Final Report
for
NASA Contract NAS 9-12236
Apollo Particles and Fields Subsatellite
Magnetometer Experiment
(S-174)

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1. The Experiment

1.1 Instrument Description

The subsatellite magnetometer consists of two fluxgate sensors mounted orthogonally at the end of a 1.83-m boom and an electronics unit housed in the main body of the spacecraft. The two sensors are mounted one parallel and one perpendicular to the spin axis. On the Apollo 15 subsatellite there are two automatically selected dynamic ranges 0 to $\pm 50\gamma$ and 0 to $\pm 200\gamma$. These are called the high sensitivity and low sensitivity ranges, respectively. The resolution of each measurement is 0.4 to 1.6$\gamma$ depending on range. There are three sampling rates referred to as telemetry store normal (TSN), telemetry store fast (TSF) and real time (RT). In the former two modes, the magnetometer measures the magnitude and phase of the magnetic field in the spin plane and the vector component along the spin axis. The sample rates are one vector every 24 seconds and every 12 seconds, respectively. The magnitude in the spin plane is measured by filtering the transverse magnetometer output about the spin frequency, rectifying and filtering this. The phase is obtained by measuring both the time of the positive going zero crossing of the magnetometer output and the time of the sun crossing. In eclipse, the sun crossing time is computed from a model of the eclipse spin up and from a knowledge of the spin frequency and phase during the sunlit portion of the orbit.
During real time operations, one sample of the spin plane output is returned every second and of the spin axis output every 2 seconds. Thus, there are about 5 samples of the spin plane signal per revolution. This signal is Fourier analyzed to obtain a magnitude and phase and referenced to the sun crossing time. Real time data are, of course, only obtained across the near side of the moon, whereas the recorded TSF and TSN data are available from both near and far sides. We note that the subsatellite did not store data while transmitting. Thus, there are gaps in the records every orbit when data were telemetered to earth. A summary of the magnetometer characteristics is given in Table 1. The only significant difference between the Apollo 15 and 16 magnetometers is an increase by a factor of 2 in the sensitivity of the Apollo 16 magnetometer increasing the resolution to 0.2 and 0.8$\gamma$ and decreasing the range to $\pm 25\gamma$ and $\pm 100\gamma$ for high and low sensitivity ranges, respectively.

1.2 Operating History

The Apollo 15 subsatellite was launched on August 4, 1971. A failure in the telemetry system after seven months of operation prevented further transmission of data from most of the magnetometer outputs although the magnetometer continued to operate normally. The Apollo 16 subsatellite was launched on April 24, 1972, into an approximately circular orbit at an altitude of 100 km, having an orbital period of close to 2 hours. Due to the decision not to perform a shaping burn prior to jettisoning the subsatellite, the Apollo 16 subsatellite crashed into the moon after 34 days in lunar orbit.
<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Second-harmonic, saturable core fluxgate</td>
</tr>
<tr>
<td>Sensor configuration</td>
<td>Two sensors, one sensor parallel $B_P$ and one perpendicular $B_T$ to the</td>
</tr>
<tr>
<td>Mounting</td>
<td>satellite-spin axis</td>
</tr>
<tr>
<td>Automatically selected dynamic ranges, $\gamma$</td>
<td>Sensor unit at end of 1.83-m boom;</td>
</tr>
<tr>
<td></td>
<td>electronics unit in spacecraft body</td>
</tr>
<tr>
<td>Resolutions, $\gamma$</td>
<td>0 to 150 at higher sensitivity, 0 to 1200 at lower sensitivity</td>
</tr>
<tr>
<td>Sampling rates:</td>
<td>$B_P$ every 2 seconds, $B_T$ every second</td>
</tr>
<tr>
<td>Real time</td>
<td>$B_P$ and $B_T$ magnitude and $B_T$ phase</td>
</tr>
<tr>
<td>High-rate storage</td>
<td>once every 12 seconds</td>
</tr>
<tr>
<td>Low-rate storage</td>
<td>$B_P$ and $B_T$ magnitude and $B_T$ phase</td>
</tr>
<tr>
<td></td>
<td>once every 24 seconds</td>
</tr>
<tr>
<td>Power, W</td>
<td>0.70</td>
</tr>
<tr>
<td>Weight:</td>
<td>±0.8</td>
</tr>
<tr>
<td>Electronics unit, kg</td>
<td>±0.2</td>
</tr>
<tr>
<td>Sensor unit, kg</td>
<td>27.9 by 15.9 by 3.8</td>
</tr>
<tr>
<td>Size:</td>
<td>1.5 (diameter) by 7.6</td>
</tr>
<tr>
<td>Operating temperature range, °K</td>
<td>30°K to 172</td>
</tr>
</tbody>
</table>
During this period the magnetometers operated normally. The minimum correlation technique of Hedgecock was used to measure sensor drift of the parallel axis. The drift rate was well within the range expected. Table 2 gives the offsets for each lunation of Apollo 15. These numbers should be added to the values presently on the plots and tapes which were obtained from the preliminary calibration. Corrected values were used in the Apollo 16 processing.

