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ISIS-B SPACECRAFT MAGNETIC TESTS

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GSFC
GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

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ABSTRACT

This report describes the magnetic testing of the ISIS B spacecraft in the Spacecraft Magnetic Test Facility at Goddard Space Flight Center. The purpose of the tests was to determine the various magnetic moments of the spacecraft, evaluate its spin and attitude control systems, and calibrate the six onboard magnetometer probes.

Test procedures and equipment are described. Techniques for evaluating the data are discussed, and test results are presented.

The spacecraft's magnetic characteristics were found to be satisfactory. Proper threshold values for gating the torquing coils were obtained. The onboard magnetometers were satisfactorily calibrated.

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INTRODUCTION

The second International Satellite for Ionospheric Studies (ISIS B) is to be spin stabilized at a nominal 3-rpm rate governed by torque produced by interaction between the terrestrial magnetic field and the magnetic moment generated by toroidal, air-cored coils onboard. In addition, the spin-axis attitude is controlled using the same onboard coils but in a different control mode. A magnetometer aligned normal to the spin axis is used in spin-rate control; a magnetometer parallel to the spin axis is used in conjunction with solar sensors in spin-axis attitude control.

Of the six magnetometer probes onboard, four are associated with experiments and two are associated with spin and attitude control

The attitude and spin control (ASC) system is capable of changing spin at a maximum rate of 0.1 rpm per orbit (2 hours) and of changing spin-axis inclination at a maximum rate of 5.2×10^{-2} radians (3°) per orbit. This requires that the air-cored torquing coils produce a magnetic moment of about 150 000 mA-m^2 (150 000 pole-cm). Whenever the magnetic field component associated with a control mode exceeds approximately 8 A-m^{-1} (100 millioersteds), the torquing coils are gated on to the full 150 000 mA-m^2. Conversely, when the field drops below 8 A-m^{-1}, the torquing coils are gated off.

PURPOSE

The magnetic tests comprise one part of the ISIS B environmental test program as outlined in Reference 1. The objectives of the tests were as follows:

(1) To determine the permanent, induced, and stray magnetic moments of the spacecraft, and to assess its magnetic stability.

(2) To evaluate the ASC system.

(3) To calibrate the six magnetometer probes onboard to determine the effects of the spacecraft permanent, induced, and stray magnetic fields at these probes.

(4) To deperm, compensate, and make any other adjustments necessary to achieve satisfactory magnetic characteristics for the spacecraft.

TEST DESCRIPTION

Setup

A plan view of the GSFC Magnetic Test Site is shown in Figure 1. The tests were conducted in GSFC's Spacecraft Magnetic Test Facility (SMTF), which utilizes a 12-m (40-ft) diameter Braunbek coil system to produce a controlled magnetic field of high uniformity over a large central volume. (The facility is described in Appendix A.)

The ISIS B spacecraft was mounted on the turntable dolly and positioned at the center of the 12-m (40-ft) coil system. The turntable dolly was, in turn, mounted on the Mark III torquemeter located below floor level (also described in Appendix A). The torquemeter was immobilized during the acquisition of magnetic data and was activated for the torque-measuring portion of the test. The normal orientation of the spacecraft's axes during testing was such that its $+x$-axis was directed north, its $+y$-axis directed east, and its $+z$-axis directed upward. The setup is shown in Figure 2.

Magnetic measurements were made at locations 1.524 m (5 ft), 2.134 m (7 ft), 2.743 m (9 ft), and 3.073 m (11 ft) north of the coil system center at an elevation of 1.524 m (5 ft) above the floor level. The signals from the probes, hard wired to the Operations and Instrumentation Building for monitoring, were displayed as meter indications and as analog traces on direct-writing recorders. They were also recorded in digital coding on magnetic tape through the magnetic analog-to-digital acquisition system (MADAS). This instrumentation is shown in Figure 3. The meter readings and analog traces were used for real-time "quick look" monitoring; the MADAS data were processed by a digital computer programmed to perform a near-field analysis of dipole moment.

Torque signals from the Mark III transducer were monitored on a two-channel direct-writing recorder in the truck lock of the SMTF building.

Procedure

Initial magnetic tests consisted of the following:

(1) Measurement of initial permanent dipole moment.

(2) Exposure to 15×10^{-4} T (15 G), and subsequent measurement of dipole moment.

(3) Deperm from 30×10^{-4}-T (30-G) maximum, and subsequent measurement of dipole moment.

(4) Measurement of induced dipole moment.

(5) Measurement of stray field dipole moments.

(6) Measurement of torquing coil dipole moment and torque.

