Apollo 15 ALSEP ARCSAV Heat Flow Experiment Raw Cleaned ASCII Data Collection (1975-092 to 1975-181)

Overview

The astronauts on the Apollo missions deployed a set of scientific instruments that were collectively known as the Apollo Lunar Surface Experiments Package (ALSEP) at each of the Apollo 12, 14, 15, 16, and 17 landing sites [1]. The ALSEP instruments operated from the time of deployment to September 1977 at each site [2]. This collection from the Apollo 15 site consists of cleaned (corrected) ASCII tabular files of Heat Flow Experiment (HFE) raw data for the period of April 2, 1975 through June 30, 1975. These scientific, housekeeping, and command verification data were extracted from NASA's original ALSEP data archival tapes (also known as ARCSAV tapes) that recorded rearranged and time-edited, raw, unprocessed binary data transmitted from the Moon.

ARCSAV Processing History

From April 1973 to February 1976, approximately 5000 ALSEP ARCSAV tapes were generated at the NASA Johnson Space Center. They were 7-track, digital, open-reel magnetic tapes. One ARCSAV tape contained a 24-hour, continuous recording of the raw binary data for all the ALSEP instruments deployed at one of the Apollo landing sites [3]. Data from several instruments were intermeshed into ALSEP frames, each consisting of 64 ALSEP data words as shown in Appendix A.

In the years following the conclusion of the Apollo program, all of these tapes were lost. In the year 2010, 439 of these tapes, containing data from April 2, 1975 through July 1, 1975, were found at the Washington National Records Center [4]. Funding from the NASA Lunar Advanced Science & Exploration Research (LASER) and Planetary Data Archiving, Restoration, & Tools (PDART) programs NNH10ZDA001N-LASER and NNH14ZDA001N-PDART14 facilitated the extraction of data from ARCSAV tapes [4] and transformation to raw digital data sets of various levels of processing, some of which are archived at the NASA Space Science Data Coordinated Archive (NSSDCA) [5]:

- NSSDCA data set PSPG-00914 consists of daily binary files of raw, intermeshed Apollo 15 experiment data “as read” and extracted from those 439 ARCSAV tapes, but without corrections for obvious bit errors. These obvious bit errors and byte shifts and splits from tape reads were corrected to make cleaned, raw Apollo 15 daily binary files for NSSDCA data set PSPG-00918. Corrections were possible because the original ALSEP ARCSAV document is still available [3].
- NSSDCA data set PSPG-00921 consists of 90 daily files of raw binary HFE data extracted from the cleaned ARCSAV data set for Apollo 15 (PSPG-00918). All raw HFE-related data contained in the ARSAV tapes are captured in these NSSDCA datasets.
- This present collection is a transformation of 90 daily HFE raw binary files in NSSDCA data set PSPG-00921 into ASCII format. The Fortran programs used by the data provider for this transformation are included, for documentation purposes only, in same document collection as this data description file. This ASCII collection contains all raw HFE-related data from the ARSAV tapes.

Required Reading

The user should read several publications before using this archive.

Required: [3] provides a detailed description of the contents of the ALSEP ARCSAV tapes. Relevant sections in [3] are 1.0, 2.0, 6.8, and Appendix C including pages C-71 through C-80 that explain the HFE measurements. [6] provides detailed engineering and operations information about the Apollo 15 ALSEP station (also known as Array A2) and the HFE experiment. The most relevant chapters in [6] are 6 - ALSEP telemetry subsystem, and 12 - HFE operations, modes and measurements.

Strongly Recommended: [2] provides a very detailed operational history of each individual ALSEP experiment, including operational status, anomalies, and failures by date. [9] describes the HFE experiment and reports initial results. [11] reduced and calibrated these restored raw HFE data to reanalyze the long-term subsurface warming observed at the Apollo 15 and 17 sites; the calibrated data are archived in the NASA

Additional detailed engineering and operations information on the Apollo 15 ALSEP station and the HFE are provided in [7] and [8]. For a brief description of a specific Apollo scientific experiment together with its operational history and its data content, formats, and availability during the Apollo era, see [9].

Overview of Data Products

This collection contains four types of data products, where each type consists of a file of time-ordered, ASCII data in fixed-width tabular format (.tab) and a detached PDS label (.xml) that defines the format and contents of the data file:

- Raw Mode 1 (Normal Gradient Mode) Science Data: One product containing of raw scientific measurements from HFE Mode 1 operations for the time span of April 2 to June 30 1975: a15_hfe_1975_l1_arcsav_1.tab/.xml,
- Raw Mode 3 (High Conductivity Mode) Science Data: One product containing of raw housekeeping measurements from HFE Mode 3 operations for the time span of April 2 to June 30 1975: a15_hfe_1975_l1_arcsav_3.tab/.xml,
- Raw Digital Analog Housekeeping: One product of raw digital analog HFE Housekeeping (Engineering) data: a15_hfe_1975_l1_arcsav_hk.tab/.xml, and
- Command Verification: One product containing a log of HFE Command Verifications: a15_hfe_1975_l1_arcsav_cv.tab/.xml.

Raw Mode 1 (Normal Gradient Mode) Science Data Product

The product contains raw, unreduced, Mode 1 measurements, identified as Measurement Numbers DH-n [3, 6], that were converted within the HFE experiment to digital data numbers (DN) and stored in the designated ALSEP data word 24 [3, 6] at the proper demand time in serial form for relay to Earth. Mode 1 is also known as Mode G.

The data file, a15_hfe_1975_l1_arcsav_1.tab. consists of one header record followed by two tables in this order:

1. Header: A single record that identifies the columns (fields) in the TimeOffsets and RawData tables.

2. TimeOffsets Table: A one-record fixed-width ASCII table that provides a derived sampling-rate-adjusted delay time as an offset in milliseconds for computing the time for each data measurement in each RawData Table record.

