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IMP-I SPACECRAFT INITIAL MAGNETIC TEST

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GSFC

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

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William L. Eichhorn
Test and Evaluation Division
Systems Reliability Directorate

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Greenbelt, Maryland

IMP-I SPACECRAFT
INITIAL MAGNETIC TEST

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IMP-I SPACECRAFT

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SUMMARY

The IMP-I spacecraft's initial magnetic test, conducted in the Spacecraft Magnetic Test Facility at Goddard Space Flight Center, consisted of dc rotation deperming on two axes. This procedure reduced the perm bias at the location of the flight sensor to within the specified limits (≤ 0.125 nanoteslas on each axis) and reduced the permanent magnetic moment of the spacecraft from 376 to 55 mA-m^2. The flight magnetometer was successfully calibrated on all ranges.

PROJECT STATUS

This is the initial report of the determination of the magnetic properties of the IMP-I protoflight spacecraft. The final test is scheduled for February 1971.

AUTHORIZATION

Test and Evaluation Charge No. 325-801-51-25-02

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INTRODUCTION

The preliminary magnetic test of the IMP-I protoflight spacecraft was conducted at GSFC's Spacecraft Magnetic Test Facility (SMTF) during the period May 25 to June 5, 1970.

The IMP-I mission places stringent requirements on the magnetic characteristics of this spacecraft. A major concern is the field level at the flight-sensor location, which must be kept within design limits for correct magnetometer performance. To keep the spacecraft magnetically clean, most of the subsystems were tested before spacecraft assembly. NASA X-document X-325-70-412 contains a complete description of this test program.* Another concern is the performance of the flight magnetometer. This monitors the interplanetary magnetic field and is located on a boom about 3.5 m (11.5 ft) long.

PURPOSE OF TEST

Test objectives were:

- To determine the amount of magnetic-field disturbance at the flight-magnetometer position, to show whether this value was within acceptable limits
- To determine the spacecraft net dipole moment for permanent, induced, and stray magnetic states
- To determine the spacecraft magnetic interference levels at experiment sensor locations

TEST DESCRIPTION

The Spacecraft Magnetic Test Facility (Appendix A) uses three orthogonal Braunbek coils to produce a homogeneous zero-field test environment and to sustain the highly accurate magnetic fields required for calibration.

*C. A. Harris, October 1970

The spacecraft was mounted on a moveable turntable dolly, with the magnetometer boom pointing along the +X axis of the facility (north) (Figure 1). This dolly was used both as a means of transporting the spacecraft between the coil center and the trucklock and as a means of rotating the spacecraft when in the center of the coil system during remotely controlled rotation.

While in the center of the coil, the spacecraft was enclosed in a nonmagnetic cleanroom shroud to minimize the threat of contamination. A downward stream of clean air was maintained in the shroud at all times.

Four Förster/Hoover MF 5050 triaxial fluxgate magnetometers were used for magnetic measurements. Figure 1 shows the locations of these magnetometers. The output signals of these magnetometers were sent to the operations and instrumentation building, where they were recorded on strip charts and magnetic tape. Microswitches were used to index the strip charts every 10 degrees during a rotation and every foot from the coil center during roll out.

The sensor outputs were digitized and placed on magnetic tape by the magnetic data acquisition system (MADAS). In this system the output of a digital angle encoder is used to initiate the sampling of the 12 sensors every 10 degrees during a rotation. This tape is then processed by a computer for a printout of the data.