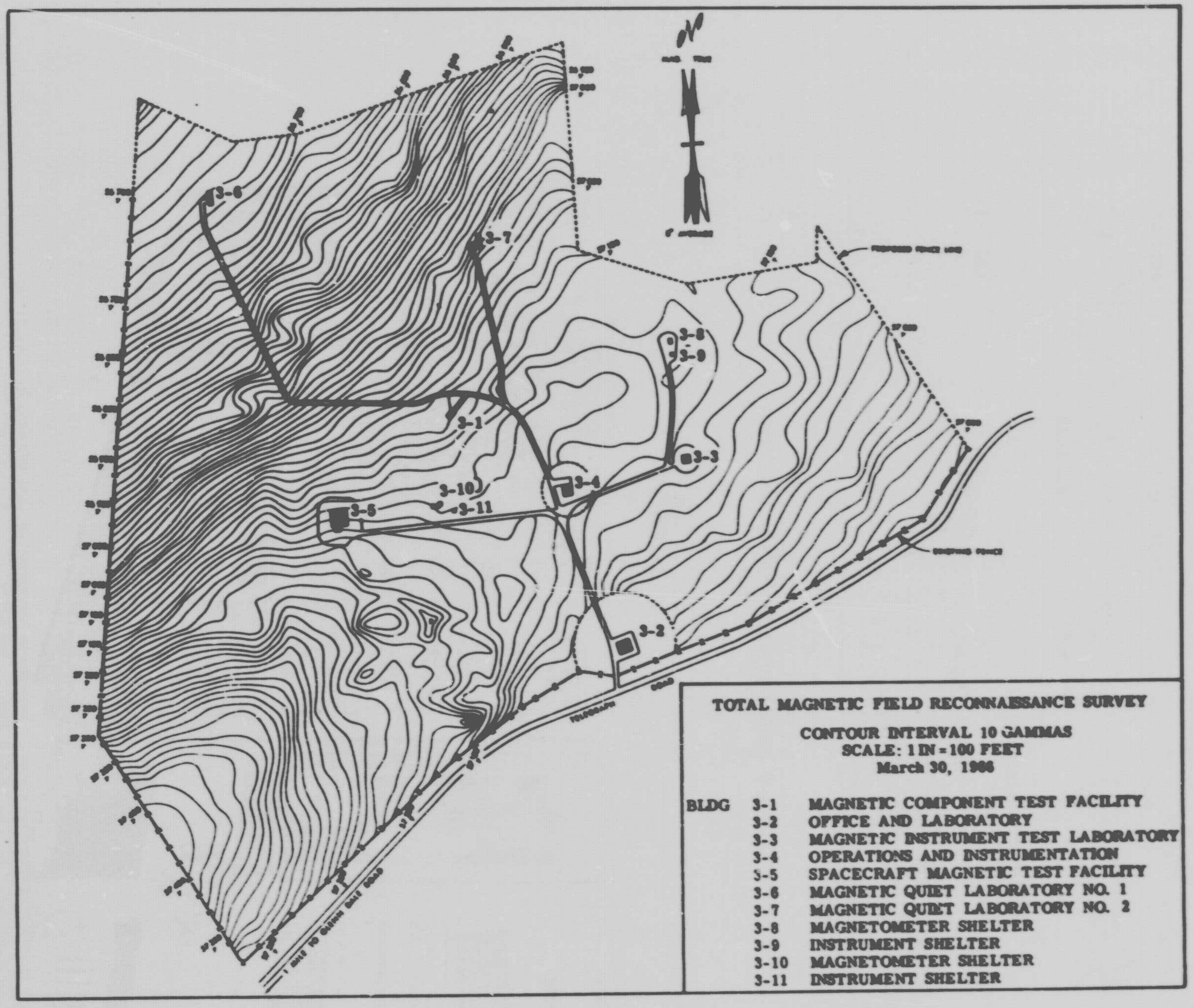

Figure 1–Total magnetic field reconnaissance survey of the Magnetic Test Site.