   These sampling-rate-adjusted delay times (offsets) were calculated specifically for this restoration using an ALSEP frame duration time of 603.75 milliseconds per frame, or 9.4336 milliseconds per ALSEP data word. (There are 64 words per ALSEP frame). This frame duration time was computed by taking the average of the minimum and maximum of the daily mean sampling rates for the ALSEP frames for the time span of this data collection.

3. RawData Table: A multi-record fixed-width ASCII table where each record contains 16 sets of four related data measurements for one HFE data cycle while the experiment was operating in Mode 1: DH-1A/B/C/D through DH-13A/B/C/D, DH-14/24/34/44, DH-15A/B/C/D, and DH-16/26/36/46. Each set consists of a reference earth-received time in UTC and the four data measurements for a specific HFE data point, e.g. DH-1A, DH-1B, DH-1C, and DH-1D. The 16 sets are ordered by the earth-received time within each record, and records are ordered by the earth-received time within the table. A cross reference of each DH measurement number to a specific data point ("Measurement Name") is provided on pages C-73 to C-79 of [3] and in Appendix B. Each "Measurement Name" is encoded such that "T1" indicates temperature measurements from HFE probe 1 and "T2" from probe 2 while "TC1" and "TC2" indicate temperature measurements of the four thermocouples in probe 1 (DH-14/24/34/44) and probe 2 (DH-16/26/36/46), respectively.

   These raw measurements are provided in this table as decimal integers with units of data number (DN) which is another name for digital unit (DU), the term typically used in ALSEP documentation. DN or DU, also known as digital count or instrument count, is the unit of measure for the raw digital number output by the experiment analog-to-digital converter. The label specifies units of DN which is the PDS convention. The user should refer to the required reading sections in [3] and [6] to understand the raw measurement values. These publications indicate the value for a raw HFE measurement comprises 13-bits, and thus the range of integer values in the RawData table is 0 to 8191 DN. Please note the Mode 1 operating ranges shown in Appendix B are units of temperature, not DN.

   The PDS data label defines for layout of this table and describes the contents of each column. Additional explanation of the contents is provided here:

   - The earth-received time for each of the 16 sets of measurements is the time when the first word of the ALSEP frame containing the first of the four related data measurements was received on earth, referenced to the standard time signal received at the Manned Space Flight Network station. When the operators had a problem reading the time signal, they substituted it with a computer-generated time, which they called the "software clock". The format for the earth-received time is YYYY-DDDTHH:MM:SS.sss, where DDD is day of year YYYY.

     Each earth-received time is followed by a quality flag which is set to an asterisk "*" if the time value is from the software clock; if there is a suspected transmission, data synchronization or tape read error in the value; or if the time value is clearly outside the expected range for this restoration effort. A negative sign "-" indicates this value is the earth-received time, and the value does not have a suspected read or transmission error or that it is unknown if there was an error and therefore could still contain an error.

- A set of missing or unavailable data is identified by the string value '9999' for the earth-received time and integer -9 (negative nine) in the four related data measurements.
- Each DH data column is followed by a quality flag which is set to an asterisk "*" if that data value has a suspected transmission, data synchronization or tape read error. A negative sign "-" indicates this data measurement does not have a suspected read or transmission error or that it is unknown if there was an error and therefore the measurement could still contain an error.
- To compute the time for a specific data measurement, add the milliseconds time offset, which is found in the single-record table TimeOffsets for the data measurement column of interest, to the time stamp (earth-received time) in the RawData record for the set of four related measurements to which the one of interest belongs.
- The earth-received times can be reformatted from YYYY-DDDTHH:MM:SS.sss to decimal day by extracting the day of year (DDD), hour (HH), minute (MM), and seconds (SS.sss) strings from the timestamp, converting them to floating point, then performing this calculation:

  decimal day = DDD + (HH*3600. + MM+60. + SS.sss) / 86400.0

  where 86400.0 is the number of seconds in a day. Pay careful attention to the number of digits the computer carries. For example, to preserve the millisecond-resolution of the timestamps 11 decimal digits (or 35 binary digits) need be kept, and therefore the variables DDD, HH, MM, and SS.sss may need to be defined as double-precision floating point. Using single-precision floating-point variables to reformat the timestamps would reduce the resolution to about a second.

Raw Mode 3 (High Conductivity Mode) Science Data Product

The product contains raw, unreduced, Mode 3 measurements identified as Measurement Numbers DH-n [3, 6], that were converted within the HFE experiment to digital data numbers (DN) and stored in the designated ALSEP data word 24 [3, 6] at the proper demand time in serial form for relay to Earth. Mode 3 reads out a different set of measurements than Mode 1. Mode 3 is also known as Mode HK.

The data file, a15_hfe_1975_l1_arcsav_3.tab. consists of one header record followed by two tables in this order:

1. Header: A single record that identifies the columns (fields) in the TimeOffsets and RawData tables.
2. TimeOffsets Table: A one-record fixed-width ASCII table that provides a derived sampling-rate-adjusted delay time as an offset in milliseconds for computing the time for each data measurement in each RawData Table record.

   These sampling-rate-adjusted delay times (offsets) were calculated using the same ALSEP frame duration time as the Raw Mode 1 Science Data Product: 603.75 milliseconds per frame, or 9.4336 milliseconds per ALSEP data word.
3. RawData Table: A multi-record fixed-width ASCII table where each record contains 12 sets of four related data measurements while the experiment was operating in Mode 3: DH-50A/B/C/D, DH-51A/B/C/D, DH-60A/B/C/D, DH-61A/B/C/D DH-56A/B/C/D, DH-57A/B/C/D, DH-70A/B/C/D, DH-71A/B/C/D, DH-80A/B/C/D, DH-81A/B/C/D, DH-76A/B/C/D, and DH-77A/B/C/D. Each set consists of a reference earth-received time in UTC

and the four data measurements for a specific HFE data point, e.g. DH-50A, DH-50B, DH-50C, and DH-50D. The 12 sets are ordered by the earth-received time within each record, and records are ordered by the earth-received time within the table. A cross reference of each DH measurement number to a specific data point ("Measurement Name") is provided on pages C-73 to C-79 of [3] and in Appendix B. Appendix B associates Measurement Names with probe 1 or probe 2.

