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ANALYSIS OF PAYLOAD BAY MAGNETIC FIELDS DUE TO DC POWER MULTIPOINT AND SINGLE POINT GROUND CONFIGURATIONS

AVIONICS SYSTEM ENGINEERING

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1.0 SUMMARY

The objective of this design note is to present an analysis of magnetic fields in the Orbiter Payload Bay resulting from the present grounding configuration (structure return) and to determine the amount of improvement that would result from installing wire returns for the three DC power buses. AC and DC magnetic fields at five points in a cross-section (YZ plane) of the bay are calculated for both grounding configurations. Y and Z components of the field at each point are derived in terms of a constant coefficient and the current amplitude of each bus. This will simplify any future analyses when a specific load condition is known and magnetic field intensity is desired. The DC loads assumed in this note are 100 Amperes for each bus. The AC noise current used is a spectrum 6 dB higher than the Orbiter equipment limit for narrowband conducted emissions allowed by Specification SL-E-0002.

Maximum absolute DC values for the Multipoint (MPG) and the Single Point (SPG) ground configurations, assuming 100 AMPS on each bus, are

MPG = 11.5 AMPS/METER, SPG = 0.38 AMPS/METER

Maximum absolute AC values are:

MPG = 117 dBμ AMP/METER, SPG = 77 dBμAMP/METER

It is concluded that installing return wiring to provide a single point ground for the DC Buses in the Payload Bay would reduce the AC and DC magnetic field intensity by approximately 30 dB.

2.0 DISCUSSION

The magnetic fields addressed in this note are functions of the DC power grounding configuration, the payload bay structure geometry, the DC power conductor geometry, and the load condition for each of the three aft DC buses.

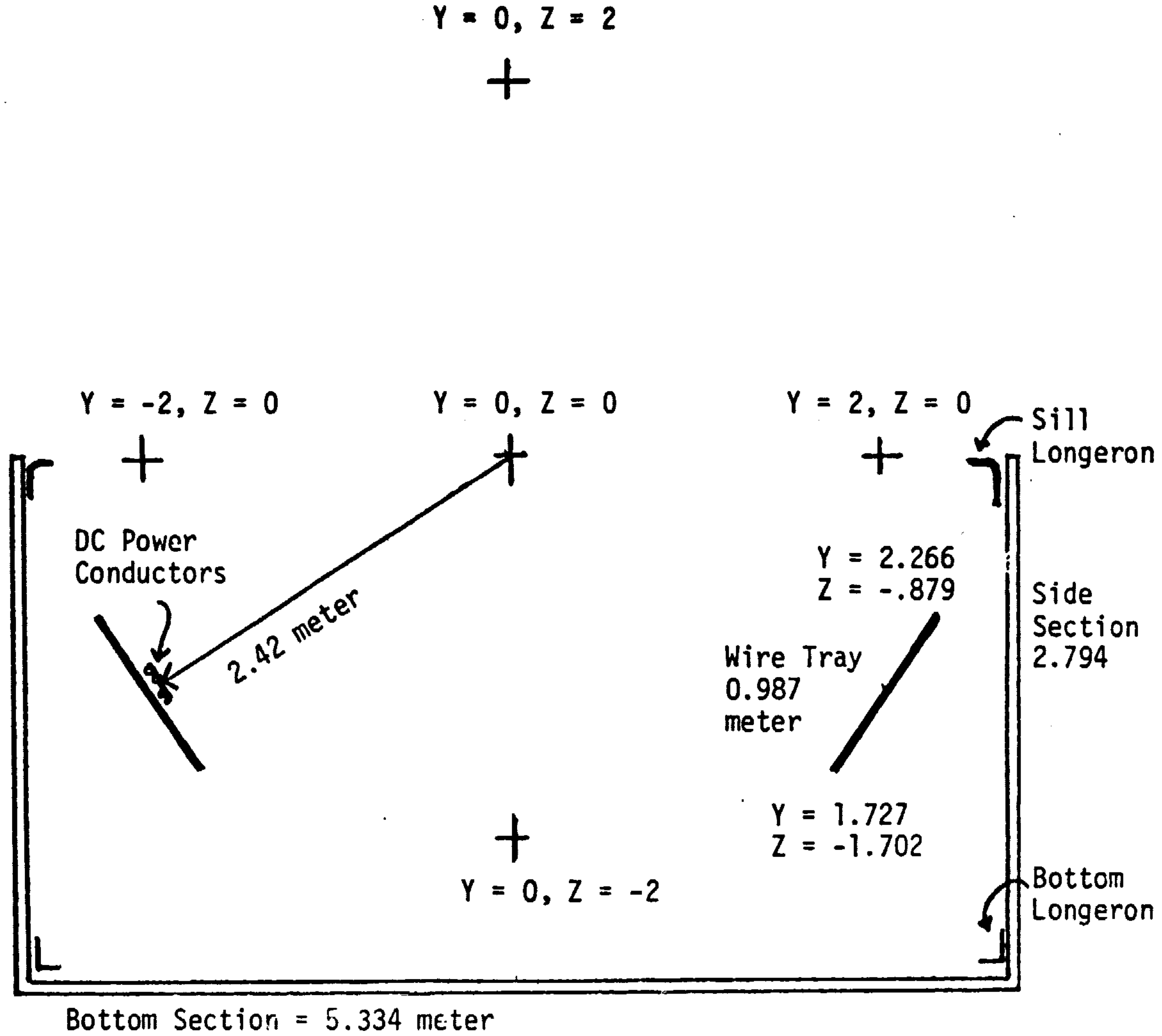
Figure 1 illustrates the structural geometry assumed in this note. Dimensions were furnished by RI personnel.