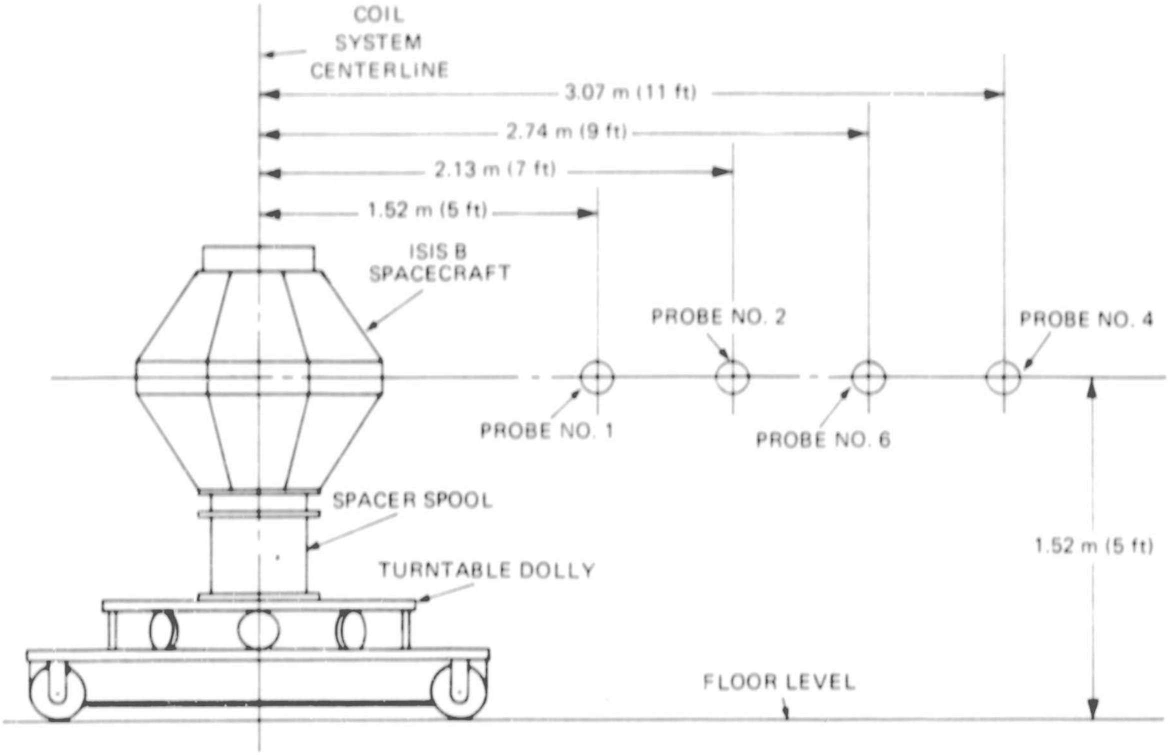

Figure 2—ISIS B mounting for spacecraft tests.

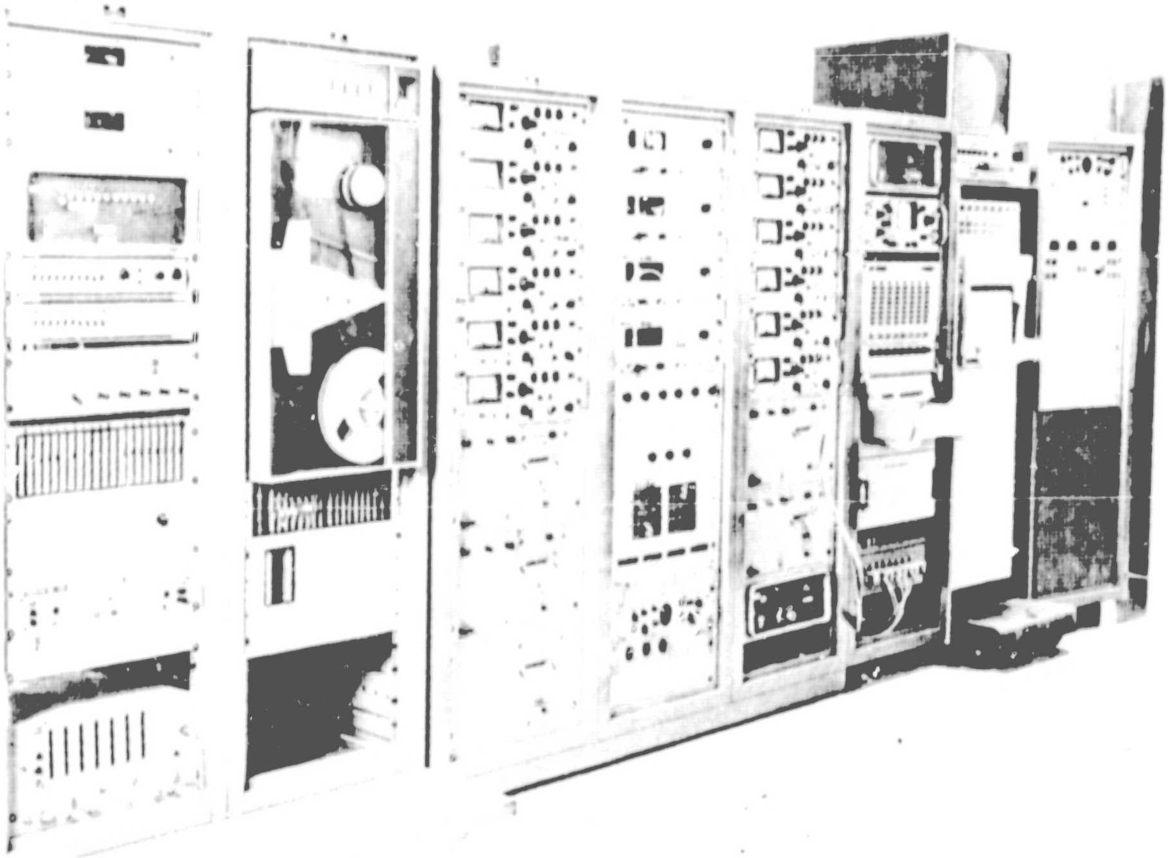

Figure 3—Recording instrumentation for magnetic tests.