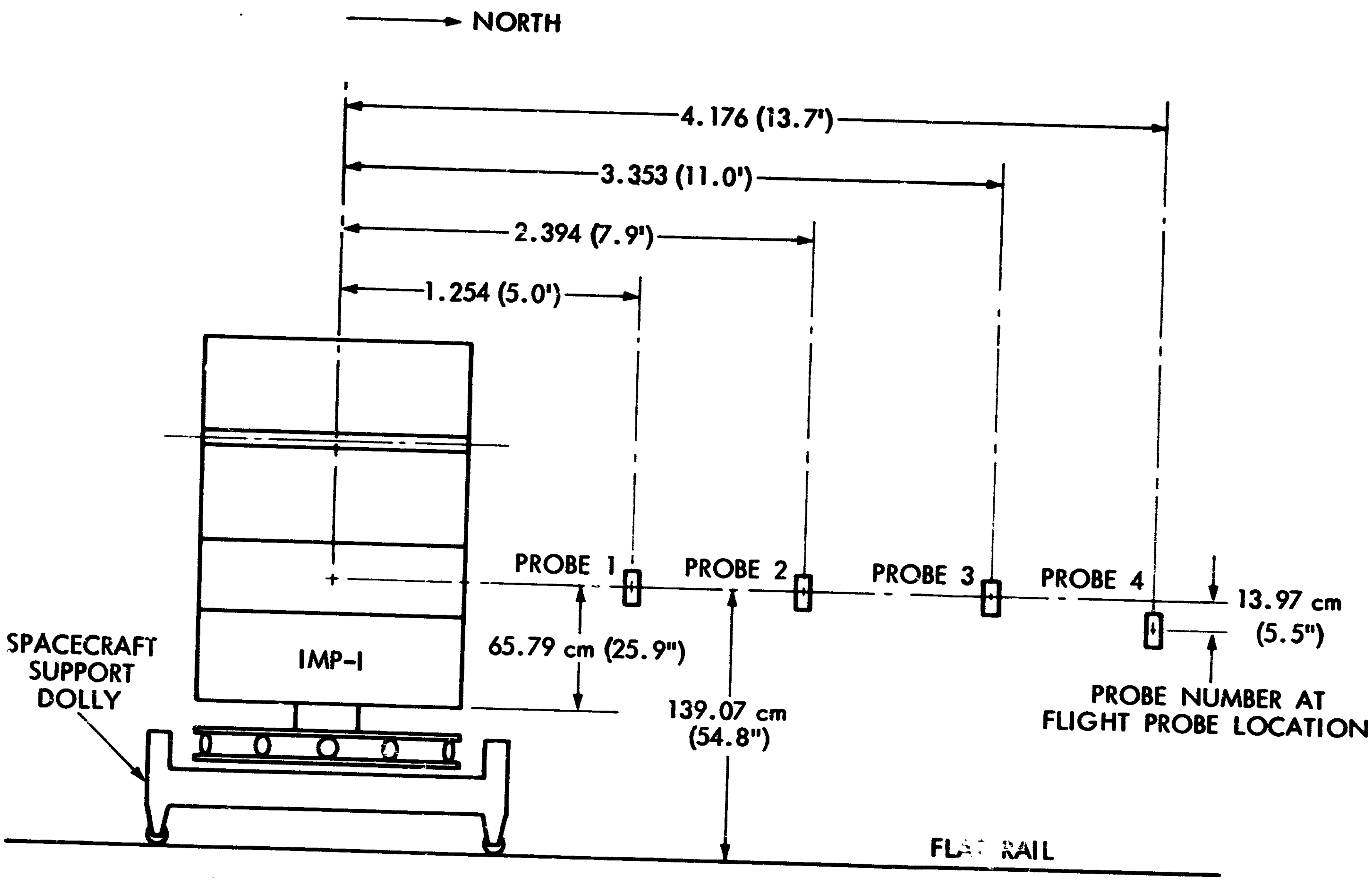
STATIC MAGNETIC STATES

With the spacecraft in the trucklock, a Schoenstedt magnetometer was used to establish zero field at the coil center. The Förster/Hoover magnetometers were adjusted to read zero, and a background was taken on MADAS. The spacecraft was brought to the center, rotated clockwise several times, then returned to the trucklock where another background was taken. The magnetic moments of these states were determined by hand by far-field analysis and on the 3100 computer by near-field analysis.

DYNAMIC MAGNETIC STATES

Induced Moment

With the spacecraft in the trucklock, a field of 10,000 nanotesla north was established at the coil center. The magnetometers were adjusted to read zero, and the spacecraft was rolled in. Rotational data were taken, and the spacecraft was rolled out. In this case, moments were determined by far-field analysis only.



(ALL DIMENSIONS ARE IN METERS UNLESS OTHERWISE INDICATED)

Figure 1. Test Setup for Magnetic Measurements of IMP-I as viewed from the east

Solar Simulation

A battery of sun guns, adjusted so that each band of solar cells received equal illumination, illuminated spacecraft solar panels. Rotational data were taken.

Stray Field

With the spacecraft alternately on external power and on battery power, one experiment was activated at a time to determine the effects of its operation on the spacecraft's magnetic field. No rotational data were taken.

EXPOSURE AND DEPERM

The spacecraft was rotated so that the peak of its magnetic field was along the east-west axis of the coil system. A dc magnetic field of 15×10^{-4} tesla was applied with the two 9-foot coils on either side of the spacecraft. The direction which would maximize spacecraft moment was chosen.

The same pair of coils were used for deperming. During deperming with the spacecraft in the upright position, the spacecraft was rotated at about 9 rpm for 2 minutes while a dc field was decreased from 27×10^{-4} tesla to zero. For Z-axis deperm, the spacecraft was placed on its own dolly with the spin axis horizontal, and a similar treatment was conducted.