All fields are calculated for five points in the payload bay cross-section (YZ plane). These points are at the bay center line, two meters above and below the center line, and two meters on either side of the center line. Since the power current flow is in a longitudinal direction through the bay, all fields are calculated in a lateral plane.

The reference coordinate system used is positive Z up and positive Y right when viewed from aft to forward in the payload bay.

The sequence of operations performed in this analysis is as follows:

1) Determine the resistance of the nine major structural sections of the Payload Bay and calculate the fraction of total return current carried by each section. (Table I)
2) Calculate the fields contributed by the power conductors. (Table II)
3) Calculate the fields, as a function of Bus Current, for each of the nine structural sections. Sum the fields contributed by the nine structural sections at each of the five points in the bay cross-section. Tables III thru VII
4) Sum the fields from structure current with the fields from the power conductors. (Table IX)
5) Calculate the fields from power and return conductors for single point ground configuration. (Table X, XI)
6) Compare the fields from the different grounding configurations. (Paragraph 2.5)



PAYLOAD BAY CROSS-SECTION

MAJOR CURRENT CARRYING STRUCTURAL SECTIONS

FIGURE 1

2.1 Structure Currents

Table 1 below is a list of the major structural sections which are considered to carry the DC power return current through the payload bay. It should be noted that payload bay doors are not considered a significant current path. The resistances given were furnished by RI personnel. It is understood that resistances of the side and bottom skin sections and longerons are measured values, while the wire tray resistances are calculated values. Also shown are the calculated percentages of the total return current carried by each section.

SECTION	RESISTANCE (Micro ohms)	% OF CURRENT
RIGHT SIDE SKIN	348.3	10.81
LEFT SIDE SKIN	209.3	17.98
BOTTOM SKIN	163.3	23.05
RIGHT SILL LONGERON	347	10.85
LEFT SILL LONGERON	347	10.85
RIGHT LOWER LONGERON	1030	3.65
LEFT LOWER LONGERON	943	3.99
RIGHT WIRE TRAY	400	9.41
LEFT WIRE TRAY	400	9.41