(7) Measurement of torquing coil threshold field.

(8) Calibrations of spacecraft magnetometers.

During final magnetic testing, the following activities were performed:

(1) Measurement of initial permanent dipole moment.

(2) Deperm from 25×10^{-4} T (25 G) and subsequent measurement of dipole moment.

(3) Measurement of induced dipole moment.

(4) Calibration of spacecraft magnetometer.

(5) Measurement of torquing coil threshold field.

(6) Check of VLF system by ac calibration.

(7) Measurement of torquing coil dipole moment and torque.

The details of the procedures followed in performing these tests and the computational techniques used are summarized in Appendix B.

TEST RESULTS AND DISCUSSION

Initial Test

Magnetic moment. The history of the magnetic moment of the spacecraft appears in Table 1. The measured moments are seen to be well within the nominal values considered acceptable. The only exception to this is the induced moment. However, it is noted that the induced moment is directly in line with the applied field; therefore, no induced torque is produced.

Torquing coil moment. The results of the torquemeter measurements of torquing coil moment appear in Table 2. The average moment value as determined from static tests is 143 500 mA-m^2. This is in good agreement with the value of 142 500 mA-m^2 obtained from magnetic measurements. The nominal value is 150 000 mA-m^2. It was also confirmed that the proper direction of torque resulted on command. During the ASC tests, the field produced by the ASC coil was measured by a magnetometer positioned east of the spacecraft and approximately in line with the coil axis. A comparison was made between the coil field produced when the coil was energized in a static facility field and that produced when the coil was triggered by a rotating facility field. That the coil fields were always of the same magnitude leads to the conclusion that the dynamic coil moment was the same as the static coil moment.

Compensation. The permanent moment of the spacecraft was sufficiently within bounds that no compensation was deemed necessary.

Table 1—Magnetic moments (initial test).

Task Reference*	Magnetic State	Applied Field (T)	Nominal Moment (mA-m^2)	Magnitude (mA-m^2)			Orientation (rad clockwise from +x direction)
				M_{xy}	M_z	M_{total}	
	Initial						
6B.2	Spacecraft unpowered	0	3000	750	200	780	0.349 (20°)
6B.3	Spacecraft powered	0	3000	790	200	780	0.349 (20°)
6G	Post 15 X 10^{-4} T exposure						
	x-axis	0	7500	6300	-150	6302	0.698 (40°)
	z-axis	0	7500	180	6100	6603	
	Post 30 X 10^{-4} T deperm						
6H.1g	IMS** removed	0	1500				
6H.1h	IMS installed	0	1500	180	370	410	4.36 (250°)
6H.2	After compensation	0	1500				
6I	Induced	0.3 X 10^{-4} +x	500	825	0	825	+x
		0.3 X 10^{-4} +z	500	0	835	835	+z
	Stray fields						
6J.1h	Battery No. 2 load	0		500	160	525	3.49 (200°)
6J.1k	Battery No. 1 and No. 2 loads	0		770	260	815	3.32 (190°)
6J.1m	Battery No. 1, No. 2, and No. 3 loads	0		1030	300	1070	3.14 (180°)
6J.1r	Battery charging by solar panels	0		no change			
6K	Unpowered (flight plug in)	0.3 X 10^{-4}	750	375			
	Torquing coil on						
6D.1e	Spin-up	0.5 X 10^{-4}	1.5 X 10^5	1.425 X 10^5			
6L.1d	Spin-up	(dc)					
6D.1	Despin			1.425 X 10^5			

*Numbers in this column are derived from Reference 2.
**Ion mass spectrometer.

Table 2 Torquemeter results (initial test).

Control Mode	Applied Field			Torque		Magnetic Moment	
	Frequency (rad/s)	Amplitude (nT)	Direction*	Amplitude** (N-m)	Direction*	Amplitude (mA-m^2)	Direction
Spin-up	0	30 000	$+x$	$44\ 100 \times 10^{-7}$	CCW	147 000	$+y$
Spin-down	0	30 000	$+x$	$42\ 000 \times 10^{-7}$	CW	140 000	$-y$
Spin-down	0.314	30 000	CW	$*25\ 200 \times 10^{-7}$	CW		
Spin-up	0.314	30 000	CW	$*25\ 200 \times 10^{-7}$	CCW		
Spin-down	0.15	30 000	CW	$*25\ 200 \times 10^{-7}$	CW		
Spin-up	0.15	30 000	CW	$*25\ 200 \times 10^{-7}$	CCW		
Spin-down	0.45	30 000	CW	$*23\ 100 \times 10^{-7}$	CW		
Spin-up	0.45	30 000	CW	$*23\ 100 \times 10^{-7}$	CCW		

*CW denotes clockwise; CCW denotes counterclockwise.
**Average value.

