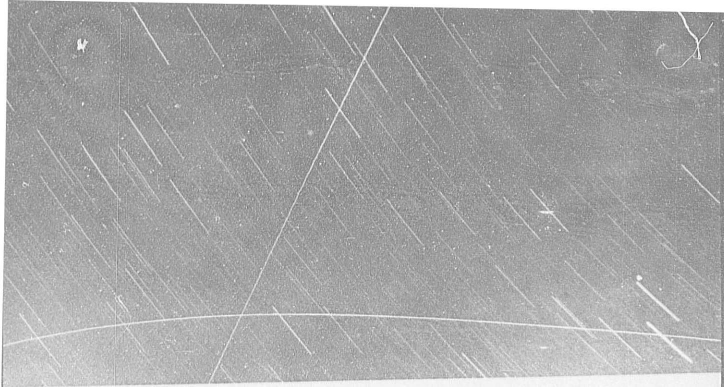
B05094



DATA USERS' NOTE

NSSDC 67-34

EXPLORER 18 (1963 46A)

MAGNETIC FIELD EXPERIMENT

AUGUST 1967

NATIONAL SPACE SCIENCE DATA CENTER

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • GODDARD SPACE FLIGHT CENTER, GREENBELT, MD.

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EXPERIMENTER
N. F. Ness

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FOREWORD

This Data Users' Note is specifically designed to help potential data users decide if they can make use of the data obtained in the Explorer 18 (1963 46A) magnetic field experiment. Once a data user decides that he requires the data, it will serve as the unifying element – the key – in the actual use of the data available at the National Space Science Data Center (NSSDC). To achieve these goals, the Note briefly describes the experiment, including the instrumentation and measurements, the telemetry, and the operational experience. All available details are then provided on the actual reduction techniques and format of recorded data. For those desiring more details, the name and address of the experimenter are provided to facilitate direct contact. As a further aid, detailed references (and bibliography) are also included. When available, NASA accession numbers* are given. The primary purpose of these references is to identify the sources containing complete information concerning the subject under discussion. Most of these references are physically available at NSSDC – those that are not are readily obtainable.

Inquiries concerning the availability of data should be directed to:

National Space Science Data Center
Goddard Space Flight Center
Greenbelt, Maryland 20771
Area Code 301 982-6695

*For example, N64-2243 is an accession number for an article reported in the *Scientific and Technical Aerospace Reports* (STAR), and A63-5921 refers to an entry in the *International Aerospace Abstracts* (IAA).

CONTENTS

LIST OF FIGURES

EXPLORER 18 (1963 46A)
MAGNETIC FIELD EXPERIMENT

BACKGROUND

Scientists at the Goddard Space Flight Center designed the magnetic field experiment on board Explorer 1. The primary mission of the experiment was to investigate the interplanetary magnetic field and the transition region associated with the interaction of the solar wind with the geomagnetic field. The investigation of the transition region involved a study of the collisionless magnetohydrodynamic shock wave surface separating the undisturbed interplanetary medium from the transition region, and the magnetopause separating the transition region from the magnetosphere. Two flux-gate magnetometers and one rubidium 87 magnetometer were used for the study of magnetic field data.[1] This Note, however, deals primarily with information necessary for the interpretation of flux-gate data, which are the only data currently available at NSSDC. Other Explorer 18 experiments are listed in Figure 1.

The Explorer 18 satellite, also known as IMP 1, was launched from Cape Canaveral (Cape Kennedy), Florida on November 27, 1963 at 0230 UT. The satellite achieved an initial apogee of 197 616 km (geocentric), and a perigee of 192 km. IMP 1 had an initial period of ~93.5 hr, an inclination to the earth's equator of 33.3 deg and an eccentricity of 0.937. The spacecraft was spin stabilized at an initial rate of 22.3 rpm with an initial spin-axis satellite-sun angle of 111 deg, measured by the spacecraft optical aspect sensor.[1]

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EXPERIMENT

Instrumentation and Measurements

Each flux-gate magnetometer measured the relative magnetic field intensity along the axis of its sensing element. The flux-gate sensor consisted of a saturable magnetic core which was driven at a rate of 10 kc/s from positive to negative saturation by a solenoidal drive coil. Any second harmonic signal generated was due to the presence either of an ambient field component along the axis of the element or to permanent magnetization of the core material.[1]