The orientation of the spin axis of the subsatellite was determined from the variation of the sun elevation angle with time during the first 30 days after launch. On Apollo 15 the predicted variation of this angle and the measured variation followed each other almost exactly until December 1971. Thereafter, measurable deviation occurred amounting to δ° in February 1972.
<table>
<thead>
<tr>
<th>Station</th>
<th>Orbit Number</th>
<th>Offset</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 - 378</td>
<td>0.27Y</td>
</tr>
<tr>
<td>2</td>
<td>379 - 732</td>
<td>0.05</td>
</tr>
<tr>
<td>3</td>
<td>733 - 1086</td>
<td>-0.17</td>
</tr>
<tr>
<td>4</td>
<td>1087 - 1440</td>
<td>-0.38</td>
</tr>
<tr>
<td>5</td>
<td>1441 - 1784</td>
<td>-0.60</td>
</tr>
<tr>
<td>6</td>
<td>1785 - END</td>
<td>-0.81</td>
</tr>
</tbody>
</table>
3. The Data

Two types of data are relevant to this experiment: the support data and the observations. The support data consists of orbital information generated to relate the measurements to lunar position and the observations consist of magnetic field data and engineering parameters telemetered from the spacecraft. In this section we describe the data as it has been sent to the National Space Science Data Center.

2.1 Orbit Data

Three different displays of orbit data have been made plus one tape. These were all created at the Manned Spacecraft Center under the supervision of W. Wollenhaupt. The three orbit plots are altitude versus time, selenographic longitude versus latitude, and the ecliptic projection of the earth-moon system.

2.1.1 Altitude versus time

This plot shows altitude versus time for one orbit, but includes information on up to six consecutive orbits. At the top of the plot are the orbit number, the orbit start time (hours and minutes, day/month/year), the perilune time and altitude (km), the apolune time and altitude, and the time of sunrise and sunset. The plot includes two vertical shaded bars marking sunset and sunrise at the subsatellite. Time grids below the plot permit the use of this graph for up to six consecutive orbits. However, these grids may be up to four minutes off. Figure 1 shows a sample plot.
**APOLLO 15 SUBSATELLITE**

<table>
<thead>
<tr>
<th>ORBIT</th>
<th>START</th>
<th>PERILUNE</th>
<th>APOLUNE</th>
<th>SUNRISE</th>
<th>SUNSET</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2019</td>
<td>2041.4</td>
<td>2141.8</td>
<td>2141.8</td>
<td>2055.4</td>
</tr>
<tr>
<td>2</td>
<td>2219</td>
<td>2241.6</td>
<td>2340.1</td>
<td>2340.1</td>
<td>2254.1</td>
</tr>
<tr>
<td>3</td>
<td>18</td>
<td>40.9</td>
<td>140.3</td>
<td>140.3</td>
<td>54.1</td>
</tr>
</tbody>
</table>

**Figure 1**

**UNIVERSAL TIME**

PAGE 1.
2.1.2 Latitude versus Longitude

This plot shows the track of the satellite across the lunar surface in selenographic coordinates. We note that the vertical and horizontal scale are different by a factor of two. The points of sunrise and sunset at the subsatellite are indicated by shaded vertical bars. Perilune and apolune are marked on the orbit track with an 'X' and labelled with P and A, respectively. The subsolar point is similarly marked with an 'X' and labelled with an S. The location of the Apollo 15 ALSEP is similarly shown and encircled by an ellipse showing the area within 15° of the ALSEP site. Underneath the plot are given orbit numbers, perilune and apolune times. Figure 2 shows a sample plot.