Flight magnetometer. Measurements were made of the magnetometer probe bias, magnetometer system hysteresis, magnetic feedback from the torquing coils, hysteresis widths, and threshold switching levels. This information was collected directly by the project via telemetry from the spacecraft and is reported in Reference 3.

Final Test

Magnetic moment. The magnetic moment history of the final test appears in Table 3. As in the initial test, all values of moment are within nominal ranges except for the induced moment, which again is in line with the applied field so that no induced torque is produced.

Torquing coil moment. Results of the torquing coil moment measurements appear in Table 4. The moment value of 142 000 mA-m^2 is in good agreement with the value of 142 500 mA-m^2 obtained during the initial test. Proper directions for spin-up and spin-down torques were reconfirmed. As in the initial test, the magnetic field due to the torquing coil was monitored to ensure that the dynamic moment was the same as the static moment.

Magnetometer calibration. Onboard magnetometer calibrations were repeated satisfactorily. Also, ac data were obtained on the VLF equipment using the 2.7-m (9-ft) diameter deperm coils to generate ac fields. These data were collected directly by the project.

PROBLEMS

No serious problems were encountered; however, some difficulty was experienced in attempting to reduce the z-axis component of moment, which had increased significantly between the initial and final tests. After a series of four separate deperming treatments, a reduction from 925 to 578 mA-m^2 was finally effected.

Table 3–Magnetic moments (final test).

Task Reference*	Magnetic State	Applied Field (T)	Nominal Moment (mA-m^2)	Measured			
				Magnitude (mA-m^2)			Orientation (rad clockwise from $+x$ direction)
				M_{xy}	M_z	M_{total}	
	Initial						
6B.2	Spacecraft unpowered	0	3000				
6B.3	Spacecraft powered	0	3000	372	925 down	1000	
6H	Post 25 × 10^{-4} T deperm	0	1500	559	578 up	805	2.09 (120°)
6I	Induced	0.3 × 10^{-4}	500	544	738		0 (0°)
	Post torque	0	1500	630	422 up	758	1.90 (109°)

*Numbers in this column are derived from Reference 2.

Table 4–ISIS B torquemeter results (final test).

Control Mode*	Applied Field			Torque		Magnetic Moment	
	Frequency (rad/s)	Amplitude (nT)	Direction**	Amplitude (N-m)	Direction**	Amplitude (mA-m^2)	Direction
Spin-up	0	30 000	$+x$	42 500	CCW	141 500	$+y$
Spin-down	0	30 000	$+x$	42 500	CW	141 500	$-y$
Spin-up	0.314	30 000	CW		CCW	141 500	
Spin-down	0.314	30 000	CW		CW	141 500	
Spin-up	0.15	30 000	CW		CCW	141 500	
Spin-down	0.15	30 000	CW		CW	141 500	
Spin-up	0.45	39 000	CW		CCW	141 500	
Spin-down	0.45	39 000	CW		CW	141 500	

*Directions for spin-up and spin-down were confirmed.
**CW denotes clockwise; CCW denotes counterclockwise.

CONCLUSIONS

The spacecraft's magnetic history was satisfactory in both the initial and final series of tests. All measured moment values, except for the induced moment, fell within the limits prescribed. Although the magnitude of the induced moment exceeded the nominal value, it was observed to be in line with the applied field vector and therefore should not be a disturbing factor in attitude control.

The ASC system was tested in all its control modes. Proper threshold values for gating the torquing coils were obtained as well as proper direction of the moment generated. The moment values achieved were slightly less than the design goals: approximately 142 000 mA-m^2 versus a goal of 150 000 mA-m^2.

The onboard magnetometers were satisfactorily calibrated.

ACKNOWLEDGMENTS

The magnetic testing of this spacecraft and the acquisition of all data presented were accomplished as a team effort by the personnel of the Magnetic Test Section. Acknowledgment is also made of the excellent cooperation of the personnel of RCA Ltd., the ISIS B project personnel, and G. L. Coble, Jr., the Test and Evaluation Flight Project Support Manager.

REFERENCES

1. G. L. Coble, Jr., "ISIS-B Environmental Test Specification for Spacecraft System Tests," GSFC Document S-320-ISIS-2, July 14, 1970.
2. RCA Ltd., "Environmental Test Procedure for ISIS-B Spacecraft," Montreal.
3. D. Bevan, "ISIS-B Flight Spacecraft Initial Magnetic Test Results, Goddard Space Flight Center," RCA Ltd. Report 1B-ET-006, January 7, 1971.

Appendix A

DESCRIPTION OF FACILITY

The SMTF provides a controlled magnetic environment in which magnetic tests of spacecraft or spacecraft components can be performed. The 12-m (40-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 nT (60 000γ) per component. Current-regulated power supplies provide stability of ±1 nT over a 24-hour period; the coil geometry provides for uniformity of field within 0.6 nT over a spherical volume of 0.98-m (3.2-ft) radius. Three Earth's field magnetometers and associated control systems automatically compensate for daily variations in the Earth's field.