These raw measurements are provided in this table as decimal integers with units of data number (DN). The user should refer to the required reading sections in [3] and [6] to understand the raw measurement values. These publications indicate the value for a raw HFE measurement comprises 13-bits, and thus the range of integer values in the RawData table is 0 to 8191 DN.

The PDS data label defines for layout of this table and describes the contents of each column. Additional explanation of the contents is provided here:

- The earth-received time for each of the 12 sets of measurements is the time when the first word of the ALSEP frame containing the first of the four related data measurements was received on earth, referenced to the standard time signal received at the Manned Space Flight Network station. When the operators had a problem reading the time signal, they substituted it with a computer-generated time, which they called the "software clock". The format for the earth-received time is YYYY-DDDTHH:MM:SS.sss, where DDD is day of year YYYY.

  Each earth-received time is followed by a quality flag which is set to an asterisk "*" if the time value is from the software clock; if there is a suspected transmission, data synchronization or tape read error in the value; or if the time value is clearly outside the expected range for this restoration effort. A negative sign "-" indicates this value is the earth-received time, and the value does not have a suspected read or transmission error or that it is unknown if there was an error and therefore could still contain an error.

- Typically each record contains only two sets of DH measurements with data because the sampling rate for Mode 3 was sparse. Sets without data are identified by string value '9999' for the earth-received time and integer -9 (negative nine) in the four related data measurements.

- Each DH data column is followed by a quality flag which is set to an asterisk "*" if that data value has a suspected transmission, data synchronization or tape read error. A negative sign "-" indicates this data measurement does not have a suspected read or transmission error or that it is unknown if there was an error and therefore the measurement could still contain an error.

- To compute the time for a specific data measurement, use the same method described for the Raw Mode 1 Science Data Product.

Raw Housekeeping Data Product

This product contains raw HFE Housekeeping (HK) measurements, identified by Measurement Numbers AH-n, from analog sensors that indicate the condition of the HFE experiment. Housekeeping measurements were stored in ALSEP Word 33 [3] for relay to Earth.

The ASCII HK file (a15_hfe_1975_l1_arcsav_hk.tab) consists of one header record followed by two tables in this order:

1. Header: A single record that identifies the columns (fields) in the TimeOffsets and RawHK tables.

2. TimeOffsets Table: A one-record fixed-width ASCII table that provides a derived sampling-rate-adjusted delay time as an offset in milliseconds for computing the time for each data measurement in each RawHK Table record.

   The sampling-rate-adjusted delay times (offsets) were calculated using the same ALSEP frame duration time as the Raw Mode 1 Science Data Product: 603.75 milliseconds per frame, or 9.4336 milliseconds per ALSEP data word.

3. RawHK Table: A multi-record fixed-width ASCII table containing raw analog HFE Housekeeping data, where one record contains the housekeeping measurements from multiple ALSEP frames. Each record begins with the reference earth-received time for the set of data in that record followed by 6 raw digital analog measurements identified by their HFE Measurement Number, AH-n: four measurements AH-1 to AH-4 for supply voltage numbers 1-4, respectively, and two measurements AH-6 and AH-7 for high and low conductivity heater power status, respectively.

   These raw measurements are provided in this table as decimal integers with units of data number (DN). The user should refer to the required reading sections in [3] and [6] to understand the raw HK values and the operating range and nominal limits for the HK analog sensors. These publications indicate the value for a raw HFE HK measurement comprises 8-bits, and thus the range of integer values in the RawHK table is 0 to +255 DN. Please note the operating ranges for AH-1 to AH-4 shown in Appendix B and C are units of volts, not DN.

   The PDS data label defines for layout of this table and describes the contents of each column and if applicable its range of values and their meanings. Additional explanation of the contents is provided here:

   - Records are ordered by the earth-received time in the first column.

     This earth-received time in UTC is the time when the first word of the ALSEP frame containing the AH-1 measurement was received on earth, referenced to the standard time signal received at the Manned Space Flight Network station. When the operators had a problem reading the time signal, they substituted it with a computer-generated time, which they called the "software clock".

     The earth-received time is followed by a quality flag which is set to an asterisk "*" if the time value is from the software clock; if there is a suspected transmission, data synchronization or tape read error in the value; or if the time value is clearly outside the expected range for this restoration effort. A negative sign "-" indicates this value is the earth-received time, and the value does not have a suspected read or transmission error or that it is unknown if there was an error and therefore could still contain an error.

   - The status column, which follows the earth-received time, contains four 1-byte flags copied from the ARCSAV tapes. Each byte is one of the four 3-bit sync status flags for the ALSEP frame. The one-byte flags from left to right are: 1) unedited time sync status; 2) unedited data sync status; 3) edited time sync status; and 4) edited data sync status. The time sync status can be any value between 0 and 7, while the data sync status can only be 0, 4, 5, or 7. Although Section 2 of [3] explains the status values, it does not define the difference between unedited and edited status flags.

   - A Housekeeping value of integer -9 (negative nine) indicates a missing value.

- Each AH data column is followed by a quality flag which is set to an asterisk "*" if that data value has a suspected transmission, data synchronization or tape read error. A negative sign "-" indicates this data measurement does not have a suspected read or transmission error or that it is unknown if there was an error and therefore the measurement could still contain an error.
- To compute the start time for a specific Housekeeping measurement, add the milliseconds time offset, which is found in the single-record table TimeOffsets for the Housekeeping measurement column of interest, to the time stamp (earth-received time) in the first column of the RawHK record containing the Housekeeping measurement of interest.