2.1.3 Earth-moon system plots

This plot gives the ecliptic plane projection of the earth-moon system and includes the expected position of the magnetopause and bow shock. One point is given per orbit. Distances are labelled in earth radii. Figure 3 shows a sample plot.

2.1.4 Magnetic tape

The orbit tape contains position and orientation information which changes slowly in a header record once per orbit and rapidly changing positional data every minute in a data record (one record per minute). The format of this tape is given in Table 3.
APOLLO 15 SUBSATELLITE SELENOGRAPHIC COORDINATES

![Graph showing selenographic coordinates with orbit data and dates][1]

ORBIT 2002 2003 2004 2005 2006 2007
PERILUNE 542 742 942 1142 1342 1541
APOLUNE 442 642 842 1042 1242 1442

START DAY-FIRST ORBIT 1/18/72 CALCULATED 1/18/72 PROCESSED 3/04/72
TRACKING ORBIT - 2013

Figure 2

---

[1]: # Image of the graph illustrating the selenographic coordinates with orbit data and dates.
SOLAR ECLIPTIC POSITION EARTH-MOON SYSTEM

Figure 3
Table 3
Orbit Tape Contents

Header Record (Record 1)
Words 1-4 Integer, words 5 on Real.
1. Number of orbit on tape
2. Orbit number
3/4 Date calculated/processed
5/6 Altitude of perilune/apolune
7/8 Day of year of orbit start/year mod. 1900
9 Start time (seconds)
10 Number of points (records) in orbit
11/12 Time of perilune/apolune
13/14 Sunset time (start/stop)
15/16 Sunrise time (start/stop)
17/18 Earthrise/earthset times
19 End time of orbit

Transformation matrices of form A11 A12 A13, A21 A22 A23,
A31 A32 A33

| 20-28  | GEI to GSE | 101-109 | GEI to SG |
| 29-37  | GEI to GSM | 110-118 | SG to SSE |
| 38-46  | GEI to GSEQ | 119-127 | SG to SSEQ |
| 47-55  | GSM to GSE | 128-136 | SG to GSM |
| 56-64  | GSM to GSEQ | 137-145 | S/C to SSE |
| 65-73  | GSE to GSEQ | 146-154 | S/C to SSEQ |
| 74-82  | GEI to SSE | 155-63  | S/C to GSM |
| 83-91  | GEI to SSEQ | 164-172 | S/C to GSE |
| 92-100 | SSE to SSEQ | 173-181 | S/C to SG |
Table 3 (continued)

GEI = geocentric equatorial inertial coordinates
GSE = geocentric solar ecliptic
GSM = geocentric solar magnetospheric
GSEQ = geocentric solar equatorial
SSE = selenocentric solar ecliptic
SG = selenographic
S/C = spacecraft coordinate
Data Record - Repeated N times - All real
1/2 Day of year/year mod. 1900
3 Seconds of day
4/5 Earth-sun/earth-moon distances
6/7 Sun-moon/subsatellite-moon distances
8-10 Unit vector to sun GEI
11-13 Unit vector to moon GEI
14-16 Unit vector parallel PFS spin axis GEI
17-19 Unit vector parallel earth's dipole GEI
20-22 Unit vector to earth SSE
23-25 Unit vector to subsatellite SSL
26-28 Unit vector parallel to PFS spin axis SSE
29-31 Unit vector to subsatellite SG
32-34 Unit vector to earth SG
35-37 Unit vector to sun SG
38-40 Unit vector parallel to PFS spin axis SG
41 Altitude of PFS
2.2 Magnetometer data

Two microfilm reels of data and one magnetic tape have been produced in preliminary processing of the data. The first reel contains two plots consisting of magnetometer measurements on the A plot and engineering data on the B plot. The second reel contains a computer listing of 192 second averages of the data. The magnetic tape contains 24 second averages of the data.