In addition to generating static magnetic fields, coil currents may be programmed to produce a vector that will rotate about any desired axis through the center of the coil system at a maximum rate of 100 rad/s. The maximum magnitude of this vector is 60 000 nT.

The SMTF is also equipped with a 22 240-N (5000-lb) capacity overhead hoist, an 8896-N (2000-lb) capacity hydroset for gentle handling of delicate spacecraft, a track system and dolly for transporting the spacecraft from the truck lock to the center of the coil system, and a turntable at the coil center, powered to rotate the spacecraft through 2π rad (360°) while it is centered in the coil. The turntable is equipped with an angle encoder so that angular position and magnetic measurements may be synchronized. In addition, a gimbal is available with which to produce rotation of the spacecraft about a horizontal axis.

For perming and deperming the spacecraft, fields of up to 5 mT can be provided by means of a portable Helmholtz coil pair of 2.7-m (9-ft) diameter. A 1.5-m (5-ft) diameter coil is available for applying such fields along a second axis of smaller spacecraft.

A highly sensitive torquemeter located directly below the turntable provides for the direct measurement of torques resulting from the interaction between the magnetic moment of the spacecraft under test and the field produced by the coil system itself. The torquemeter can accept loads of up to 22 240 N (5000 lb) and can measure torques to an accuracy of 50×10^{-7} N-m (50 dyne-cm).

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

Figure A1 shows the ISIS B spacecraft under test in the SMTF.

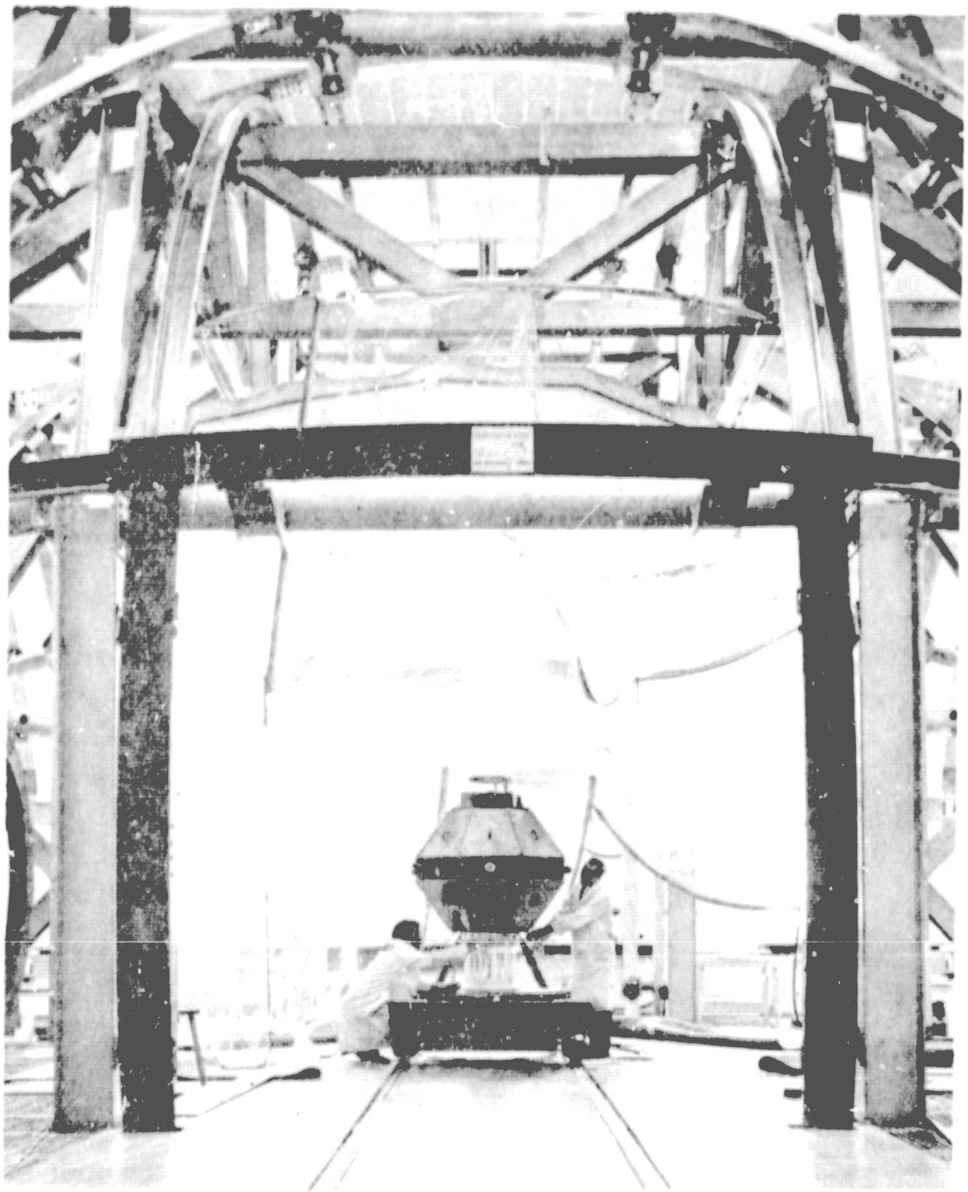

Figure A1—ISIS B spacecraft in the SMTF.