Command Verification Data Product

This product provides a time-ordered log of commands specific to HFE operations that were received by Apollo 15 ALSEP and acted upon. These Command Verifications (CV) are stored in ALSEP Word 46 as Measurement Numbers DA-5 and DA-6 [3] for relay to Earth.

The ASCII CV file (a15_hfe_1975_l1_arcsav_cv.tab) consists of one header record and one table in this order:

1. Header: A single record that identifies the columns (fields) in the CVLog table.
2. CVLog Table: A multi-record fixed-width ASCII table providing a log of time-ordered Command Verification (CV) messages for HFE operations. CV messages consist of a command counter code (the CV value) and its Message Acceptance Pulse (MAP) bit flag that reads out a "1" when the command parity error check was successful and the command was accepted and acted upon, as explained on page C-8 of [3]. Each record contains an earth-received time, a time status field, the command counter code as an octal integer, and its MAP for one CV message. The CV values for HFE operations are listed in Appendix D.
   - Records are ordered by the earth-received time in the first column.
   - The time given here is not the command time. It is the earth-received time in UTC of the first word of the ALSEP frame in which the CV was recorded, referenced to the standard time signal received at the Manned Space Flight Network station. The command was received and acted upon sometime before the CV was recorded (+425 milliseconds after the earth-received time). When the operators had a problem reading the time signal, they substituted it with a computer-generated time, which they called "software clock".

     The earth-received time is followed by a quality flag which is set to an asterisk "*" if the time value is from the software clock; if there is a suspected transmission, data synchronization or tape read error in the value; or if the time value is clearly outside the expected range for this restoration effort. A negative sign "-" indicates this value is the earth-received time, and the value does not have a suspected read or transmission error or that it is unknown if there was an error and therefore could still contain an error.
   - The status column, which follows the earth-received time, contains four 1-byte flags copied from the ARCSAV tapes. Each byte is one of the four 3-bit sync status flags for the ALSEP frame. The one-byte flags from left to right are: 1) unedited time sync status; 2) unedited data sync status; 3) edited time sync status; and 4) edited data sync status. The time sync status can be any value between 0 and 7, while the data sync status can only be 0, 4, 5, or 7. Although Section 2 of [3] explains the status values, it does not

define the difference between unedited and edited status flags nor does ALSEP literature that was searched.

- The command counter code and its MAP bit are followed by a quality flag which is set to an asterisk "*" if the CV and/or its MAP has a suspected read or transmission error. A negative sign "-" indicates these values do not have a suspected read or transmission error or that it is unknown if there was an error and therefore could still contain an error.

Caveats/Confidence Level

Earth-Received Time vs. Data Acquisition Time

The earth-received times in the data products are approximately 1.19 to 1.37 seconds after the time when the data were acquired on the moon. This estimate, taken from ephemerides computed by the JPL Horizons System (https://ssd.jpl.nasa.gov/?horizons), is the minimum and maximum one-way down-leg light-time from the center of the moon (radius 1737 km) to a Manned Space Flight Network station on Earth (Canberra or Goldstone) for the time span of the data products.

Raw Data vs. Reduced Data

This collection contains only raw, unreduced data in units of DN (digital counts). [11], [12], and [13] provide information and references about how to transform the raw DN values to physical quantities and calibrate the HFE data from the Apollo 15 and 17 sites.

Thermocouple Naming Convention

Two numbering conventions exist in the literature for the thermocouples. This collection follows the nomenclature of original HFE investigators [10], where the thermocouple at the top of probe 1 is designated as TC11, followed successively in the cable by TC14, TC13, and TC12. Another convention, used in [14] and [15], designates the thermocouple at the top of probe 1 as TC14, TC13 is the cable thermocouple closest to probe 1, followed by TC12 and TC11.

Data Quality

The goal for this restoration was to recover as much of the original data from tape as possible without overinterpreting and overcorrecting the values. The source binary files contain data that were corrected (cleaned) to remove byte shifts caused by missing, combined, extra, and split bytes that resulted from tape-reading errors. Only the obvious errors were corrected, and thus many bit errors may still remain in the source binary files and are carried over to the ASCII products in this archive. The user needs to aware of these errors and know that these could, if necessary, be corrected, but not always. Some known data quality issues most likely caused by a transmission, data synchronization or tape read errors are:

- Some values for earth-received time appear to be out of temporal order; may overlap with other timestamps; are outside the time range of this collection; or are an unreasonable value for day of year. These cases are likely caused by bit errors. Since this type of problem is always present in the ALSEP data, the restoration effort attempted to flag earth-received times whenever such a problem was suspected. Since the data that follow are likely to be correct, the incorrect times can often be interpolated from correct times before and after. Some bit errors, such as a single-bit error, can be corrected if it is obvious, but correcting other types errors, such as those already existed when the ARCSAV tapes were created and

thus indicated with their time-sync status flags, can require subjective judgments, which can be false. One solution would be to ignore the data when an error is suspected, but this may not be appropriate.

The user should aware that this attempt to evaluate the earth-received times was not perfect, and therefore there may be cases where the quality flag for is not turned on (not set to an asterisk "*") for a value that appears to be incorrect.

- Some values in the status column may be incorrect that most likely resulted from tape read or data synchronization errors. This is often reflected in the quality flags for the data columns, which are turned on (set to an asterisk "*") when the data are out of synchronization.
- The CV file excludes entries where both a CV and its associated time stamp were determined to be poor quality, mainly originating from tape read errors that caused both quality flags to be turned on (set to an asterisk "*").