MAGNETOMETER CALIBRATION

The spacecraft's flight magnetometer was calibrated with the spacecraft located so that the magnetometer on its fully deployed boom was at the center of the facility (Figure 2). The magnetometer was aligned through the alignment of the axes of the spacecraft with those of the coil system. The Spacecraft Magnetic Test Facility artificial field system incrementally applied field vectors to calibrate each axis of the sensor at 11 points on each range. Spacecraft spin was simulated by rotating the magnetic field of the coil system at 5 rpm in the horizontal plane.

POWERDOWN QUIET TEST

All ac power to the magnetic test site was turned off while the spacecraft's crew conducted electromagnetic interference tests.

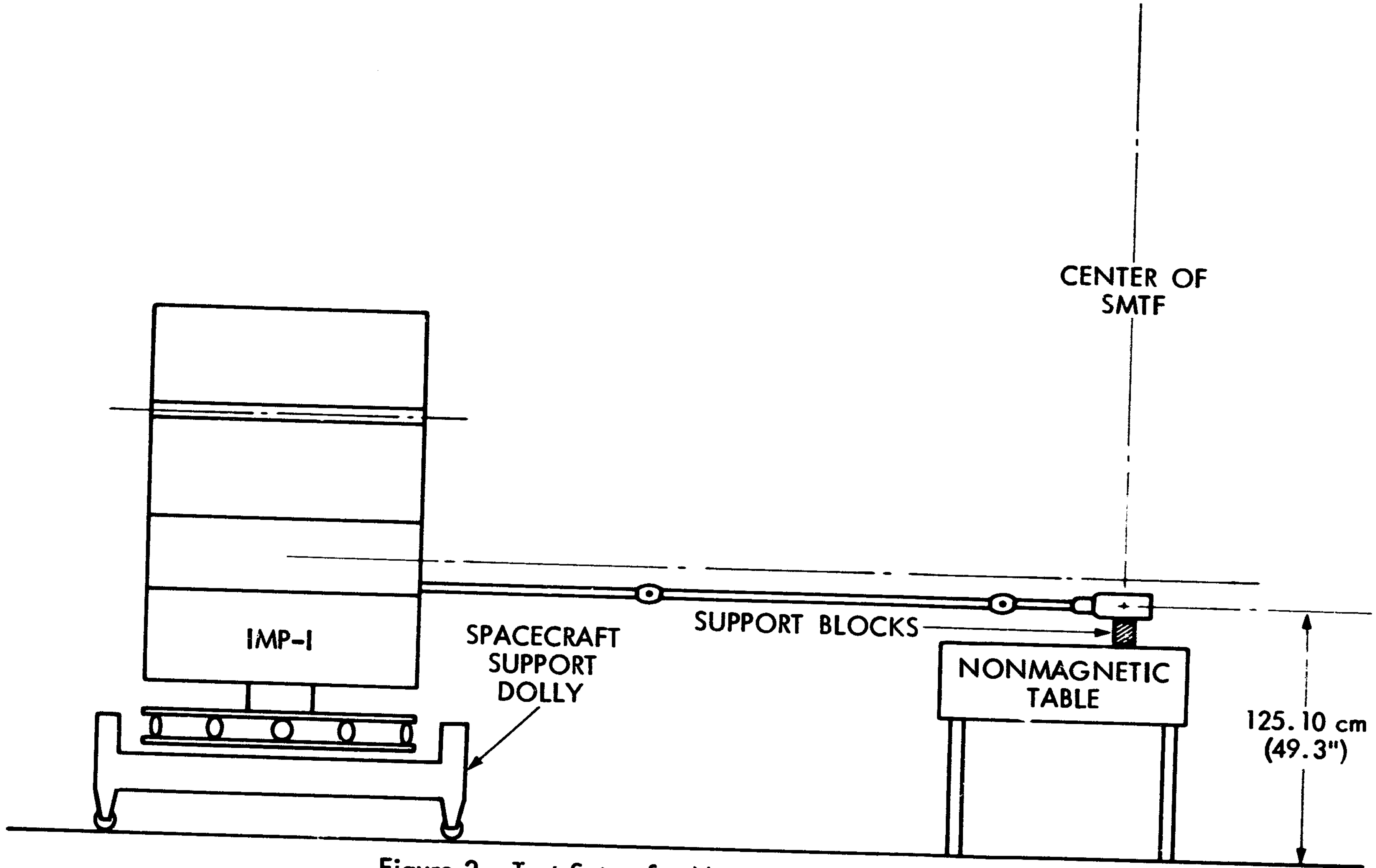


Figure 2. Test Setup for Magnetometer Calibration

RESULTS AND DISCUSSION

Table 1 lists general field levels seen during each of the tests, by giving peak-to-peak field excursion seen on each of the sensors, and the in-versus-out reading for each state. The data in the table indicate that the spacecraft was magnetically clean.