Appendix B

TEST PROCEDURES AND COMPUTATIONAL TECHNIQUES

Dipole Moment Determination

With the spacecraft in the truck lock, the station fluxgate magnetometer is used to establish zero field at the center of the coil. All four triaxial fluxgate probes are then adjusted to read zero. The spacecraft is rolled in on the dolly and rotated clockwise (as seen from above) through a complete revolution about a vertical axis.

From the magnetic field data obtained during the above operation, the dipole moment components may be calculated on the assumption that near-field effects can be disregarded and that the measured field is due to a theoretical dipole. The total moment in the xy-plane may be calculated from the peak-to-peak probe readings as follows:

$$M_{xy} = (H_x)_{\text{p-p}} r^3/4$$
$$M_{xy} = (H_y)_{\text{p-p}} r^3/2 \ ,$$

where H_x and H_y are the components of the field in the x and y directions, respectively.

The vertical component of dipole moment may be calculated by subtracting the average value of the vertical field, H_z, obtained with the spacecraft removed from the coil from the average value of H_z obtained during rotation of the spacecraft in the center of the coil. The expression used is

$$M_z = [(H_z)_{\text{in}} - (H_z)_{\text{out}}] r^3 \ .$$

When significant distortion exists in the probe signatures during rotation, more accurate results are obtained through near-field analysis. The mathematics of this approach are quite complex and will not be described here.[1] The magnetometer data are recorded in digital form on magnetic tape (through MADAS) and calculations are performed by digital computer using a GSFC program written for this purpose.

Exposure

Exposure is accomplished by energizing with direct current the pair of 2.7-m (9-ft) diameter deperming coils within which the spacecraft is centered. The current is adjusted to produce a field level of 15×10^{-4} T.

[1]W. L. Eichhorn, "New Methods for the Determination of the Magnetic Dipole Moment of a Spacecraft from Near Field Data," GSFC Document X-325-69-350, August 1969.

Deperming

Deperming is accomplished by slowly alternating the flux produced by the 2.7-m diameter coils in the form of dc pulses. The current to the coils is programmed to produce pulses alternating with a period of approximately 12 s and gradually diminishing to zero amplitude in a period of 5 min.

Magnetometer Calibration

With the spacecraft centered in the coil, the outputs of the flight magnetometers are compared with the strength of the field produced by the coil facility. The VLF experiment is checked by energizing the 2.7-m diameter deperm coils with alternating current.

Torquing Coil Magnetic Testing

Magnetic fields are produced by the SMTF to activate the torquing system. Threshold values for activation and turn-off are measured, and the magnetic moment of the torquing coil is calculated from rotational magnetic data by the far-field technique described above.

Torquemeter Tests

The Mark III torquemeter is used both to determine the permanent dipole moment of the spacecraft and to evaluate its ASC.

In the dipole moment determination, a dynamic field technique, supplemented by the use of two solenoids of known coil constants, was used. The test configuration is shown in Figure B1. The procedure is as follows:

(1) One of the solenoids is energized with a known current in order to produce a moment with both known magnitude and known direction.

(2) A facility field is oscillated at a selected amplitude and frequency at right angles to the moment vector of the solenoid.

(3) The amplitude of the torque signal is recorded.

(4) The moment vector of the solenoid is reversed by reversing the current, and a second torque signal amplitude is measured.

(5) The dipole moment component in the direction of the solenoid is calculated from the expression

$$M = \frac{A_1 - A_2}{A_1 + A_2} M_s ;$$

where A_1 and A_2 are the torque signal amplitudes, and M_s is the dipole moment of the solenoid.