References

[1] Davies, M. E., and T. R. Colvin, Lunar coordinates in the regions of the Apollo landers, Journal of Geophysical Research, Volume 105, Issue E8, pages 20,227-20,280, 2000. (doi:10.1029/1999JE001165)

[2] Bates, J. R., et al., ALSEP Termination Report, NASA Reference Publication 1036, April 1979. (https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19790014808.pdf)

[3] Apollo Lunar Surface Experiments Package Archive Tape Description Document, JSC-09652, NASA Johnson Space Center, Houston, Texas, May 1975. (https://repository.hou.usra.edu/handle/20.500.11753/42)

[4] Nagihara, S., Y. Nakamura, L. R. Lewis, D. R. Williams, P. T. Taylor, E. J. Grayzeck, P. Chi, and G. K. Schmidt, Search and Recovery Efforts for the ALSEP Data Tapes, 42nd Lunar and Planetary Science Conference, held March 7-11, 2011 at The Woodlands, Texas, Lunar and Planetary Institute Contribution No. 1608, Abstract 1103, 2011. (https://www.lpi.usra.edu/meetings/lpsc2011/pdf/1103.pdf)

[5] Nagihara, S., Y. Nakamura, D. R. Williams, P. T. Taylor, W. S. Kiefer, M. A. Hager, and H. K. Hills, Availability Of Previously Unprocessed ALSEP Raw Instrument Data and Derivative Data and Metadata Products, 47th Lunar and Planetary Science Conference, held March 21-25, 2016 at The Woodlands, Texas, Lunar and Planetary Institute Contribution No. 1903, Abstract 1194, 2016. (https://www.hou.usra.edu/meetings/lpsc2016/pdf/1194.pdf)

[6] Apollo Lunar Surface Experiments Package Systems Handbook: ALSEP A2, PCN-1, unnumbered, NASA Manned Spacecraft Center, Houston, Texas, 24 March 1971, revised 15 April 1971. (https://www.lpi.usra.edu/lunar/ALSEP/pdf/31111000675122.pdf)

[7] Apollo Lunar Surface Experiments Package, ALSEP Flight System Familiarization Manual, Revision B, ALSEP-MT-03, NASA CR-99604, The Bendix Corporation for [8] NASA Manned Spacecraft Center, published 1 August 1967, revised 15 April 1969. (https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19710014816.pdf or https://repository.hou.usra.edu/handle/20.500.11753/238)

[8] Apollo Lunar Surface Experiments Package, ALSEP Flight System Familiarization Manual, Revision B / Change 1, ALSEP-MT-03, NASA CR-99604, The Bendix Corporation for NASA Manned Spacecraft Center, Houston, Texas, 18 March 1970. (https://repository.hou.usra.edu/handle/20.500.11753/45)

[9] Lauderdale, W. W., and W. F. Eichelman, Apollo Scientific Experiments Data Handbook, NASA, TM-X-58131, Houston, Texas, August 1974, updated August 1976. (https://repository.hou.usra.edu/handle/20.500.11753/17 or https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19760007062.pdf)

[10] Apollo 15 Preliminary Science Report, NASA SP-289, NASA, Washington, D.C., January 1972. (https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19720015164.pdf)

[11] Nagihara, S., W. S. Kiefer, P. T. Taylor, D. R. Williams, and Y. Nakamura, Examination of the long-term subsurface warming observed at the Apollo 15 and 17 sites utilizing the newly restored heat flow experiment data from 1975 to 1977, Journal of Geophysical Research: Planets, 123, 1125–1139, 2018. (doi:10.1029/2018JE005579)

[12] Nagihara, S. and Y. Nakamura, "Apollo 15 ALSEP ARCSAV Heat Flow Experiment Calibrated Gradient Bridge Temperatures Bundle", NASA Planetary Data System, id: urn:nasa:pds:a15hfe_calibrated_arcsav.

[13] Nagihara, S. and Y. Nakamura, "Apollo 17 ALSEP ARCSAV Heat Flow Experiment Calibrated Gradient Bridge Temperatures Bundle", NASA Planetary Data System, id: urn:nasa:pds:a17hfe_calibrated_arcsav.

[14] Langseth, M. G., K. Peters, and H. K. Hills, "Apollo 15 Heat Flow Thermal Conductivity RDR Subsampled V1.0", 1971-07-31 to 1974-12-31 data, NASA Planetary Data System, id. A15A-L-HFE-3-THERMAL-CONDUCTIVITY-V1.0, 2012.

[15] Langseth, M. G., K. Peters, and H. K. Hills, "Apollo 17 Heat Flow Thermal Conductivity RDR Subsampled V1.0", 1972-12-12 to 1974-12-31 data, NASA Planetary Data System, id. A17A-L-HFE-3-THERMAL-CONDUCTIVITY-V1.0, 2012.

Appendix A

The Apollo 15 ALSEP main frame word assignments from [6], [3].

ALSEP A2
BASIC

1 x	2 x	3 x	4 X	5 o	6 X	7 S	8 X
9 -	10 X	11 -	12 X	13 -	14 X	15 I	16 X
17 o	18 X	19 o	20 X	21 o	22 X	23 S	24 HF
25 -	26 X	27 -	28 X	29 -	30 X	31 I	32 X
33 H	34 X	35 •	36 X	37 •	38 X	39 S	40 X
41 -	42 X	43 -	44 X	45 -	46 CV	47 I	48 X
49 o	50 X	51 o	52 X	53 o	54 X	55 S	56 I
57 -	58 X	59 -	60 X	61 -	62 X	63 I	64 X

Word totals	Legend
3	x = Sync
28	X = Passive seismic - short period
12	- = Passive seismic - long period
2	• = Passive seismic - long period tidal and one temperature
7	o = Magnetometer experiment
4	S = Solar wind spectrometer experiment
5	I = Suprathermal ion detector experiment
1	HF = Heat flow experiment
1	CV = Command verification
1	H = Housekeeping

Each box contains one 10-bit word

Total bits per frame = 10 x 64 = 640 bits

Data rate = 1060 bits/second or 530 bits/second

Figure 6-2.- Main frame format.

6-7

Appendix B

List of measurements for Mode 1 and Mode 3 including operating range for Mode 1 measurements, excerpted from pages 6-31 and 6-33 in [6].