2.2.1 The A Plot

This plot shows the $B_x$, $B_y$, $B_z$ components and $B_1$ (total field) in spacecraft coordinates versus time for one orbit. The orbit start time is defined here and in the orbit data to be the time of the crossing of the lunar noon meridian. Spacecraft coordinates have $X$ and $Y$ in the spin plane with $X$ along the projection of the earth-sun line in the spin plane and $Y$ roughly antiparallel the direction of planetary motion. The $Z$ direction is chosen to be parallel to the spin axis and points northward relative to the ecliptic plane. At launch the spin axes of both the Apollo 15 and 16 subsatellites were close to perpendicular to the ecliptic. Thus initially the data were returned in essentially solar ecliptic coordinates. Time on the horizontal scale is given in terms of day of year (Jan 1-365), hour and minute. No sensor drift corrections have been applied to these data. Note that the scale of this plot varies to keep the data on scale. Figure 4 shows a sample plot.
Figure 4
2.2.2 The B plot

The second plot contains relevant engineering and processing data and some data from the Berkeley particle experiment. The top line shows the telemetry mode TSN, TSF or RT. The second shows the array current in amps. The third shows the spin period in seconds. This is measured in sunlight and predicted in eclipse. Finally, on the bottom plotted on the same scale are Berkeley particle counts per accumulation period for the shielded and unshielded detectors. Figure 5 shows a sample plot.

2.2.3 The Printout

The microfilm reel containing the printout of the data first contains data and tables generated during the processing of the data. The printouts which follow are 192 second averages of the data (192 seconds is the basic repetition cycle of the data system). The data given are:

Day of year (Jan. 1=1)
Month/day
Elapsed time on spacecraft clock (1 tick=16 sec)
B_x, B_y, B_z, B_T (spacecraft coordinates, in gammas)
Open counts (Berkeley data)
Shielded counts (Berkeley data)
Sun elevation angle (degrees)
Spin period (seconds)
Spin count (from sun pulse or magnetometer pulse)
Magnetometer temperature (°F)
Battery temperature (°F)
Battery voltage (volts)
Battery current (amps)
Array current (amps)
Reference voltage of magnetometer (volts)
Flag 1  I Satellite ID (1=Apollo 15)
        F Data format (0=Store mode, 1=Real time)
        M Automatic/manual (0=Manual mode)
        C Calibration (1=On)
        T Transverse range (1=low sensitivity)
        P Parallel range (1=low sensitivity)
Flag 2 not used (repeats elapsed time fine). Figure 6 shows a sample plot.

2.2.4 Magnetic tape
The magnetic tape contains magnetic field data every 24 seconds and associated engineering data every 192 seconds. Its format is given in Table 4.
**SUBJECT:** LUNAR SUBSATELLITE MAGNETOMETER DATA REDUCTION PROGRAM (SSMAGE)

**PHASE 3 DATA TAPE FORMAT**

**PHYSICAL DESCRIPTION OF THE TAPE**

A. **PARITY:** ODD

B. **DENSITY:** 800 BPI

C. **WORD LENGTH:** 36 BITS

D. **WORD MODES USED**
   1. INTEGER
   2. FLOATING POINT
   3. FIELDATA

E. **FORMAT**

<table>
<thead>
<tr>
<th>RECORD NO.</th>
<th>NO. OF WORDS</th>
<th>MODE</th>
<th>ARRAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
<td>MIXED</td>
<td></td>
</tr>
</tbody>
</table>