FIGURE 1
EXPLORER 18 EXPERIMENTS

No.	Experiment	Investigator(s)	Affiliation
01	Retarding Potential	G. P. Serbu E. Maier	GSFC* GSFC*
02	Magnetic Field	N. Ness	GSFC*
03	Solar and Galactic Protons (Cosmic-Ray)	J. A. Simpson C. Y. Fan G. Gloeckler	University of Chicago University of Chicago University of Chicago
04	Cosmic-Ray	F. B. McDonald G. Ludwig V. Balasubrahmanyan T. L. Cline	GSFC* GSFC* GSFC* GSFC*
05	Energetic Particles	K. A. Anderson H. K. Harris	University of California University of California
06	Ames Plasma Probe	J. H. Wolfe R. W. Silva	ARC** ARC**
07	Plasma Probe	H. S. Bridge A. Egidi A. Lazarus	MIT*** MIT*** MIT***

*Goddard Space Flight Center
**Ames Research Center
***Massachusetts Institute of Technology

The voltage output (0 to +5) represented the discriminated second harmonic output which was calibrated to yield the magnitude of the field component parallel to the sensor axis, while the phase indicated the direction, parallel or antiparallel.[1]

The flux-gate magnetometers operated within specified limits over a wide range of temperatures. This obviated the necessity of providing temperature sensors in the flux-gate instrumentation. The dynamic range of the flux-gate magnetometers was ±40 gammas ($1\gamma = 10^{-5}$ gauss) with a sensitivity of ± $1/4\gamma$.

A rubidium 87 magnetometer with a dynamic range of 3-500γ measured the absolute scalar intensity of the magnetic field by utilizing the Zeeman splitting of the sublevels in the ground state of the Rb^{87} atom.[2] The magnetometer was operated as an atomic self-oscillator through an optical pumping technique in combination with a weak a-c magnetic field. The resonant frequency, the Larmor frequency, was that corresponding to the separation of the Zeeman sublevels. The scalar Rb^{87} magnetometer was converted to a vector instrument by using a set of McKeehan coils to apply a sequence of known bias magnetic fields.

The bias coil system used for the refinement of the Rb^{87} magnetometer also provided a means for inflight calibration of the flux-gate magnetometer zero field levels, since it was possible to measure the unknown vector field simultaneously with two vector instruments. The flux-gate magnetometers measured the magnetic field vector at an extended range even when the rubidium vapor magnetometer was in a null region. There were two of these null regions of magnetic field orientation, polar and equatorial relative to the spin axis, in which the magnetometer would not self-oscillate with sufficient signal-to-noise ratio for accurate data.[1]

The magnetometer sensors were placed as far as possible from the satellite. The rubidium vapor magnetometer was contained within the spherical enclosure mounted on top of a telescoping two-section boom. The Rb^{87} magnetometer resonance gas cell was thus placed 1.65 meters from the center of the spacecraft. The two mono-axial flux-gate magnetometers were mounted at the extremities of double-sectioned folding booms. These sensors were located 2.1 meters from the center of the spacecraft. Two booms were used to make the spacecraft both statically and dynamically stable. Both their axes were oriented to lie in the same meridian plane containing the spin axis of the satellite but at different angles to the spin axis. The purpose of the two angles was to allow the sampling of magnetic fields larger than 40γ by one of the two sensors, depending on the orientation of the unknown field to the spin axis. Because two angles whose sum equals 90 deg were used, the sensors complemented each other in their ability to measure accurately, and in an undistorted manner, fields of intensity greater than 40γ.

The necessary measures were taken to ensure that permanent or induced magnetic fields would be kept at a minimum. Preflight mapping of the actual spacecraft magnetic fields due to permanent, induced, and stray magnetic fields indicated contamination levels at the flux-gate sensors of less than 0.6γ. Further tests were performed on the effects of the vibration of ferromagnetic materials in the earth's magnetic field to evaluate any possible changes in magnetization which might result from the vibration of the satellite during the launch maneuver. These tests indicated that these effects would be beneath the range of the instrument sensitivity.[1]

Telemetry

The pulse-frequency modulation (PFM) telemetry system used on IMP 1 encoded the flux-gate data by applying them to a voltage-controlled oscillator whose frequency output, 333 to 938 cps, modulated the 136-Mc/s carrier. The flux-gate signals were digitized on the ground through the combined use of a contiguous set of narrow bandpass filters specifically designed for the PFM telemetry scheme and commonly referred to as a "comb filter." This led to a precision in the digitization of $\pm 0.4\gamma$, due to the precision of the comb filters, which was $\pm 1\%$ of full scale range.[1]