FCD 12-69.23.22A

ALSEP A2
BASIC

Heat Flow Word	Bit Position										ALSEP Frames
	1	2	3	4	5	6	7	8	9	10	
0	R_2	R_1	0	P_4	P_3	P_2	P_1	2^{12}	2^{11}	2^{10}	0
	2^9	2^8	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0	1
1	R_2	R_1	M_1	M_2	M_3	0	0	2^{12}	2^{11}	2^{10}	2
	2^9	2^8	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0	3
2	R_2	R_1	H_4	H_3	H_2	H_1	0	2^{12}	2^{11}	2^{10}	4
	2^9	2^8	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0	5
3	R_2	R_1	0	0	0	0	0	2^{12}	2^{11}	2^{10}	6
	2^9	2^8	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0	7

Notes:

1. It takes two ALSEP main frames to downlink one heat flow word. It takes four heat flow words to obtain one measurement except in Thermocouple Group Probe 1 and 2. In Thermocouple Group Probe 1 and 2 each heat flow word contains a single measurement.
2. Measurement DH-90: M_1, M_2, and M_3 identifies mode.
3. Measurement DH-91:
   P_4, P_3, P_2, and P_1 are measurement identification in gradient mode and low conductivity mode.
4. Measurement DH-92:
   R_2 and R_1 are the binary equivalent of heat flow word and identify the analog parameters (13-bits) that are used in the calculation to derive the engineering units for a measurement number.
5. Measurement DH-93:
   H_4, H_3, H_2, and H_1 identify the conductivity heater status. In the high conductivity mode it identifies the measurement numbers also.
6. Measurement DH-94:
   Filler bits (shown as zeros in above chart).

Figure 6-6. - HFE word format.

6-31

TABLE 6-XVI.- HFE MEASUREMENTS, MODE 1 AND 2 GRADIENT AND LOW CONDUCTIVITY

	SYMBOL	LOCATION/MEASUREMENT	FRAME	RANGE
	DH-1	ΔT_{11} H Temp Grad High Sens	0-7	$\pm 2°C$
	DH-2	ΔT_{12} H Temp Grad High Sens	8-15	$\pm 2°C$
	DH-3	ΔT_{21} H Temp Grad High Sens	90-97	$\pm 2°C$
	DH-4	ΔT_{22} H Temp Grad High Sens	98-105	$\pm 2°C$
	DH-5	ΔT_{11} L Temp Grad Low Sens	180-187	$\pm 20°C$
	DH-6	ΔT_{12} L Temp Grad Low Sens	188-195	$\pm 20°C$
	DH-7	ΔT_{21} L Temp Grad Low Sens	270-277	$\pm 20°C$
	DH-8	ΔT_{22} L Temp Grad Low Sens	278-285	$\pm 20°C$
	DH-9	T_{11} Probe, Ambient Temp	360-367	200 to 250°K
	DH-10	T_{12} Probe, Ambient Temp	368-375	200 to 250°K
	DH-11	T_{21} Probe, Ambient Temp	450-457	200 to 250°K
	DH-12	T_{22} Probe, Ambient Temp	458-465	200 to 250°K
	DH-13	Ref T_1, Temp Ref Junction	540-547	-20 to +60°C
*	DH-14, 24, 34, 44	TC_1 Group Probe Cable Temp	548-555	90 to 350°K
	DH-15	Ref T_2, Temp Ref Junction	630-637	-20 to +60°C
*	DH-16, 26, 36, 46	TC_2 Group Probe Cable Temp	638-645	90 to 350°K

*See Table 8-1 for these measurements.

*

TABLE 6-XVII.- HFE MEASUREMENTS, MODE 3, HIGH CONDUCTIVITY

SYMBOL	LOCATION/MEASUREMENT	FRAME	RANGE	H-BITS	PROBE	BRIDGE	HEATER STATUS
DH-50	Differential Temp	0-7		0000	1	1	Off
DH-51	Ambient Temp	8-15		0000	1	1	Off
DH-52	Differential Temp	0-7		0001	1	1	H_{12} On
DH-53	Ambient Temp	8-15		0001	1	1	H_{12} On
DH-60	Differential Temp	0-7		0010	1	2	Off
DH-61	Ambient Temp	8-15		0010	1	2	Off
DH-62	Differential Temp	0-7		0011	1	2	H_{14} On
DH-63	Ambient Temp	8-15		0011	1	2	H_{14} On
DH-56	Differential Temp	0-7		0100	1	1	Off
DH-57	Ambient Temp	8-15		0100	1	1	Off
DH-58	Differential Temp	0-7		0101	1	1	H_{11} On
DH-59	Ambient Temp	8-15		0101	1	1	H_{11} On
DH-66	Differential Temp	0-7		0110	1	2	Off
DH-67	Ambient Temp	8-15		0110	1	2	Off
DH-68	Differential Temp	0-7		0111	1	2	H_{13} On
DH-69	Ambient Temp	8-15		0111	1	2	H_{13} On
DH-70	Differential Temp	0-7		1000	2	1	Off
DH-71	Ambient Temp	8-15		1000	2	1	Off
DH-72	Differential Temp	0-7		1001	2	1	H_{22} On
DH-73	Ambient Temp	8-15		1001	2	1	H_{22} On
DH-80	Differential Temp	0-7		1010	2	2	Off
DH-81	Ambient Temp	8-15		1010	2	2	Off
DH-82	Differential Temp	0-7		1011	2	2	H_{24} On
DH-83	Ambient Temp	8-15		1011	2	2	H_{24} On
DH-76	Differential Temp	0-7		1100	2	1	Off
DH-77	Ambient Temp	8-15		1100	2	1	Off
DH-78	Differential Temp	0-7		1101	2	1	H_{21} On
DH-79	Ambient Temp	8-15		1101	2	1	H_{21} On
DH-86	Differential Temp	0-7		1110	2	2	Off
DH-87	Ambient Temp	8-15		1110	2	2	Off
DH-88	Differential Temp	0-7		1111	2	2	H_{23} On
DH-89	Ambient Temp	8-15		1111	2	2	H_{23} On