**DESCRIPTION**

**PROCESSING DATE AND ROUTINE VERSION**

<table>
<thead>
<tr>
<th>WORD</th>
<th>MODE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>FIELDATA</td>
<td>Date processed &quot;DUMMYY&quot;</td>
</tr>
<tr>
<td>2</td>
<td>FIELDATA</td>
<td>Time of day processed &quot;HHMMSS&quot;</td>
</tr>
<tr>
<td>3</td>
<td>INTEGER</td>
<td>Routine version number</td>
</tr>
<tr>
<td>4</td>
<td>FIELDATA</td>
<td>Routine version generation date &quot;DUMMYY&quot;</td>
</tr>
<tr>
<td>5</td>
<td>FIELDATA</td>
<td>Routine version generation time of day &quot;HHMMSS&quot;</td>
</tr>
</tbody>
</table>

2  100  INTEGER ORBIT(100)

Lunar orbit numbers for data contained on this tape

3  100  INTEGER NOON(100)

Lunar noon meridians associated with the beginning of each of the above orbits

4  100  INTEGER ECLIPSE(100)

Lunar eclipse time associated with the above orbits

5  100  INTEGER SUNRIS(100)

Lunar sunrise time associated with the above orbits

6  200  INTEGER ECL(100,2)

Lunar eclipse intervals (start and stop times) found from the data (last subscript denotes start or stop)

7  200  INTEGER SUN(100,2)

Lunar sunlight intervals found from the data

8  200  INTEGER ASUN(100,2)

Lunar sunlight intervals prior to lunar eclipse found from the data associated with the above orbits

*Written on Univac 1108*
<table>
<thead>
<tr>
<th>RECORD NO.</th>
<th>N. OF WORDS</th>
<th>MODE</th>
<th>ARRAY</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>200</td>
<td>INTEGER</td>
<td>NITE(100,2)</td>
<td>Lunar eclipse intervals found from the data associated with the above orbits</td>
</tr>
<tr>
<td>10</td>
<td>260</td>
<td>INTEGER</td>
<td>MSUN(100,2)</td>
<td>Lunar sunlight intervals after lunar eclipse found from the data associated with the above orbits</td>
</tr>
<tr>
<td>11</td>
<td>250</td>
<td>INTEGER</td>
<td>BN(100,2)</td>
<td>TSN data intervals found from the data</td>
</tr>
<tr>
<td>12</td>
<td>200</td>
<td>INTEGER</td>
<td>TSF(100,2)</td>
<td>TSF data intervals found from the data</td>
</tr>
<tr>
<td>13</td>
<td>200</td>
<td>INTEGER</td>
<td>RT(100,2)</td>
<td>Real time data intervals found from the data</td>
</tr>
<tr>
<td>14-N</td>
<td>560</td>
<td>MIXED</td>
<td>BUF(560)</td>
<td>24 second average data</td>
</tr>
</tbody>
</table>

Note: All the above times are integer milliseconds  
(a) 1 Day = 86,400,000 milliseconds  
(b) 1 Hour = 3,600,000 milliseconds  
(c) 1 Minute = 60,000 milliseconds

The BUF array is described in terms of  
(a) 8 words per frame  
(b) 8 frames per data cycle  
(c) 16 extra words per data cycle  
(d) 80 total words per data cycle  
(e) 7 data cycles per record  
(f) 106 seconds per data cycle

SEE DESCRIPTION OF A DATA CYCLE BELOW

N - is the total number of records on the tape and is followed by 2 1108 software end-of-file marks, i.e., one word records containing an octal 17 in the 6 most significant bits and the remaining 30 least significant bits are zero.
DATA CYCLE DESCRIPTION

1 Data Cycle is 80 words. It is considered as an array dimensioned 8 by 10.

Then for DATCYC(8,10) or DATCYC(I,J):

1. I implies A_I for I = 1 to I = 8.
2. J implies frame of A_I for J = 1 to J = 8.
3. J is meaningless for A_I for J = 9 to J = 10, but the B_K data is contained in these cells.
   a. K takes on values 1 through 16.
   b. K = I + (J-9)*8 for I = 1 to I = 8, J = 9 and J = 10.