The magnetic field data were transmitted by the satellite sequentially in a format which time-multiplexed the magnetic field information with the other scientific sensors and spacecraft performance in a predetermined time-shared manner. Each normal telemetry sequence was 81.9144 sec in length and contained four samples of real-time flux-gate magnetometer data consisting of continuous transmission of 4.8 sec at intervals of 20.48 sec. Four such samples per sequence were shared between the two flux gates. The procedure was repeated for the next two sequences in identical fashion. Every fourth sequence contained only rubidium vapor magnetometer data, which were continuously transmitted for a period of 81.91 sec with gaps every 5.12 sec to allow for the synchronization time channels included in the PFM telemetry format.[1,3]

Operational Experience

The successful operation of the satellite continued from November 27, 1963, to May 30, 1964. Transmission of data ended as a result of insufficient power from the solar paddle system. However, data were again transmitted from November 12 to December 18, 1964.[3]

About 80% of the IMP 1 orbital period was beyond 10 R_e or $\sim$64 000 km. The initial apogee of IMP 1 was 25 deg west of the sun, and, owing to the heliocentric motion of the earth, processed approximately 4 deg per orbit west of the sun during the first six months of operation. Despite this precession, the satellite moved in an inertial coordinate system so that the relative orientation of the satellite orbit to the ecliptic plane remained approximately the same. Measurements of the position of both the magnetospheric boundary and the shock wave ended early in the lifetime of the IMP 1 satellite due to the precession of the orbit in solar ecliptic coordinates.[1,3]

From orbit 22 on, the satellite was within the interaction region surrounding the magnetosphere, and from orbit 31 to 47 the satellite was entirely within the earth's magnetosphere. The tail region of the earth's magnetic field showed no indication of any termination at satellite apogee (31.4 R_e).[1,3]

During the period February 17 to May 30, 1964, the sun-earth-apogee angle decreased from 253 deg to 156 deg. The observations during this period showed a distortion of the earth's magnetic field by the flow of the solar wind which resulted in a draping back of the field into the anti-solar direction.[3] These measurements gave the first detailed evidence for the earth's geomagnetic tail. A possible detection of the lee wake of the magnetohydrodynamic interaction of the solar wind with the moon by this experiment has been discussed.[4]

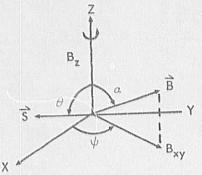
DATA

Reduction Techniques

A natural coordinate system which was used in the initial reduction of magnetic field data (on a spin-stabilized spacecraft) is one associated with the spin axis of the satellite and the satellite-sun direction. This system is defined in Figure 2; the Z axis is coincident with the spin axis of the spacecraft, the XZ plane contains the satellite-sun vector, and the Y axis is chosen to form a right-handed coordinate system. The analysis of the mono-axial flux-gate data was carried out through the use of numerical filters, which were designed to extract from the spin-modulated magnetometer signal the first harmonic and the first and second time derivatives of the magnetometer signal at a particular instant of time. As shown in Figure 2, it is possible to combine the first and second time derivatives to determine both the component of the magnetic field perpendicular to the spin axis $B_{xy} = B \sin \alpha = B_\perp$ and the azimuthal angle of the magnetic field ψ. These two quantities and the first harmonic then determine the component of the magnetic field parallel to the spin axis $B_{\parallel} = B \cos \alpha$. The three quantities, $B_\perp$, $B_{\parallel}$, and ψ completely specify the vector magnetic field B.[1]

A limited amount of processing of the flux-gate A magnetometer data was performed on board IMP 1. A signal peak detector was developed to provide a pulse in time coincidence with the maximum field value which occurred during each spin period. A 100-cps counter was gated on by an optical-aspect sun pulse

FIGURE 2
PAYLOAD COORDINATE SYSTEM



Z	=	Spin axis of spacecraft
$\vec{B}$	=	Unknown vector field
$\vec{S}$	=	Sensor axis $\lvert\vec{S}\rvert = 1$
ψ	=	Azimuthal angle of B_{xy}
ω	=	Angular spin frequency
X, Y, Z	=	nonrotating RH coordinate system

$$\text{Detector Output} = D = \vec{B} \cdot \vec{S} = B \cos \alpha \cos \theta + B \sin \alpha \sin \theta \cos (\omega t - \psi)$$

$$\frac{\delta D}{\delta t} = -\omega B_{xy} \sin \theta \sin (\omega t - \psi)$$

$$\frac{\delta^2 D}{\delta t^2} = -\omega^2 B_{xy} \sin \theta \cos (\omega t - \psi)$$

$$B_{xy}^2 = \left[\left(\frac{\delta D}{\delta t}\right)^2 \omega^2 + \left(\frac{\delta^2 D}{\delta t^2}\right)^2\right] \Big/ \omega^4 \sin^2 \theta$$

$$\psi = \tan^{-1} \left[\omega \frac{\delta D}{\delta t} \Big/ \frac{\delta^2 D}{\delta t^2}\right]$$