Tables 2 and 3 list the calculated values for the spacecraft moments for each state. The moments listed in Table 2 were determined from data taken on the probe at 11 feet by far-field analysis, which assumes that the spacecraft's field is purely dipolar. Appendix B contains an example of far-field analysis.

The moments of the spacecraft in the static magnetic states were determined, from the complete field signatures seen on the closest sensors, by near-field analysis. Table 3 lists the results. The calculations were done on the 3100 computer; Appendix B explains this procedure and the theory behind it.

Data taken on magnetometers 1 and 2 were used for the initial and post-exposure moments. The moments for the other perm states were determined from data taken on magnetometer 1 because data taken on the other sensors were considered too weak to be reliable for near-field analysis. Values calculated from this limited amount of data were found to be consistent with the observed data when expected field levels on the other sensors were calculated.

After the first deperm of the spacecraft, the field magnitudes seen at the flight-magnetometer position warranted a Z-axis deperm treatment. After this and another standard deperm were performed, the perm bias at the flight sensor was found to be within design limitations (≤ 0.125 nanoteslas on each axis).

The final moments as determined by near-field analysis were:

$$M_x = 3 \pm 15 \text{ mA-m}^2$$

$$M_y = 6 \pm 15 \text{ mA-m}^2$$

$$M_z \; 55 \pm 15 \text{ mA-m}^2$$

CONCLUSIONS

The magnetic moment of the IMP-I spacecraft was reduced from an initial value of $376 \pm 20 \times 10^{-3}$ A-m^2 to a final value of 55 ± 20 mA-m^2 by several dc rotation deperm treatments. These treatments also reduced to zero the perm bias at the flight magnetometer.

Table 1
IMP-I Magnetic Fields (in Nanoteslas)

Magnetic State	Data	Magnetometer 1			Magnetometer 2			Magnetometer 3			Magnetometer 4		
		X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
Initial	In/out	-10	-3	+12	-2	-0.5	+2.5	-1	0	+1	-0.5	0	+5
	P-to-P	16	7	7	2.5	1	1.2	0.5	0.2	0	0.5	0	0
Post 15 x 10^{-4} tesla expo-sure	In/out	-60	-10	+10	-12	-2	+2.5	-4.5	-0.8	+0.1	-2.5	-0.5	+0.5
	P-to-P	120	40	5	24	10	0	8.5	4	0	4.3	2	0
Post final deperm	In/out	-1	0	2.5	-5	0	0.4	0	0	0	0	<0.1	0
	P-to-P	2.5	2.0	3.5	0	0.2	0.6	0	0	0.2	0	<0.1	0
Perm plus in-duced (0.1 x 10^{-4} tesla applied)	In/out	7.2	0.5	3.5	-1.1	0	0.6	0.6	0	0	-0.4	0	0
	P-to-P	2	1.5	3.5	0.3	0.4	0.5	0	0	0			
Stray		RF	RF	RF	1.2	0.6	0.7	0.6	0.1	0.1	RF	RF	RF
Solar simulation		RF	RF	RF	0.4	0.2	0.8	RF	RF	RF	<0.1	0	0
Final	In/out	-1	0	+5	-0.4	0	0.5	0	0	0	0	0	0
	P-to-P	2.5	1.5	3.5	0.6	0.2	0.6	0	0	0	0	0	0

Table 2
IMP-I Magnetic Moments by Far-Field Analysis in mA-m^2

State	Mxy	Mz	Mt
Initial	47	380	382
Post 15 x 10^{-4} tesla exposure	800	380	885
Post deperm	14	56	58
Induced + perm	120	82	145
Stray + perm	66		
Post stray	14	68	69
Solar simulation	14		
Final	14	68	69

Table 3
IMP-I Magnetic Moments by Near-Field Analysis in mA-m^2

State	Mx	My	Mz	Mt
Initial	41 ±20	-54 ±20	370 ±20	376 ±35
Post exposure	657 ±16	-235 ±20	284 ±20	751 ±35
Post deperm	+6 ±15	-3 ±15	55 ±15	56 ±25
Post stray	+3 ±15	+6 ±15	55 ±15	56 ±25
Final	3 ±15	6 ±15	55 ±15	56 ±25

The relative weakness of the initial field of the spacecraft attests to the effectiveness of the IMP-I magnetics control program. This program placed strict magnetic requirements on all spacecraft subsystems in order to create a magnetically clean spacecraft.