Graphically, DATCYC(8,10) looks as follows:

<p>| | | | | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A_1</td>
<td>A_2</td>
<td>A_3</td>
<td>A_4</td>
<td>A_5</td>
<td>A_6</td>
<td>A_7</td>
<td>A_8</td>
<td>A_9</td>
<td>A_10</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>A_11</td>
<td>A_12</td>
<td>A_13</td>
<td>A_14</td>
<td>A_15</td>
<td>A_16</td>
<td>A_17</td>
<td>A_18</td>
<td>A_19</td>
<td>A_20</td>
</tr>
<tr>
<td>11</td>
<td>12</td>
<td>13</td>
<td>14</td>
<td>15</td>
<td>16</td>
<td>17</td>
<td>18</td>
<td>19</td>
<td>20</td>
</tr>
</tbody>
</table>

Integer Cells

Floating Point Cells

Cells Not Used
From the above chart it is evident that:

1. \(((A(I,J), I=1,3), J=1,8)\) are integer numbers
2. \(((A(I,J), I=4,8), J=1,8)\) are floating point numbers
3. \((B(K), K=1,3)\) and \((B(7))\) are integer numbers
4. \((B(K), K=4,6)\) and \((B(K), K=8,13)\) are floating point numbers
5. \((B(K), K=14,16)\) are cells not used.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A(1,J)</td>
<td>Time (days)</td>
</tr>
<tr>
<td>A(2,J)</td>
<td>Time(milliseconds of day)</td>
</tr>
<tr>
<td>A(3,J)</td>
<td>Flag</td>
</tr>
<tr>
<td>A(4,J)</td>
<td>Transverse Field (Gammas)</td>
</tr>
<tr>
<td>A(5,J)</td>
<td>Parallel Field (Gammas)</td>
</tr>
<tr>
<td>A(6,J)</td>
<td>Sun Pulse Delay (seconds)</td>
</tr>
<tr>
<td>A(7,J)</td>
<td>Magnetometer Time Delay (seconds)</td>
</tr>
<tr>
<td>A(8,J)</td>
<td>Particle Counts</td>
</tr>
<tr>
<td>B(1)</td>
<td>Elapsed time coarse</td>
</tr>
<tr>
<td>B(2)</td>
<td>Elapsed time fine</td>
</tr>
<tr>
<td>B(3)</td>
<td>Flag</td>
</tr>
<tr>
<td>B(4)</td>
<td>Sun Elevation Angle (Degrees)</td>
</tr>
<tr>
<td>B(5)</td>
<td>Spin Period</td>
</tr>
<tr>
<td>B(6)</td>
<td>Sector Period</td>
</tr>
<tr>
<td>B(7)</td>
<td>Spin Count</td>
</tr>
<tr>
<td>B(8)</td>
<td>Magnetometer Temperature (°F)</td>
</tr>
<tr>
<td>B(9)</td>
<td>Battery Temperature (°F)</td>
</tr>
<tr>
<td>B(10)</td>
<td>Battery Current (amps)</td>
</tr>
<tr>
<td>B(11)</td>
<td>Battery Voltage (volts)</td>
</tr>
<tr>
<td>B(12)</td>
<td>Array Current (amps)</td>
</tr>
<tr>
<td>B(13)</td>
<td>Reference Voltage (volts)</td>
</tr>
</tbody>
</table>
3. Summary of Results

3.1 Lunar Magnetic Field

The earliest data clearly showed the evidence of fossil lunar magnetism during the portion of each lunation when the moon was in the geomagnetic tail (1-1, 1-2).* These lunar fields were most evident over the farside highlands. Preliminary quick look data were used to construct a contour map of the lunar contributions to the transverse magnitude choosing an arbitrary zero level near the crater Van de Graaff (1-3, 1-4). The Van de Graaff region at about 170°E and 20°S has the strongest fields encountered along the Apollo 15 subsatellite orbit track and was the first to be examined with low altitude data (1-4, 1-5). These data revealed that the magcon was not centered on either the crater Van de Graaff or the crater Aitken. At 67 km the field over Van de Graaff was about 2.5γ. The launch of the Apollo 16 subsatellite provided data at all altitudes from 200 km down to the lunar surface. Below 20 km fields up to 50γ were observed (1-6, 1-7).