The procedure given is the one used to obtain vector fields with monoaxial flux-gate magnetometers on a spin-stabilized spacecraft.

and was gated off by this peak pulse. In this manner, the azimuthal angle ψ was measured on board once during each telemetry sequence, and the numerical procedures that were used to demodulate the spin-modulated magnetometer data were thereby accurately checked. Angle measurements were more precise for azimuth because of this procedure and were accurate to ±2 deg. The angular error of the polar angle α was dependent upon direct measurements of $B_{\perp}$ and $B_{\parallel}$ and could therefore be large for certain ratios of $B_{\perp}$ and $B_{\parallel}$. This angular error was not significant when the data from the initial payload coordinate system were transformed to the XYZ coordinate system since $B_{\perp} \sin \psi$, $B_{\perp} \cos \psi$, and $B_{\parallel}$ were used directly. The uncertainties in the field values and azimuth angle combine so that an estimate of the general directional accuracy of ±5 deg was conservative.[1]

Each flux-gate magnetic field vector measurement was obtained from a sample of data 4.8 sec in length and containing 30 discrete samples of the magnetic field with a sensitivity of 0.4γ. The bandpass of the magnetometer sensors was flat with negligible phase shift from 0 to 5 cps and fell off at 6 db per decade for higher frequencies. The procedure used to obtain a vector measurement, from the sampling of the magnetic field, limited the final information bandwidth in the analysis to approximately 0 to 0.1 cps.[1]

Timespan of Data

Data available at NSSDC are stored on magnetic tape and cover orbits 1 through 48. The actual timespan covered is from November 27, 1963, to May 23, 1964.

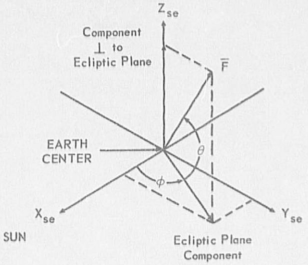
Format of Available Data

Figure 3 illustrates a set of coordinates which have proven successful in the analysis and interpretation of the magnetic field data. In this system, the origin is at the center of the earth, the X_{se} axis points to the sun, the Z_{se} axis is normal to the ecliptic plane, and Y_{se} is chosen to form a right-handed coordinate system.

The vector magnetic field will be presented as a magnitude F and two angles, θ and ϕ. The angle θ represents the latitude of the magnetic field, being positive above the plane of the ecliptic and negative below, and the angle ϕ represents the longitude, being 0 deg when it points to the sun and 180 deg when it points away from the sun. The coordinate system is not stationary in inertial coordinates, but rotates about two principal axes and maintains its orientation, as shown in Figure 3, at all times. Viewed from a nonrotating heliocentric position, the coordinate system moves around the sun once each year following the orbital motion of the earth.[1]

FIGURE 3

SOLAR ECLIPTIC COORDINATE SYSTEM



The coordinate system is also useful for studying the magnetic field phenomena associated with the interaction of the solar wind with the geomagnetic field. Since the interaction leads to the formation of a geomagnetic cavity which is strongly solar-oriented, the coordinate system chosen is particularly meaningful in presenting the magnetic field data in a frame of reference which illustrates the close relationship of the solar-terrestrial phenomena being studied.[1]

The magnetic field results presented in the format of data represent the time average of the 12 flux-gate measurements occurring in the telemetry transmission in sequences 1, 2, and 3. The average of these measurements yields a sampling interval of 5.46 min. The solar ecliptic components for these 12 measurements are averaged by simple addition, and no special filters are employed. For the X_{se} component, if X^i_{se} represents the i^{th} value of the magnetic field in the sample set possible,

$$\overline{X}_{se} = \frac{1}{N} \sum_{i=1}^{N} X^i_{se}$$

where N is less than or equal to 12, depending on the percentage of missing data points in the original 30-point data samples. If the number of missing points, owing to either digitization errors or transmission errors, is greater than 10%, the corresponding vector field sample is not used in the analysis to determine the 5.46-min average.

These average values for the three components are used to compute the magnitude F and the two angles θ and ϕ. In addition, the average value for the components is used in computing estimates of the variance of the magnetic field for the 12-sample data set. The variance is defined as

$$\delta X_{se} = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (X^{i}_{se} - \overline{X}_{se})^2}$$

for the X_{se} component and similarly for Y_{se} and Z_{se}.