APPENDIX A

SPACECRAFT MAGNETIC TEST FACILITY

The Spacecraft Magnetic Test Facility provides a controlled magnetic environment for magnetic testing of spacecraft or spacecraft components. The 12.8-meter (42-ft) diameter, 3-axis coil system permits the establishment of zero field or of a field of any desired magnitude and direction with a maximum of 60,000 nanoteslas (gamma) per component. Current-regulated power supplies provide stability of ±1 nanotesla (gamma) over a 24-hour period, and the coil geometry provides uniformity of field within 0.6 nanoteslas (gamma) over a spheric volume of 1 meter (3.2 ft). Three earth's field magnetometers and associated control systems provide automatic compensation for the daily variation of the earth's field.

In addition to being capable of generating static magnetic fields, programmed coil currents can produce a vector which will rotate about any desired axis through the center of the coil system at a maximum of 100 radians per second. The magnitude of the rotating vector has a maximum limit of 60,000 nanoteslas (gammas).

The facility is equipped with a 22,200-newton (5000-pound) capacity overhead hoist; a 8800-newton (2000-pound) capacity hydroset for gentle handling of delicate spacecraft; a track system and dolly for transporting the spacecraft from the trucklock to the center of the coil system; and, at the coil center, a turntable which is powered to rotate the spacecraft while it is centered in the coil. The turntable has an angle encoder to synchronize angular position and magnetic measurements. In addition, the facility has a gimbal for producing spacecraft rotation about a horizontal axis.

A portable Helmholtz coil pair, 2.74-meter (9-ft) diameter, can provide fields up to 25×10^{-4} tesla (25 gauss) for perming and deperming the spacecraft along one axis. A 1.53-meter (5-ft) diameter coil is also available for applying such fields along a second axis of the smaller spacecraft.

A highly sensitive torquemeter, located directly below the turntable, permits direct measurement of torques resulting from interaction between the magnetic moment of the spacecraft under test and the field produced by the coil system. The torquemeter can be rigged to accept loads up to 22,200 newtons (5000 pounds) and to measure torques to an accuracy of 50×10^{-7} newton-meters (50 dyne centimeters).

Four triaxial fluxgate magnetometers may be used simultaneously to provide meter display, strip-chart records, or digital-printout records. The positions of the magnetometer probes may be varied to suit the needs of the individual subsystem or spacecraft under test.

Figure A-1 shows the Spacecraft Magnetic Test Facility. Figure A-2 shows the IMP-I spacecraft under test.