TABLE I
STRUCTURAL SECTIONS

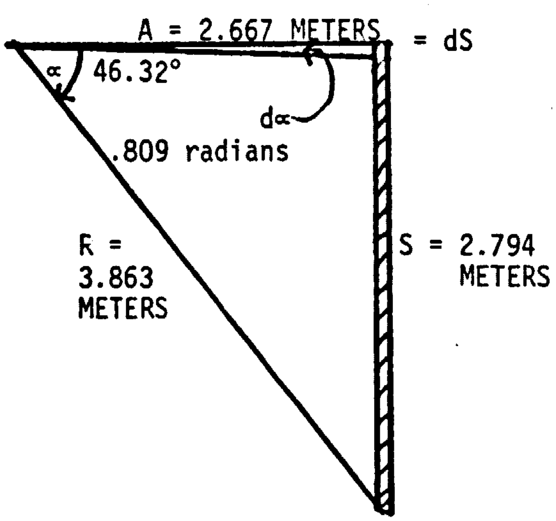
2.2 Magnetic Fields From Structure Currents

All field calculations in this note are based on the equation for the field (H) at distance (R) from a line current (I).

$$H = \frac{I \text{ AMPS}}{2\pi R \text{ METER}} \text{ (Reference 1)}$$

This is applied to structural sections by integrating over the cross-sectional dimensions. A sample calculation is given for the Y component of the field contributions at the centerline from the right side skin section. From Table 1 note that this section carries 10.81% of the total return current (I_T).

Y = 0, Z = 0



$$dHy = \frac{dI \sin\alpha}{2\pi R}, \quad dI = \frac{(.1081)\, I_T\, ds}{2.794}$$

$$R = \frac{A}{\cos\alpha}, \quad S = A \tan\alpha, \quad dS = A \sec^2\alpha \, d\alpha$$

$$dHy = \frac{.1081 I_T \sin\alpha \, d\alpha}{2\pi \cdot 2.794 \cos\alpha}$$

$$Hy = \frac{.1081 I_T}{2\pi \cdot 2.794} \int_0^{.809} \tan\alpha \, d\alpha$$

$$Hy = .00228 I_T \frac{\text{AMP}}{\text{METER}}$$

All field contributions from structure currents are calculated in this manner. By superposition, the fields are summed. The summations are given in Tables III through VII.

2.3 Total Fields From Multipoint Ground Configuration

The fields from the DC power conductors are calculated from the equation for line currents given in paragraph 2.2. These results are then summed with the total contributions from structure currents. The end result is presented in Table VIII in the form of coefficients to bus currents (I_A, I_B, I_C) for the Y and Z components of the field. Table IX gives the vector amplitude and angle of the DC magnetic fields resulting from a load of 100 amperes on each bus.

The AC field calculations are based on the conducted emission spectrum of Reference 2. All Orbiter equipment is required to limit narrowband noise on power lines to the limits of tests CE01 and CE02 of Reference 2. When many equipments are powered from a bus, the noise projected onto the bus can be additive. Since the spectrum is a narrowband specification, and the noise from each equipment is randomly distrubuted through the spectrum, it is unlikely that the outputs from any one equipment will coincide in frequency and phase with the outputs from another equipment on the same bus. However, if this should occur for two noise outputs and the amplitudes were both at maximum specification limit, the resulting amplitude would be 6 dB higher than the limit. Therefore, a noise level for each bus is assumed which is 6 dB above the equipment specification across the spectrum. This is an amplitude envelope that can be safely considered to contain the noise current for each bus. The resulting level is 6.3 amps from 30 Hz to 2000 Hz, dropping to .02 amps at 20 KHz. These values, when applied to the field coefficients, produce the spectrum illustrated in Figure 2. Note that there are two spectrums given for this configuration (Multipoint ground). They present the minimum and maximum values among the five reference points in the bay cross-section.

The AC magnetic fields are shown in Figure 2 plotted to 20 KHz. Note that at 20 KHz the noise curves are either below or approaching the limit of Reference 2 for magnetic field emissions from equipment (RE04). Any equipment located in the payload bay could radiate at that level regardless of the DC power grounding configuration. If the noise curves were continued above 20 KHz, the roll-off should continue at 25 dB/decade to 2 MHz leveling out from that point to 50 MHz. This spectrum is based on the Reference 2. specification limits between 20 KHz and 50 MHz (CE-03 and CE-04).