The magnetic field data are represented by the following six parameters sampled at 5.46-min intervals.

$\overline{F}$ = the magnitude of the average components.

$= (\overline{X}_{se})^2 + (\overline{Y}_{se})^2 + (\overline{Z}_{se})^2$

θ = the latitude of the field direction.

$= \tan^{-1}\left\{\overline{Z}_{se}/[(\overline{X}_{se})^2 + (\overline{Y}_{se})^2]^{1/2}\right\}$

ϕ = the longitude of the field measured in the plane of the ecliptic.

$= \tan^{-1}\,[\overline{Y}_{se}/\overline{X}_{se}]$

δX_{se} = variance of the field in the X_{se} direction.

δY_{se} = variance of the field in the Y_{se} direction.

δZ_{se} = variance of the field in the Z_{se} direction.

The data available at NSSDC include an hourly average deck which was generated from the binary summary tape for November 27, 1963, to February 24, 1964. Only those 5.46-minute averages with ten or more good points and with a field magnitude of less than $40\,\gamma$ were used in calculating these averages. The averages are punched on cards in the format given in Figure 4.

NSSDC also has available three 556-bpi binary summary tapes which include the 5.46-min averages taken from the flux-gate experimenter's tape. Two of the tapes were made on the IBM 7094 and cover orbits 1 – 48. A third tape, programmed for the IBM 7094-7044, using a direct couple system (DCS) covers orbits 1-23 (November 27, 1963, to February 24, 1964). The format of each of the two non-DCS binary summary tapes is given in Figure 5 and contains the word number and a description of each word. The DCS tape is in the same format except that the control words are fitted to a DCS system, and the physical records consist of 460 words. The last record of each tape is followed by an end-of-file.

FIGURE 4
FORMAT OF HOURLY AVERAGES DECK

IMP 1 1963 46A
MAGNETOMETERS (02)

Word	Description
1	Orbit Number
2	Radial Distance in earth radii
3	Solar Ecliptic X-Component in earth radii
4	Solar Ecliptic Y-Component in earth radii
5	Solar Ecliptic Z-Component in earth radii
6	Data Year
7	Data Day
8	Data Hour
9	Magnitude of Field
10	Angle between Field and Ecliptic Plane
11	Angle between Projection of Field onto Ecliptic Plane and Earth-Sun Axis
12	X Solar Ecliptic
13	Y Solar Ecliptic
14	Z Solar Ecliptic
15	X Solar Ecliptic Variance
16	Y Solar Ecliptic Variance
17	Z Solar Ecliptic Variance (truncated, so appears on the cards as I3)
Card Format I2, 4F5.1, I2, I3, I2, F5.1, 2F5.0, 6F5.1	

FIGURE 5
FORMAT OF BINARY SUMMARY TAPE

IMP 1 1963 46A
MAGNETOMETERS (02)

*Data Word	Description
1	Month ID (integer)
2	Day Count ID (integer)
3	Station Number (integer)
4	Tape Number (integer)
5	Year (integer)
6	Data Day (integer)
7	Data Hour
8	Data Minutes
9	Sequence Number
10	Spin Angle Average
11	Flux Angle Average
12	X Payload Average
13	Y Payload Average
14	Z Payload Average
15	X Solar Ecliptic
16	Y Solar Ecliptic
17	Z Solar Ecliptic
18	X Payload Variance
19	Y Payload Variance
20	Z Payload Variance
21	Magnitude of Field
22	Angle between Field and Ecliptic Plane
23	Angle between Projection of Field onto Ecliptic Plane and Earth-Sun Axis
24	X Solar Ecliptic Variance
25	Y Solar Ecliptic Variance
26	Z Solar Ecliptic Variance
27	Number of Good Points (integer)
28	Geodetic Latitude in degrees
29	Geodetic Longitude in degrees
30	Geomagnetic Latitude in degrees
31	Geomagnetic Longitude in degrees
32	Radial Distance in earth radii
33	Geomagnetic Longitude of Sub-Solar Point
34	Geomagnetic Latitude of Sub-Solar Point
35	Angle between Spin Axis and Satellite Vector

*Each physical record consists of 36 binary words, with the first word being a binary code word, which appears in octal as 00 00 43 00 00 01. The 43 is octal for 35 and indicates that 35 binary data words follow, while the 1 shows that the logical record is complete within the physical record. The 35 data words are given above and are floating point words unless otherwise indicated.

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