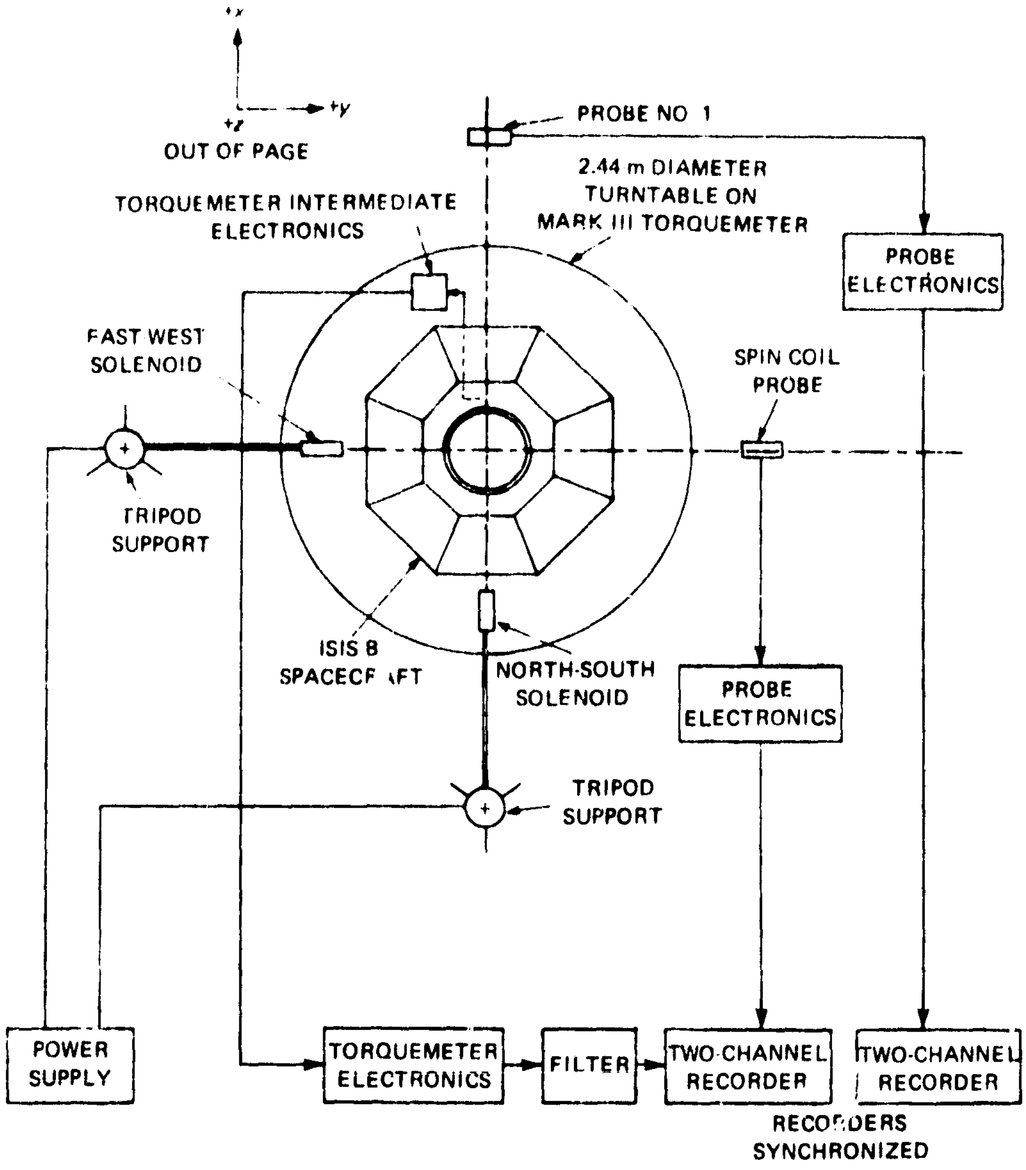

Figure B1—ISIS B torque test apparatus (plan view).

When the torquemeter is used to evaluate the spin control system, a static field of 30 000 nT is applied along the $+x$-axis, and the spin system is commanded "on." The resultant torque is measured, and the dipole moment of the torquing coils are calculated from the expression

$$M = L/H ,$$

where M is the torquing coil dipole moment, L is the measured torque, and H is the intensity of the applied field.

At the same time that the torque was being measured, the field produced by the torquing coil at a selected location was also measured. During subsequent testing with rotating fields, the torquing coil field continued to be monitored to verify that the dynamic moment of the coil was the same as the static moment.

Appendix C

CHRONOLOGY OF EVENTS

Initial Test

Monday, November 2, 1970

ISIS B spacecraft arrived at the Magnetic Test Site at 11:00 AM. Spacecraft checked out and RF link established.

Tuesday, November 3, 1970

Measured initial perm moment "as received."
Measured magnetic moment of torquing coils.
Measured turn on/off magnetic field thresholds.
Measured post-exposure dipole moment.

Wednesday, November 4, 1970

Measured post-deperm dipole moment.

Thursday, November 5, 1970

Measured induced dipole moment.
Measured stray-field dipole moments, including solar simulation.

Friday, November 6, 1970

Calibrated spacecraft magnetometers.

Monday, November 9, 1970

Torque test of ASC system.
Spacecraft departed Magnetic Test Site.

Final Test

Tuesday, February 16, 1971

ISIS B spacecraft arrived at the Magnetic Test Site at 10:30 AM.

Measured "as received" perm dipole moment.
Depermed and measured post-deperm dipole moment.

Wednesday, February 17, 1971

Measured induced dipole moment.
Calibrated spacecraft magnetometers.
Prepared torquemeter for ASC test.

Thursday February 18, 1971

Torque test of ASC system.
Post-torque dipole moment mea .:rement.
Spacecraft departed Magnetic Test Site.

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