2.4 Magnetic Fields From Single Point Ground Configuration

For this configuration, a specific geometry must be assumed for the power and return conductor. It must also be assumed that the Orbiter power distribution system is modified such that no loads are dioded between buses and that all equipment power returns be dedicated to the particular bus which supplies the power. These conditions are necessary to derive the potential advantage of a single point ground system. If, for example, the current returning on Bus A return is not equal in amplitude and opposite in phase to the current on Bus A power conductor, maximum magnetic field cancellation cannot occur. AC fields might even be increased.

The rationale for the wiring geometry assumed is as follows. The forward to aft bus power conductors are "0" gage wires almost 1/2 inch in diameter. There are two of these wires along the length of the payload bay for each of the three buses. At least two more wires of the same size would be required for bus return conductors. Each bus then would have four "0" gage conductors. It is impractical, because of the size of the conductors, to twist the power and return conductor together, a practice commonly used to reduce magnetic fields. It does seem feasible however, from a manufacturing point of view, to tightly lace a power and conductor together along the length of the wire tray. Each bus would then have two pair of tightly laced conductors laid closely adjacent. For the purpose of this paper it is assumed that each pair of power and return conductors are in direct contact (insulation layer to insulation layer) for the length of the bay and that the two pair associated with each bus are closely adjacent. The distance between centers of each laced pair is then equal to the outside diameter of one wire, 0.463 inches or .012 meters. This distance is the determining factor in calculating the fields for the single point grounding configuration.

$$H = \frac{I}{2\pi\left(R-\frac{.012}{2}\right)} - \frac{I}{2\pi\left(R+\frac{.012}{2}\right)} = \frac{I}{2\pi}\left(\frac{1}{R-\frac{.012}{2}} - \frac{1}{R+\frac{.012}{2}}\right)$$

where R is the distance to the midpoint of each laced pair

i.e. R = 2.42 meters from the centerline of the payload bay

The magnetic field coefficients are calculated as a range of field intensities. The polarity of the Y and Z components for any one bus will vary depending on whether the power or return conductor is nearer the reference point, so that the summation of the components will have a range of values. The range of field coefficients are given in Table IX. Minimum and maximum DC values resulting from 100 amperes current on each bus are given in Table X. AC fields are calculated using the maximum value coefficients and are plotted on Figure 2.

2.5 Comparison of Fields from MPG/SPG Configuration

To determine the potential improvement offered by the Single Point Ground configuration, the DC values of the payload centerline are taken as typical.

$$\text{Improvement} = 20 \log \frac{8.289 \text{ (From Table IX)}}{.2936 \text{ (From Table XI)}} = 29 \text{ dB}$$

This is typical for all locations.

Inspection of the spectral plots of Figure 2. reveals the differences between the two configurations for the AC fields is approximately 30 dB (comparing maximum to maximum or minimum to minimum values).

3.0 CONCLUSIONS

Comparisons of the AC and DC fields generated by the two grounding configurations indicate an improvement of approximately 30 db for the single point ground system.

The maximum absolute DC values for the Multipoint (MPG) and Single Point (SPG) ground configuration, assumming 100 AMPS on each bus, are:

MPG = 11.5 AMPS/METER, SPG = 0.38 AMPS/METER

The maximum absolute AC values are:

MPG = 117 dBμ AMP/METER, SPG = 77 dBμ AMP/METER

No requirement or other criteria relating to magnetic fields in the payload bay are known to exist at this time. This analysis is presented as an aid to understanding the magnitudes resulting from the present configuration and the amount of improvement to be expected from installing a single point ground system for the DC buses through the payload bay.

4.0 REFERENCES

1. "Electromagnetics", John D. Kraus, McGraw-Hill, Section 4-17.

2. JSC-SL-E-0002, Specification, Electromagnetic Interference Characteristics, Requirements for Equipment for the Space Shuttle Program.