TABLE 6-XVIII.- HFE MEASUREMENTS, ANALOG

SYMBOL	LOCATION/MEASUREMENT	CHANNEL	RANGE	DECIMAL PCM
AH-1	Supply Voltage #1	29	0 to +5 Volts	
AH-2	Supply Voltage #2	45	0 to -5 Volts	
AH-3	Supply Voltage #3	55	0 to +15 Volts	
AH-4	Supply Voltage #4	74	0 to -15 Volts	
AH-5	Not Assigned			
AH-6	Low Cond Heater Power Status	57	2 to 2.5 Volts On otherwise Off	102-128 Htr On 3-101 Htr Off
AH-7	High Cond Heater Power Status	75	2 to 2.5 Volts On otherwise Off	102-128 Htr On 3-101 Htr Off

Appendix C

Nominal operating limits for the analog sensors for Housekeeping measurements AH-1 to AH-4, AH-6, and AH-7, excerpted from page 6-14 in [6].

TABLE 6-IX.- ANALOG CHANNEL USAGE - Concluded

Symbol	Location/Name	Channel	Nominal Operating Limits Low	Nominal Operating Limits High	Nom Oper Value	Redline Limits Low	Redline Limits High
	RTG Temperatures (Fahrenheit)						
AR-1	Hot Frame 1 Temp	6	1060°	1150°	1107°	980°	1160°
AR-2	Hot Frame 2 Temp	37	1060°	1150°	1107°	980°	1160°
AR-3	Hot Frame 3 Temp	52	1060°	1150°	1107°	980°	1160°
AR-4	Cold Frame 1 Temp	7	415°	500°	450°	401°	500°
AR-5	Cold Frame 2 Temp	67	400°	470°	430°	401°	500°
AR-6	Cold Frame 3 Temp	82	415°	500°	450°	401°	500°
	DTREM						
AX-1	DTREM Inner Temp (Centigrade)	83	N/A	N/A	N/A	-150	135
AX-2	DTREM Cell Temp (Centigrade)	30	37	125	110	37	125
AX-3	DTREM Outer Temp (Centigrade)	56	N/A	N/A	N/A	-150	135
AX-4	DTREM Cell 1 Output (No Filter)	84	0 mV	75 mV	65 mV	0 mV	75 mV
AX-5	DTREM Cell 2 Output (Irradiated/Filter)	26	0 mV	75 mV	65 mV	0 mV	75 mV
AX-6	DTREM Cell 3 Output (Filter)	41	0 mV	75 mV	65 mV	0 mV	75 mV
	Central Station Discretes		Value in Decimal PCM				
AB-1	Command Demodulator 1 kHz Present	9	No modulation 0 to 76, no carrier 128 to 255 Modulation 77 to 127				
AB-4	Power Distribution Experiment 1 and 2 Standby Status	12	Exper 1 / Exper 2 Standby-off / Standby-off: 1 ± 1 Standby-on / Standby-off: 72 ± 10 Standby-off / Standby-on: 131 ± 10 Standby-on / Standby-on: 192 ± 12				
AB-5	Power Distribution Experiment 3, 4, 5 Standby Status	14	Exper 3 / Exper 4 / Exper 5 Standby-off / Standby-off / Standby-off: 1 ± 1 Standby-off / Standby-off / Standby-on: 35 ± 10 Standby-off / Standby-on / Standby-off: 69 ± 10 Standby-off / Standby-on / Standby-on: 100 ± 10 Standby-on / Standby-off / Standby-off: 131 ± 10 Standby-on / Standby-off / Standby-on: 160 ± 10 Standby-on / Standby-on / Standby-off: 188 ± 10 Standby-on / Standby-on / Standby-on: 214 ± 10				
AB-6	Data Processor X On/Off Status	25	X processor on PCM > 128 X processor off PCM < 32				
AZ-1	Timer 18 Hr Status	10	0 to 18 hrs PCM < 32 18 to 36 hrs PCM >128 } Alternates every 18 hours				
AZ-2	Timer Counter 1 Status	11	0 to 1-1/2 months PCM < 32 1-1/2 to 3 months PCM > 128 } Alternates every 1-1/2 months				
AZ-3	Timer Counter 2 Status	86	0 to 1-1/2 months PCM < 32 1-1/2 to 3 months PCM > 128 } Alternates every 1-1/2 months				

EXPERIMENTS:

Symbol	Location/Name	Channel	Nominal Operating Limits
	Passive Seismic		
AL-1	LP Amplifier Gain (X and Y)	23	Discrete
AL-2	LP Amplifier Gain (Z)	38	Discrete
AD-3	Level Direction and Speed	53	Discrete
AL-4	SP Amplifier Gain (Z)	68	Discrete
AL-5	Leveling Mode and Coarse Sensor Mode	24	Discrete
AL-6	Thermal Control Status	39	Discrete
AL-7	Calibration Status LP and SP	54	Discrete
AL-8	Uncage Status	69	Discrete
	SIDE/CCGE		
AI-1	LE Count Rate	70	0 to 1.4 x 10^6 counts/second
AI-2	HE Count Rate	85	0 to 1.4 x 10^6 counts/second
	Heat Flow		
AH-1	Supply Voltage 1 (5 V)	29	4.9 to 5.1 Vdc
AH-2	Supply Voltage 2 (-5 V)	45	-4.9 to -5.1 Vdc
AH-3	Supply Voltage 3 (15 V)	55	14.7 to 15.3 Vdc
AH-4	Supply Voltage 4 (-15 V)	74	-14.7 to -15.3 Vdc
AH-5	Not Assigned		
AH-6	Low Cond Heater Power Status	57	Discrete
AH-7	High Cond Heater Power Status	75	Discrete

See Table 6-X (PSE) Page 6-15

Appendix D

Command Verification values and their actions for the HFE instrument, excerpted from pages 5-33 to 5-37 in [6]. HFE commands are octal integers 135 to 152.