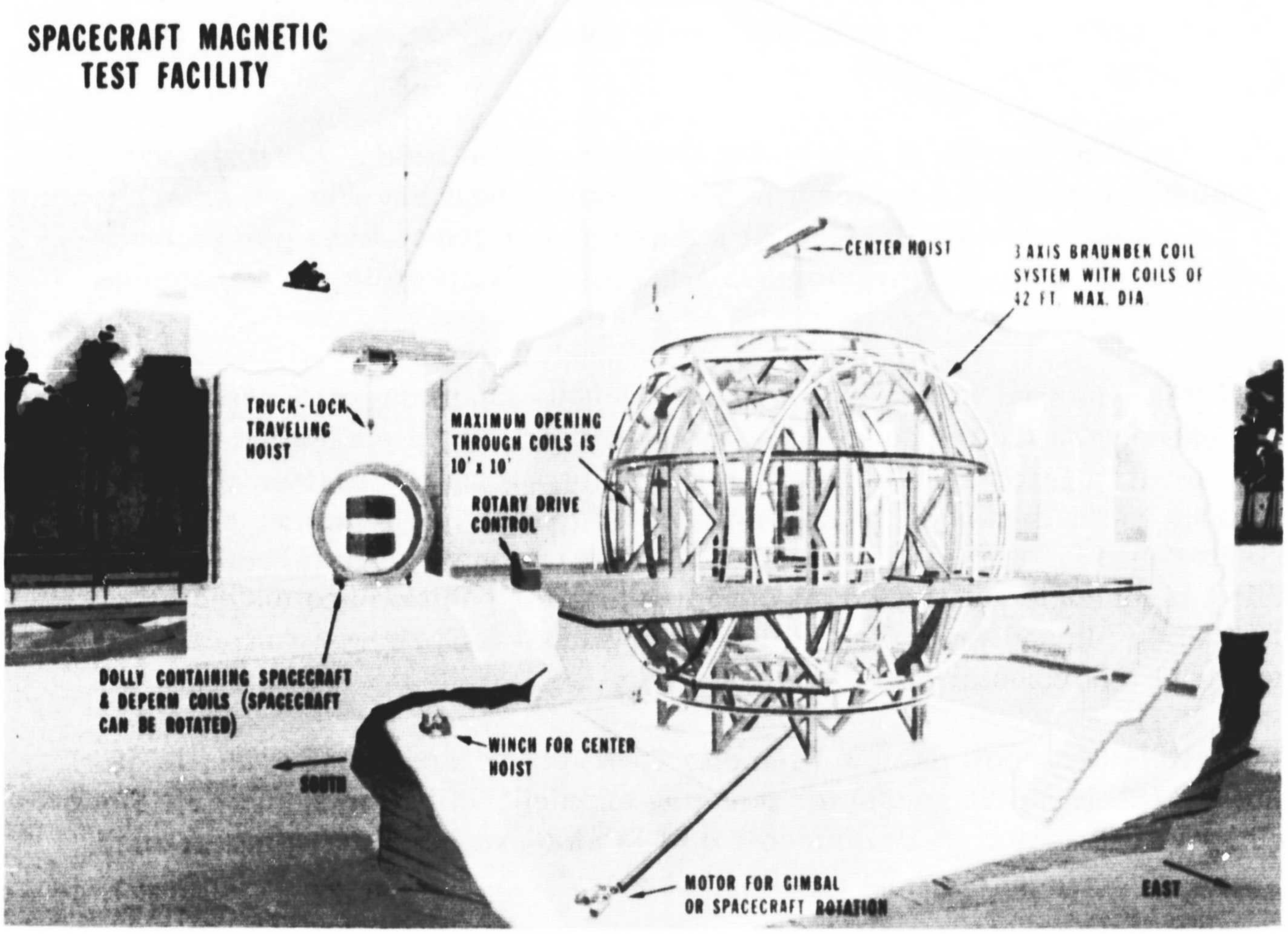


Figure A-1. Spacecraft Magnetic Test Facility

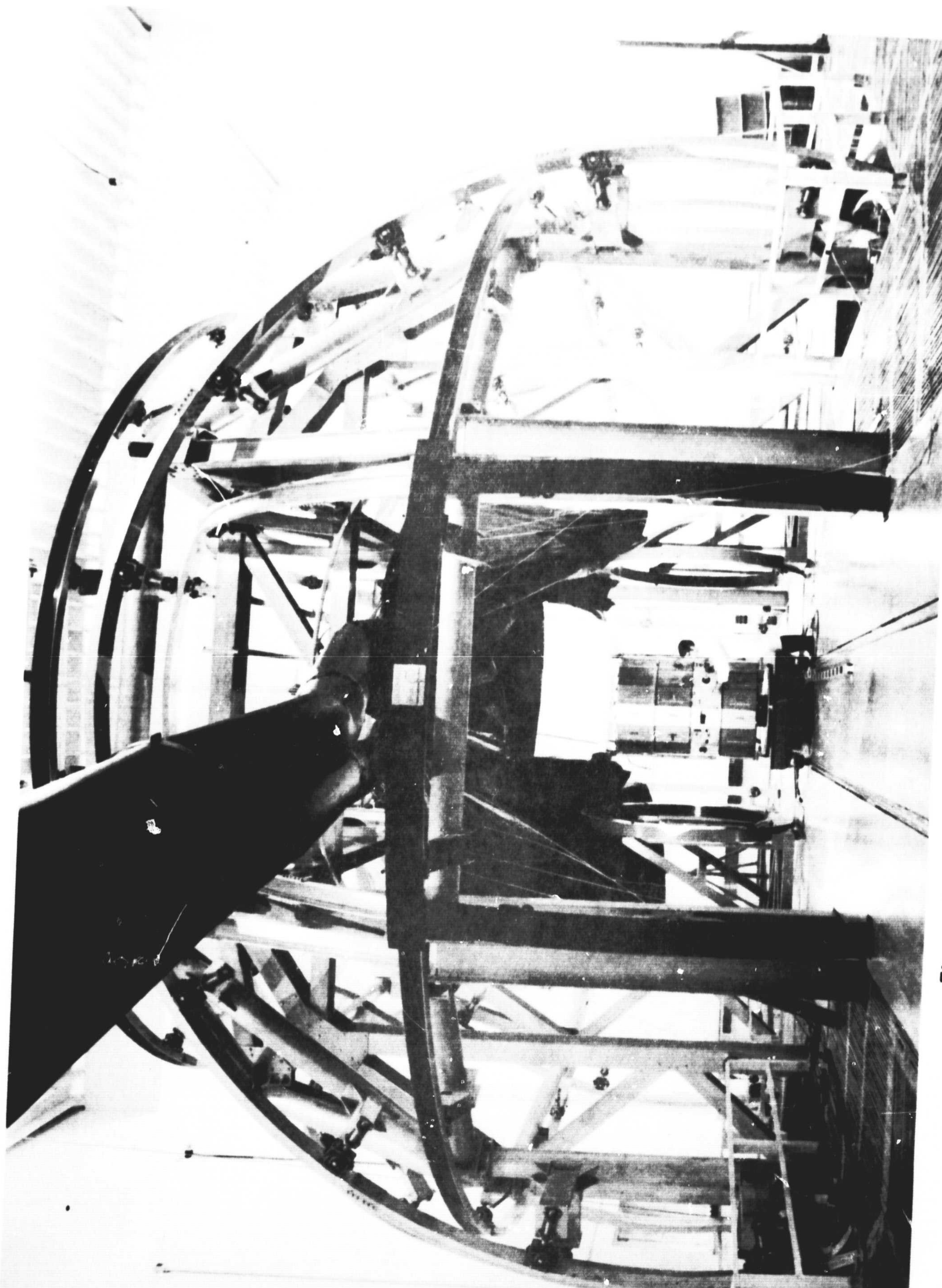


Figure A-2. Spacecraft in the Magnetic Test Facility

APPENDIX B

DATA-ANALYSIS PROCEDURES

NEAR-FIELD ANALYSIS

Data on the perm states of the spacecraft were input into the 3100 computer for near-field analysis, a procedure using the premise that the spacecraft's magnetic field is a superposition of a finite number of multiple fields.

As the spacecraft is rotated past the fixed probes, a set of field signatures can be obtained. Each of these signatures can be broken down into its Fourier components, which can be related to the multipole moments of the spacecraft. The X- and Y-axis dipole moment components are related only to the fundamental sine and cosine amplitudes on the horizontal sensors; the Z-axis moment component is related to the dc amplitude on the vertical sensors.