The receipt of data on digital magnetic tapes permitted routine large scale mapping of the vector magnetic field in lunar coordinates. Maps of the radial component of the lunar field over the Apollo 15 orbit track have been created (1-8). High resolution maps over the Van de Graaff region at two

*Numbers refer to papers listed in the bibliography in section 4.
altitudes, 67 and 130 km permitted a scale size of 83 km to be deduced (1-8). Three component vector maps over this region have also been produced (1-12). Recently a new technique for observing these magnetic features has been developed by the Berkeley group (2-2), both confirming and extending these results.

Fourier analysis of the radial and tangential components of the field has permitted a limit of $2 \times 10^{18} \Gamma \text{-cm}^3$ to be placed on the present day dipole moment in the subsatellite orbit plane (1-11, 1-12). However, since the possibility was raised that the moon has a significant induced dipole moment, we re-examined the dipole field measurement taking care to remove and measure induced effects. This lowered the measured permanent moment in the orbit plane to less than $1.3 \times 10^{18} \Gamma \text{-cm}^3$ and gave an induced moment of $-6.3 \times 10^{22} \Gamma \text{-cm}^3$ per Gauss of external field (1-13, 1-14). The fact that this is negative indicates the presence of a weak lunar ionosphere. Analysis of Apollo 16 data confirms this result (1-16). Further, the addition of the Apollo 16 data taken around a belt with a significantly different lunar pole permits the calculation of all three components of the lunar dipole moment. The total permanent moment is certainly less than $10^{19} \Gamma \text{-cm}^3$ and probably much less. The present lunar dipole field is so low that it is unlikely that the moon ever had a large magnetic dipole moon as sometimes suggested.
Finally, with the availability of the Apollo 16, data maps of the fine scale lunar field have been created over all the subsatellite orbit tracks while they were in the geomagnetic tail. These maps have been submitted for publication in the Proceedings of the Fifth Lunar Science Conference.

3.2 The Solar Wind Interaction with the Moon

The previously known enhancement in the field strength on the antisolar side of the moon, when the moon is in the solar wind, known as the diamagnetic cavity, is also seen at the 100 km altitude of the subsatellite (1-1, 1-2). Also observed are the dips in field strength adjacent to the cavity which are presumed to occur because of the expansion of the solar wind flow into the cavity. One dominant feature of the interaction is the frequent increases in field strength just in front of the terminator. While these features were previously reported on Explorer 35, they are much larger at the low altitude of the subsatellite. These have previously been termed limb shocks or penumbral increases. However, we use the more conservative term, limb compression. They are definitely correlated with the appearance of certain regions at the limbs (1-3, 1-5, 1-6, 1-7). The property of the lunar surface that appears to be responsible for the deflection of the solar wind leading to a limb compression is the lunar remanent magnetic field (1-8, 1-12). On the other hand, the occurrence rate is also a function of the orientation of the interplanetary magnetic
field similar to the dependence of the structure of the earth's bow shock on the interplanetary field orientation (3-16).

3.3 The Transfer Function of the Moon

The region of the lunar limbs is usually disturbed even when limb compressions are absent (1-1, 1-2). However, comparisons with Explorer 35 magnetometer measurements show that the field is often undisturbed by the presence of the moon over much of the subsolar hemisphere (1-11, 1-12, 1-17, 1-18). Thus, the subsatellite magnetometer at times could be used as a measure of the input wave spectrum to the moon. On the other hand when the subsatellite is in the diamagnetic cavity, it is responsive to both the solar wind input and the scattered spectrum.

3.4 The Plasma Sheet Interaction with the Moon

When the moon is in the plasma sheet the average magnetic field as a function of selenocentric solar ecliptic longitude resembles that in the solar wind but the enhancement is on the earthward side (1-17, 1-18). Further, the transfer function on the dayside (earthward side) resembles that of the lunar cavity when the moon is in the solar wind. This suggests there is an earthward flow of plasma on the average in the plasma sheet at the lunar distance (1-15).
4. Bibliography

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