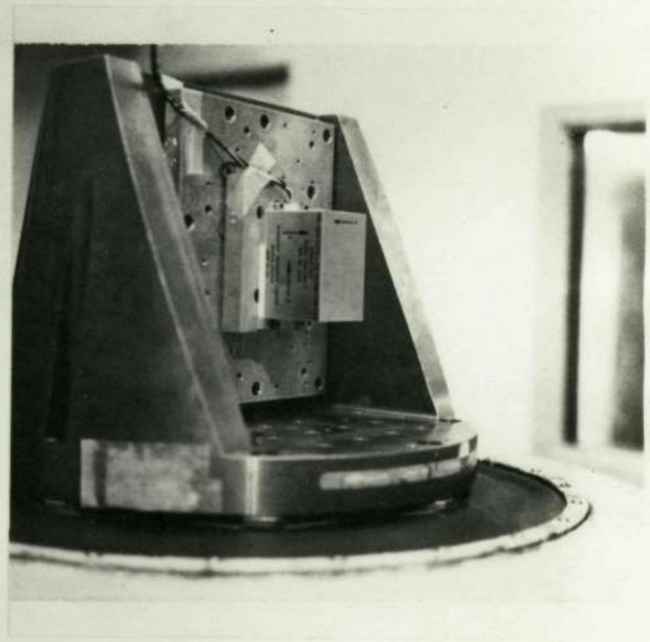
MCA - X AXIS



MCA - Y AXIS



MCA - Z AXIS
(THRUST)



MAGNETOMETER PROBE
Z AXIS (THRUST)

Report #90522 Rev A
File #10-2724
October 4, 1972

Approval:

To: G. Branchflower, MCA

From: R. Shen

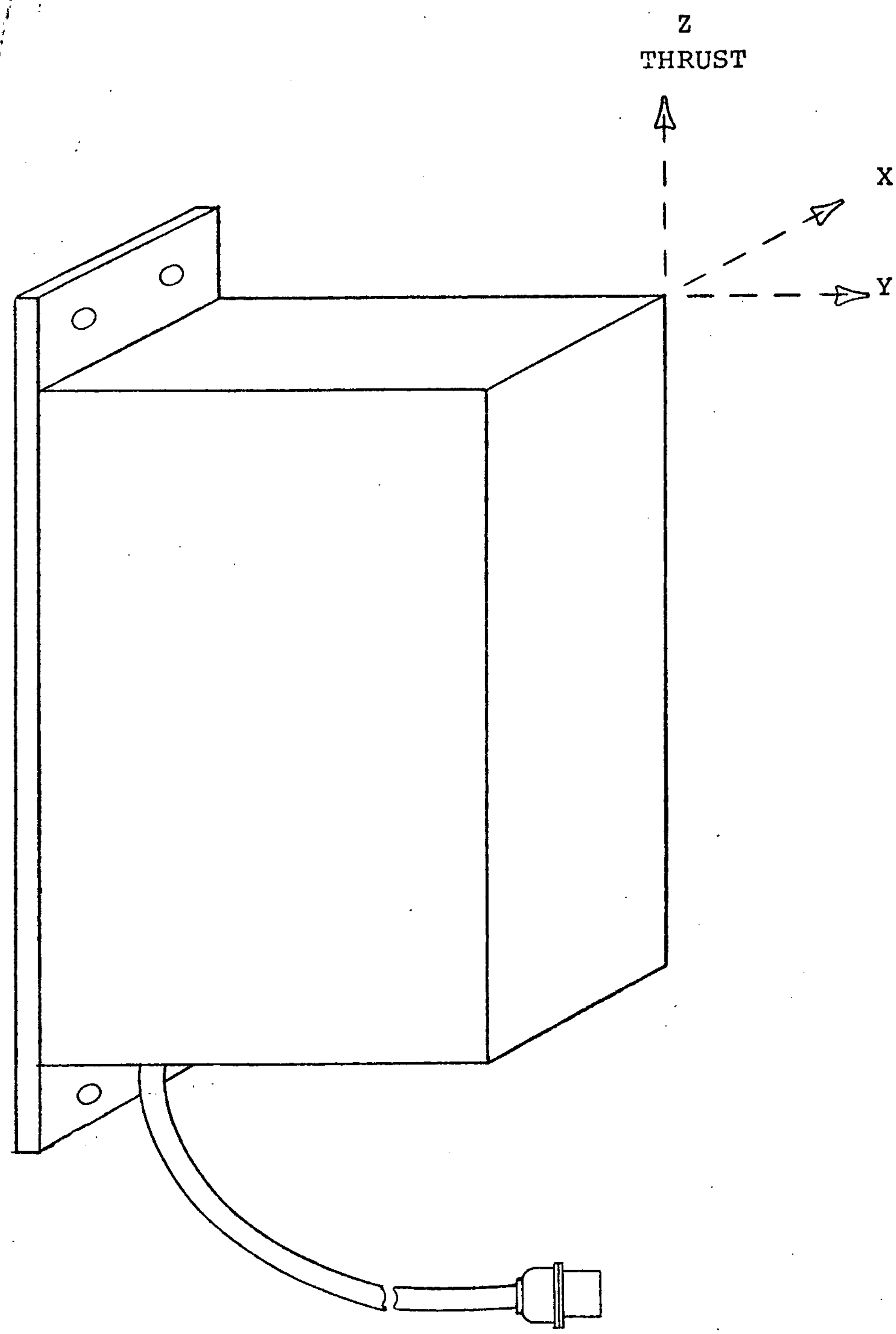
Subject: Vibration Test Plan

TABLE OF CONTENTS

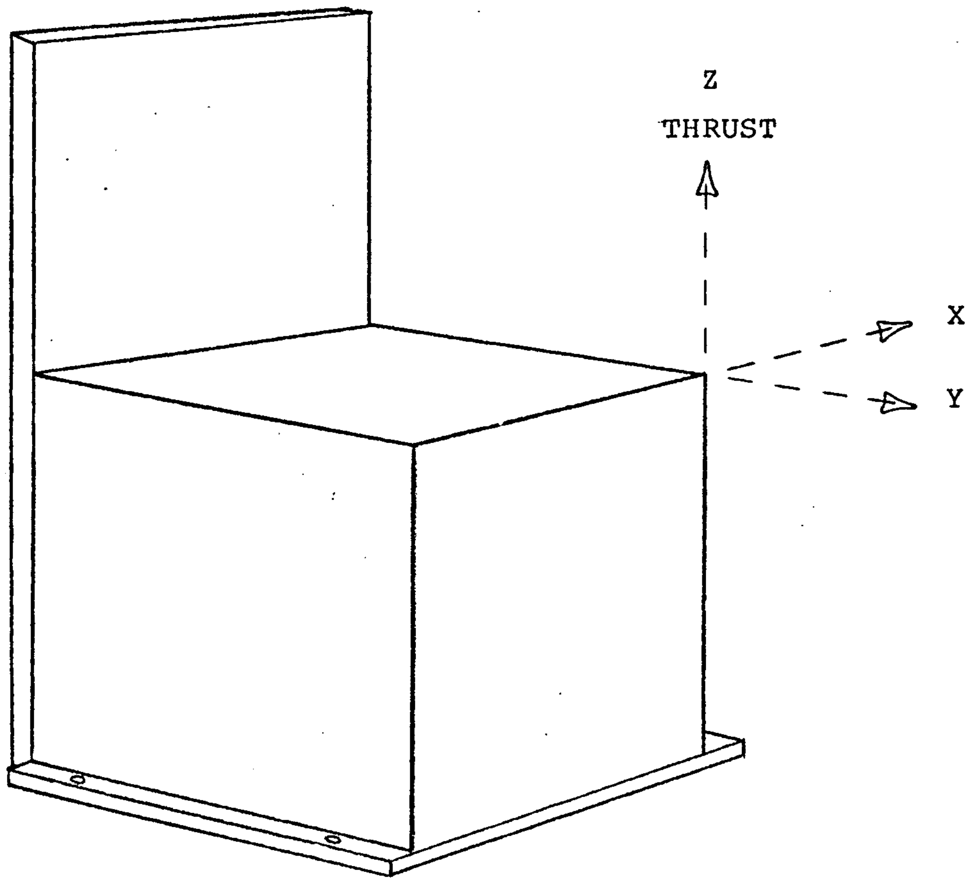
MCA AND MAGNETOMETER VIBRATION TEST

1. Mounting Axes

(a) The Schonstedt Magnetometer vibration axes are shown below.



(b) The MCA vibration axes are shown below.



Note the X and Y axes are 45° off from the actual roll and pitch axes.

2. Connectors attached to MCA during Vibration Test

(a) The only cable attached to the Magnetometer during the vibration test will be the pigtail. The cable will be taped down one foot away from the magnetometer.

(b) The connectors with cables attached to the MCA during vibration will be:

A2J1	(25 pin)	directly from the Magnetometer
A3J3	(25 pin)	
A3J3	(9 pin)	
A4J1	(15 pin)	
A4J2	(15 pin)	
A4J3	(15 pin)	
A1J1	(15 pin)	
Harness cable		

All the connectors on the cables are female type and they will be taped down about one foot away from the MCA during vibration.

3. Power

The -24V power will not be on during the Vibration Test.

4. Pre Vibration set up

Upon completion of final assembly per MOPS 30.37 and RQPS 15-31 pre vibration checks consisting of ATPS 1106 will be performed. This will include isolation checks, six XY plots and command and TLM status.

5. Vibration test levels

The vibration levels are as specified by GSFC.

a) Magnetometers
Vibration levels according to S-320-EN1, Nov. 1971

SINUSOIDAL

Frequency Range (cps)	Amplitude - "g" 0-to-Peak	
	Thrust Axis	Transverse Axes
5-100 100-200 200-2000	15.0* 10.0 5.0	15.0* 10.0 5.0

*Vibration limited to 1/2" double amplitude.
Sweep Rate: 1 octave/minute.

RANDOM

Direction	Frequency Range (cps)	Power Spectral Density (g^2/cps)	g-RMS
Thrust Axis	20-2000	0.09	13.4
Transverse Axes	20-2000	0.09	13.4

The duration of the test shall be 4 minutes in each direction -- 12 minutes total.

b) MCA
Vibration levels according to S-320-EN1, Nov. 1971

SINUSOIDAL

Frequency Range (cps)	Amplitude - "g" O-to-Peak	
	Thrust Axis	Transverse Axes
5-40	8.0*	6.0*
40-200	10.0	18.0
200-2000	5.0	5.0

*Vibration limited to 1/2" double amplitude.
Sweep Rate: 1 octave/minute.

RANDOM

Direction	Frequency Range (cps)	Power Spectral Density (g^2/cps)	g-RMS
Thrust Axis	20-2000	0.09	13.4
Transverse Axes	20-2000	0.09	13.4

The duration of the test shall be 4 minutes in each direction -- 12 minutes total.

6. Post Vibration Check

After the vibration of each axis, the assembly screws will be checked to see if any of them have come loose. Voltages of all telemetry points will be recorded.

(a) Test

After the entire vibration test has been completed, the MCA will be retested per ATPS 1106.

R. Shen

Distribution: G. Branchflower
H. Neumann
D. Murray
E. Scopel
W. Richmond
MCA Dist., ITHACO