The dipole moment component can be solved by first calculating the necessary Fourier amplitudes from the field signatures and then determining, by a least-squares procedure, the most probable sets of multiple coefficients consistent with these amplitudes. For example, after spacecraft exposure, data was obtained on two magnetometers located at 152.4 cm and 239.4 cm (Table B-1). Analysis for all three moment components was essentially the same. For one axis:

$$CX_i = \text{cosine amplitude of sensor } X_i \ (i = 1,2)$$

$$SY_i = \text{sine amplitude of sensor } Y_i$$

After analysis of the data in Table B-1,

$$CX_1 = 48.932 \pm 0.05 \text{ nanoteslas}$$

$$CX_2 = 10.066 \pm 0.05 \text{ nanoteslas}$$

$$SY_1 = -21.571 \pm 0.254 \text{ nanoteslas}$$

$$SY_2 = -4.927 \pm 0.253 \text{ nanoteslas}$$

From these quantities the most probable X-axis dipole moment of the state is determined. These fields are almost dipolar. For a pure dipole $CX_2 = 0.258\ CX_1$, $SX_2 = 0.258\ SX_1$, $|CX_2| = 2\ |SY_2|$, $CX_1 = 2\ |SY_1|$.

Table B-1
Near Field Data (in nanoteslas (gammas))