SUMMARY OF MAGNETIC FIELD COEFFICIENTS FOR POWER CONDUCTORS

COORDINATES

Y	Z	H_Y	H_Z
0	0	$(-.0410)(I_A+I_B+I_C)$	$(.0497)(I_A-I_B-I_C)$
0	-2	$(.0184)(I_A+I_B+I_C)$	$(.0795)(I_A-I_B-I_C)$
2	0	$(-.0185)(I_A+I_B+I_C)$	$(.0348)(I_A-I_B-I_C)$
0	2	$(-.0141)I_A+(-.1010)(I_B+I_C)$	$(.0352)I_A+(.0063)(I_B+I_C)$
-2	0	$(-.1010)I_A+(-.0141)(I_B+I_C)$	$(-.0063)I_A+(-.0352)(I_B+I_C)$

TABLE II

SUMMATION OF RETURN CURRENT FIELD COEFFICIENTS AT PAYLOAD BAY CENTERLINE

	HY	HZ
RIGHT SIDE SECTION	2.280×10^{-3}	4.98×10^{-3}
LEFT SIDE SECTION	3.790×10^{-3}	-8.280×10^{-3}
BOTTOM SECTION	1.048×10^{-2}	0
RIGHT WIRE TRAY	1.571×10^{-3}	2.569×10^{-3}
LEFT WIRE TRAY	1.571×10^{-3}	-2.569×10^{-3}
RIGHT SILL LONGERON	0	6.47×10^{-3}
LEFT SILL LONGERON	0	-6.47×10^{-3}
RIGHT LOWER LONGERON	1.090×10^{-3}	1.038×10^{-3}
LEFT LOWER LONGERON	1.135×10^{-3}	-1.090×10^{-3}
TOTAL	2.1917×10^{-2}	-3.352×10^{-3}

$I_A \simeq$ BUS A CURRENT, I_B = BUS B CURRENT, I_C = BUS C CURRENT

FIELD AT CENTER FROM DC POWER CONDUCTORS

$HY = (-.0410)(I_A+I_B+I_C)$ $\quad$ $HZ + (.0497)(I_A-I_B-I_C)$ FROM TABLE II

TOTAL FIELD AT PAYLOAD BAY CENTERLINE (SUM OF COEFFICIENTS OF POWER & RETURN CURRENTS)

$HY = (-.019)(I_A+I_B+I_C)$, $HZ = (.0463)\ I_A+(-.0531)I_B+I_C$

TABLE III

SUMMATION OF RETURN CURRENT FIELD COEFFICIENTS

AT Y = 0, Z = -2

	H_Y	H_Z
RIGHT SIDE SECTION	-9.51×10^{-4}	5.768×10^{-3}
LEFT SIDE SECTION	-1.582×10^{-3}	-9.592×10^{-3}
BOTTOM SECTION	1.7626×10^{-2}	0
RIGHT WIRE TRAY	-1.567×10^{-3}	4.654×10^{-3}
LEFT WIRE TRAY	-1.567×10^{-3}	-4.654×10^{-3}
RIGHT SILL LONGERON	-3.107×10^{-3}	4.146×10^{-3}
LEFT SILL LONGERON	-3.107×10^{-3}	-4.146×10^{-3}
RIGHT LOWER LONGERON	5.96×10^{-4}	2.00×10^{-3}
LEFT LOWER LONGERON	6.52×10^{-4}	-2.187×10^{-3}
TOTAL	6.99×10^{-3}	4.01×10^{-3}

I_A = BUS A CURRENT, I_B = BUS B CURRENT, I_C = BUS C CURRENT

FIELD AT Y = 0, A = -2 FROM D.C. POWER CONDUCTORS

$HY = (.0184)\ (I_A+I_B+I_C)$, $HZ = I_A(.0795)+(-.0795)(I_B+I_C)$ FROM TABLE II

TOTAL FIELD AT Y = 0, Z = -2 (SUM OF COEFFICIENTS OF POWER & RETURN CURRENTS)

$HY = (.0114)\ (I_A+I_B+I_C)$ $HZ = I_A(.0755)+(-.0835)(I_B+I_C)$

TABLE IV

SUMMATION OF RETURN CURRENT FIELD COEFFICIENTS

AT Y = 0, Z = 2

	H_Y	H_Z
RIGHT SIDE SECTION	2.972×10^{-3}	2.688×10^{-3}
LEFT SIDE SECTION	4.942×10^{-3}	-4.470×10^{-3}
BOTTOM SECTION	6.980×10^{-3}	0
RIGHT WIRE TRAY	3.300×10^{-3}	2.042×10^{-3}
LEFT WIRE TRAY	3.300×10^{-3}	-2.042×10^{-3}
RIGHT SILL LONGERON	3.110×10^{-3}	4.150×10^{-3}
LEFT SILL LONGERON	3.110×10^{-3}	-4.150×10^{-3}
RIGHT LOWER LONGERON	9.25×10^{-4}	5.15×10^{-4}
LEFT LOWER LONGERON	1.011×10^{-3}	-5.63×10^{-4}
TOTAL	2.965×10^{-2}	-1.830×10^{-3}

I_A = BUS A CURRENT, I_B = BUS B CURRENT, I_C = BUS C CURRENT

FIELD AT Y = 0, Z = 2 FROM DC POWER CONDUCTORS

HY = $(-.0185)(I_A+I_B+I_C)$ HZ = $(.0348)\ I_A + (-.0348)(I_B+I_C)$ FROM TABLE II

TOTAL FIELD AT Y = 0, Z = 2 (SUM OF COEFFICIENTS OF POWER & RETURN CURRENTS)

HY = $(.0111)(I_A+I_B+I_C)$ HZ = $(.0330)I_A+(-.0360)(I_B+I_C)$

TABLE V

SUMMATION OF RETURN CURRENT FIELD COEFFICIENTS

AT Y = 2, Z = 0

	HY	HZ
RIGHT SIDE SECTION	9.43×10^{-4}	3.32×10^{-3}
LEFT SIDE SECTION	1.4930×10^{-2}	1.368×10^{-2}
BOTTOM SECTION	8.038×10^{-3}	3.389×10^{-3}
RIGHT WIRE TRAY	1.094×10^{-3}	3.369×10^{-3}
LEFT WIRE TRAY	9.980×10^{-3}	-5.04×10^{-4}
RIGHT SILL LONGERON	0	3.700×10^{-3}
LEFT SILL LONGERON	0	-2.5889×10^{-2}
RIGHT LOWER LONGERON	6.00×10^{-4}	8.11×10^{-4}
LEFT LOWER LONGERON	2.149×10^{-3}	-5.15×10^{-4}
TOTAL	3.7734×10^{-2}	1.361×10^{-3}

I_A = BUS A CURRENT, I_B = BUS B CURRENT, I_C = BUS C CURRENT

FIELD AT Y = 2, Z = 0 FROM POWER CONDUCTORS

$HY = I_A(-.0141) + (-.1010)(I_B + I_C)$ $H_Z = I_A(.0352) + (.0063)(I_B + I_C)$ FROM TABLE II

TOTAL FIELD AT Y = 2, Z = 0 (SUM OF COEFFICIENTS OF POWER & RETURN CURRENTS)

$HY = I_A(.0236) + (-.0633)(I_B + I_C)$, $H_Z = I_A(.0366) + (.077)(I_B + I_C)$

TABLE VI

SUMMATION OF RETURN CURRENT FIELD COEFFICIENTS

AT Y = -2, Z = 0

	HY	HZ
RIGHT SIDE SECTION	8.978×10^{-3}	8.227×10^{-3}
LEFT SIDE SECTION	1.568×10^{-3}	-5.552×10^{-3}
BOTTOM SECTION	8.333×10^{-3}	-2.577×10^{-3}
RIGHT WIRE TRAY	9.954×10^{-3}	8.843×10^{-4}
LEFT WIRE TRAY	1.103×10^{-3}	-3.367×10^{-3}
RIGHT SILL LONGERON	0	2.5889×10^{-2}
LEFT SILL LONGERON	0	-3.700×10^{-3}
RIGHT LOWER LONGERON	1.966×10^{-3}	4.709×10^{-4}
LEFT LOWER LONGERON	6.50×10^{-4}	8.88×10^{-4}
TOTAL	3.255×10^{-2}	2.116×10^{-2}