Relation Angle	Magnetometer 1			Magnetometer 2		
Theta	X	Y	Z	X	Y	Z
0	60.600	13.600	-12.286	11.200	3.400	-1.761
10.0	64.500	6.600	-12.586	11.900	2.300	-1.761
20.0	63.700	-0.600	-12.386	12.200	1.000	-2.061
30.0	58.400	-6.500	-11.886	12.000	0	-2.261
40.0	51.000	-9.600	-10.286	11.400	-0.600	-2.661
50.0	44.300	-11.200	-9.286	10.500	-1.600	-2.461
60.0	38.900	-11.400	-8.686	8.700	-2.200	-1.461
70.0	33.300	-12.800	-7.386	7.900	-2.400	-2.361
80.0	28.300	-14.700	-7.286	5.900	-2.300	-1.661
90.0	21.500	-16.600	-6.186	4.900	-3.100	-2.261
100.0	14.500	-18.300	-6.286	2.600	-3.100	-1.561
110.0	6.100	-19.000	-5.486	0.700	-4.100	-1.961
120.0	-1.500	-19.000	-5.086	-0.200	-3.300	-1.861
130.0	-8.900	-19.200	-5.386	-2.400	-3.500	-1.461
140.0	-17.500	-18.500	-4.586	-3.900	-3.600	-1.861
150.0	-25.800	-18.000	-5.486	-6.200	-3.100	-1.561
160.0	-35.300	-17.000	-5.586	-7.300	-1.800	-2.161
170.0	-44.200	-13.300	-6.786	-8.800	-0.800	-2.061
180.0	-51.200	-7.600	-7.786	-9.800	0	-2.161
190.0	-54.500	0	-8.986	-10.300	0.600	-2.461
200.0	-53.400	6.900	-9.386	-10.300	1.800	-2.461
210.0	-47.800	12.700	-9.786	-10.500	2.600	-1.861
220.0	-41.500	16.000	-8.786	-8.800	3.700	-2.261
230.0	-33.900	17.900	-8.786	-8.300	4.300	-1.961
240.0	-27.800	18.700	-7.586	-6.400	4.800	-2.761
250.0	-21.300	19.300	-7.786	-5.700	5.800	-1.661
260.0	-15.400	20.000	-7.386	-4.100	5.800	-1.661
270.0	-9.700	20.900	-6.786	-2.300	5.600	-1.961
280.0	-3.600	20.500	-6.886	-0.700	6.300	-1.761
290.0	0.600	21.300	-6.386	0	6.000	-1.761
300.0	6.800	21.200	-6.786	1.700	6.700	-1.561
310.0	13.200	22.800	-6.586	3.700	6.400	-2.161
320.0	21.800	23.600	-7.886	4.800	6.500	-1.761
330.0	31.400	23.800	-8.786	6.900	5.900	-1.961
340.0	41.100	23.300	-9.486	9.000	5.000	-2.461
350.0	51.800	20.100	-10.786	10.300	4.100	-2.161

Therefore, it can be assumed that the field seen is approximately a dipole plus an octupole field.

M_x = X-axis dipole moment

M_8 = X-axis octupole moment of concern

r = 152.4 cm

r_2 = 239.4 cm

$R_2 = r_1/r_2$

$A = M_x/r_1^3 \qquad B = M_8/r_1^5$

The equations to be solved by a least-squares procedure are:

$$
\begin{aligned}
CX_1 &= 2A - 6B \\
CX_2 &= 2AR_2^3 - 6BR_2^5 \\
-SX_1 &= A - 3/2\ B \\
-SX_2 &= AR_2^3 - 3/2\ BR_2^5
\end{aligned}
\qquad (1)
$$

The solution:

$A = 18.561 \pm 0.435$ nanoteslas

$B = -1.892 \pm 0.1461$ nanoteslas

To determine the validity of these answers, these values are assumed to be correct and the Fourier amplitudes which they would produce are sought. Substitution of the calculated values for A and B into (1) yields the following values for the expected coefficients:

CX_1^e = 48.474 nanoteslas

CX_2^e = 10.764 nanoteslas

SY_1^e = -21.399 nanoteslas

SY_2^e = -5.08 nanoteslas

Because these values are very close to the measured ones, the values for A and B are assumed to be correct. Mx is calculated:

$$M_X = Ar_1^3$$

$$M_X = 656.98 \pm 15 \text{ mA-m}^2$$

FAR-FIELD ANALYSIS

Far-field analysis assumes that each sensor is remote enough from the magnetic source that all multipoles higher than the dipole can be neglected. The field seen by a given sensor is then related to the dipole moment by:

$$H = 2m/r^3 \text{ radially oriented sensor}$$

$$H = m/r^3 \text{ tangentially oriented sensor,}$$

where m is the moment parallel to the sensor, r is the radius of the sensor, and H is the field seen on the sensor.

APPENDIX C

CHRONOLOGY

<u>Monday, May 25, 1970</u>

Spacecraft placed on MTF dolly

Initial, exposed, depermed states measured

<u>Tuesday, May 26, 1970</u>

Tip over deperm and standard deperm 2 done

Induced measurements made

<u>Wednesday, May 27, 1970</u>

Stray field measurements made

Induced measurements made

<u>Thursday, May 28, 1970</u>

ac power to MTF turned off at 10:30 a.m.

Power down quiet test performed

<u>Monday, June 1, 1970</u>

Solar simulation test performed

<u>Tuesday, June 2, 1970</u>

Flight probe boom depermed

<u>Wednesday, June 3, 1970</u>

Spacecraft malfunctioned — no magnetic tests performed

<u>Thursday, June 4, 1970</u>

Flight magnetometer calibrated

<u>Friday, June 5, 1970</u>

Spacecraft departed MTF at 10:20 a.m.