I_A = BUS A CURRENT, I_B = BUS B CURRENT, I_C = BUS C CURRENTS

FIELD AT Y = -2, Z = 0 FROM POWER CONDUCTORS

$H_Y = (-.1010)\ I_A + (-.0141)\ (I_B + I_C)$, $H_Z = (-.0063)\ I_A + (-.0352)\ (I_B + I_C)$ FROM TABLE I

TOTAL FIELD AT Y = -2, Z = 0 (SUM OF COEFFICIENTS OF POWER & RETURN CURRENTS)

$H_Y = (-.0685)\ I_A + (.0184)\ (I_B + I_C)$, $H_A = (.0149)\ I_A + (-.0114)\ (I_B + I_C)$

TABLE VII

TABLE VIII SUMMARY OF MAGNETIC FIELD COEFFICIENTS IN PAYLOAD BAY - STRUCTURE RETURN

COORDINATES Y	Z	H_Y	H_Z
0	0	$(-.0191)(I_A + I_B + I_C)$	$(.0463)\ I_A + (-.0531)(I_B + I_C)$
0	-2	$(-.0114)(I_A + I_B + I_C)$	$(.0755)I_A + (-.0835)(I_B + I_C)$
2	0	$(.0236)I_A + (-.0633)(I_B+I_C)$	$(.0366)I_A + (.077)(I_B + I_C)$
0	2	$(.0111)(I_A + I_B + I_C)$	$(.0330)I_A + (-.0366)(I_B + I_C)$
-2	0	$(-.0685)I_A + (.0184)(I_B+I_C)$	$(.0149)I_A + (-.0114)(I_B + I_C)$

TABLE IX FOR $I_A=I_B=I_C=100$ AMPS, MAGNETIC FIELD IN PAYLOAD BAY (DC)

Y	Z	H(AMP/METER)	ANGLE OF VECTOR
0	0	8.289	226.27°
0	-2	9.768	249.51°
2	0	11.538	153.21°
0	2	5.220	309.64°
-2	0	3.267	193.99°

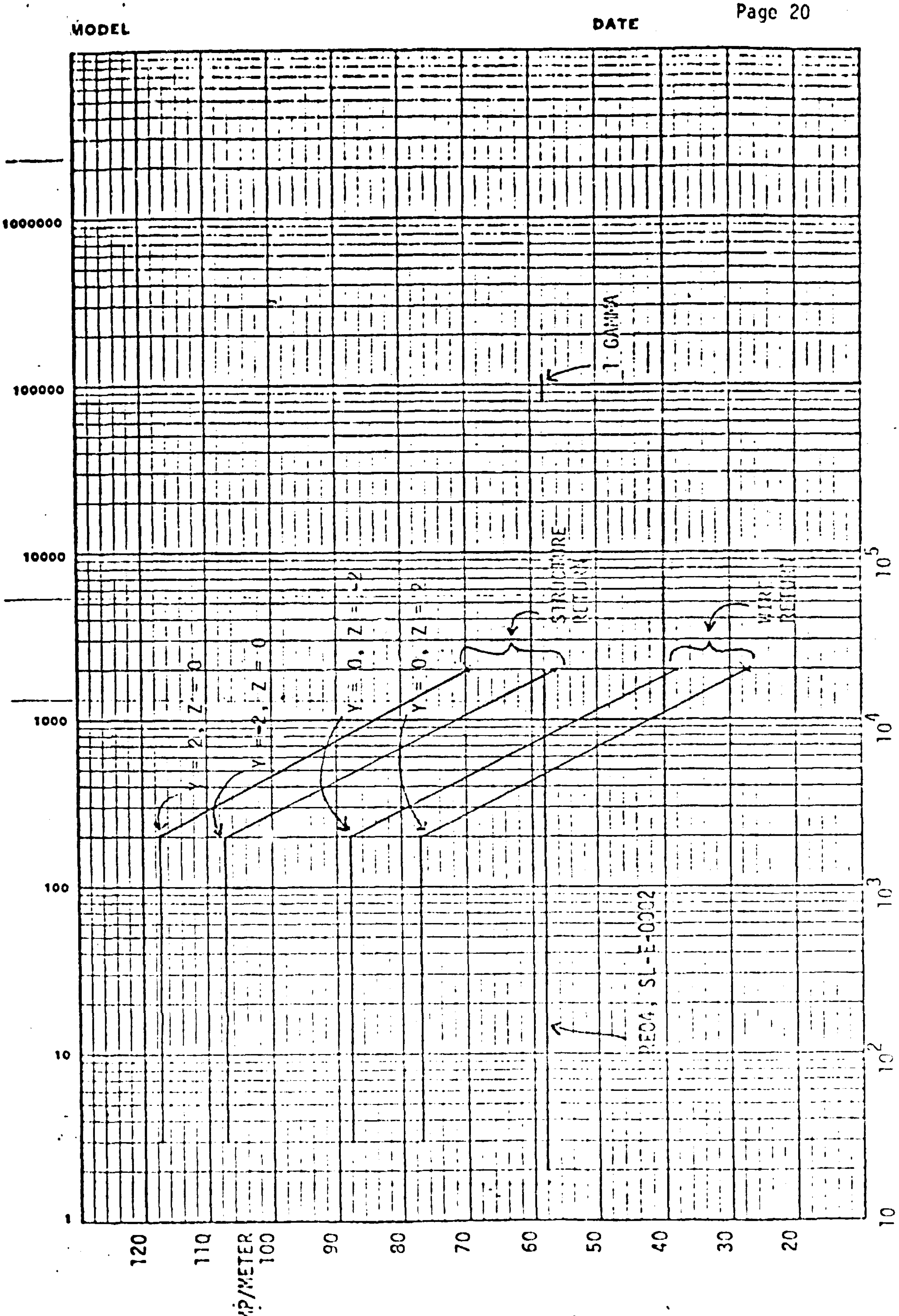
TABLE X SUMMARY OF MAGNETIC FIELD COEFFICIENTS IN PAYLOAD BAY - WIRE RETURN

Y	Z	HY: MIN TO MAX	HZ: MIN TO MAX
0	0	$\pm 1.77\times10^{-4}(I_A+I_B+I_C)$ TO $\pm 5.31\times10^{-4}(I_A+I_B+I_C)$	$\pm 2.74\times10^{-4}(I_A+I_B+I_C)$ TO $\pm 8.22\times10^{-4}(I_A+I_B+I_C)$
0	-2	$\pm 1.43\times10^{-4}(I_A+I_B+I_C)$ TO $\pm 4.29\times10^{-4}(I_A+I_B+I_C)$	$\pm 4.01\times10^{-4}(I_A+I_B+I_C)$ TO $\pm 1.203\times10^{-3}(I_A+I_B+I_C)$
2	0	$\pm 3.31\times 10^{-5}I_A \pm 1.151\times10^{-3}I_B \pm 1.151\times10^{-3}I_C$	$\pm 1.03\times10^{-4}I_A$
0	2	$\pm 1.10\times10^{-4}(I_A+I_B+I_C)$ TO $\pm 3.30\times10^{-4}(I_A+I_B+I_C)$	$\pm 6.7\times10^{-5}(I_A+I_B+I_C)$ TO $\pm 2.01\times10^{-4}(I_A+I_B+I_C)$
-2	0	$\pm 1.15\times10^{-3}I_A \pm 3.31\times10^{-5}I_B \pm 3.31\times10^{-5}I_C$	$\pm 1.03\times10^{-4}I_B \pm 1.03\times10^{-4}I_C$

TABLE XI FOR $I_A=I_B=I_C=100$ AMPS, MAGNETIC FIELD IN PAYLOAD BAY (DC)

Y	Z	H(AMP/METER)* MIN.	H(AMP/METER)* MAX
0	0	.0979	.2936
0	-2	.1277	.3832
2	0	.0108	.2337
0	2	.0386	.1159
-2	0	.1089	.1230

* Absolute magnitude is given. Polarity and angle are unknown due to random orientation of Bus wiring lay.



AC MAGNETIC FIELDS IN PAYLOAD BAY

FIGURE 2.