132 LSM FILT IN/OUT EXP 2 (LSM)

Command 132 is a two-state command (IN/OUT). LSM activation initializes the filter to IN. Application of the command to OUT will cause a major portion of the digital filter to be bypassed.

133 SITE SURVEY XYZ EXP 2 (LSM)

Command 133 is a one-state command that activates the site survey sequence generator. The first application of this command will initiate the sequence to survey the X-axis. Upon completion of the X-axis survey, the LSM instrument will return to the normal scientific mode. The second and third application of this command will initiate the sequence generator to survey the Y- and Z-axes, respectively, returning the LSM to the normal mode of operation upon completion of the respective axis survey.

NOTE

THE SITE SURVEY MUST BE PERFORMED ONLY AFTER FOUR FLIP/CALIBRATE CYCLES HAVE BEEN COMPLETED.

134 LSM T CTL XYO EXP 2 (LSM)

Command 134 is a three-state command (X, Y, OFF) which is used to select the X- or Y-axis sensor heater thermostat or to deactivate all LSM heater power. LSM activation initializes the temperature control to the X-axis thermostat. Repeated application of this command sequences the temperature control through Y-axis thermostat, off, and X-axis thermostat. The selected axis thermostat (X or Y) controls heater power to all LSM heaters. In the off position, all LSM heater power is removed. Note that there is no thermostat in the Z-axis sensor.

135 HFE MODE/G SEL EXP 5 (HFE)

This command (C1) is a one-state command. It places the HFE in the normal or gradient mode of operation (Mode 1) such that data is obtained from the gradient sensors and

cable thermocouples under the control of the measurement sequence programer. It also turns off the probe heater current supply. At turnon, the HFE is initialized in this condition.

136 HFE MODE/LK SEL EXP 5 (HFE)

This command (C2) is a one-state command. It places the HFE in the low conductivity or ring source mode of operation (Mode 2) such that data is obtained from the gradient sensors and cable thermocouples under the control of the measurement sequence programer. It also turns on the probe heater current supply in the low (or ring source) mode allowing heaters to be activated via Command 152.

140 HFE MODE/HK SEL EXP 5 (HFE)

This command (C3) is a one-state command. It places the HFE in the high conductivity or heat pulse mode of operation (Mode 3) such that data is obtained from the ring (or remote) sensors under the control of the heater excitation programer. It also turns on the probe heater current supply in the high (or heat pulse) mode allowing heaters to be activated by Command 152.

141 HFE SEQ/FUL SEL EXP 5 (HFE)

This command (C4) is a one-state command. It cancels the effect of measurement Commands 142 through 146 and thereby causes the measurement sequence programer to perform its full 16-state cycle of operation. If transmitted during operation in MODE/HK, this command will cause invalid data. At turnon, the HFE is initialized in this condition.

142 HFE SEQ/P1 SEL EXP 5 (HFE)

This command (C5) is a one-state command and alternates with Command 143 to select only one probe for measurement.

In MODE/G and MODE/LK it causes the measurement sequence programer to lock the second flip-flop (P_2) in the clear state and bypass that step; that is, act as an eight-state counter if Command 141 was previously executed or as a two-state counter if Command 144, 145, or 146 was previously executed. In MODE/HK this command is meaningless. It is cleared by subsequent execution of Command 141.

143 HFE SEQ/P2 SEL EXP 5 (HFE)

This command (C6) is a one-state command and alternates with Command 142 to select only one probe for measurement. In MODE/G and MODE/LK it causes the measurement sequence programer to lock the second flip-flop (P_2) in the set state and bypass that step; that is, act as an eight-state counter if Command 141 was previously executed or as a two-state counter if Command 144, 145, or 146 was previously executed. In MODE/HK this command is meaningless. It is cleared by subsequent execution of Command 141.

144 HFE LOAD 1 EXP 5 (HFE)

This command (C7) is a one-state command and is used alone or in combination with either Command 145 or 146 to position and lock the measurement sequence programer's third and fourth flip-flops (P_4P_3). It places these two flip-flops in the clear position (00) and bypasses those steps; thus the MSP acts as a four-state counter if Command 141 was previously executed and as a two-state counter if either Command 142 or 143 was previously executed. In MODE/HK this command must be executed, otherwise the data will be invalid. Subsequent execution (in MODE/G or MODE/LK) of Command 145 or 146 locks P_4P_3 in the 01 or 10 state respectively. All positioning and locking of P_4P_3 is cleared by subsequent exectution of Command 141.

145 HFE LOAD 2 EXP 5 (HFE)

This command (C8) is a one-state command and is used in combination with either Command 144 (preceding 145) or Command 146 (preceding or subsequent to 145) to position and lock P_4P_3 (see 144). It sets P_3; therefore, 144 followed by 145 placed P_4P_3 in the 01 state. In combination with 146, it places P_4 P_3 in the 11 state. Depending on whether Command 141 was previously executed or one of Commands 142 or 143, the MSP acts as a four-state or two-state counter. Execution of this command in MODE/HK causes invalid data until Command 144 is executed. It is cleared by subsequent execution of Command 141.

146 HFE LOAD 3 EXP 5 (HFE)

This command (C9) is a one-state command operating essentially the same as Command 145 except that it sets P_4. Therefore, when preceded by 144 it places P_4P_3 in the 10 state.

150 TIMER RESET TIMER

Command 150 is a one-state command that will reset timer counters 1 and 2 to a zero count (clear). The 1-minute and the 18-hour output pulses and the timer transmitter turnoff function (at 97 ± 5 days) is referenced to the timer reset. Note that this command does <u>not</u> affect the hours or minutes counters or the sequence decoding gates in the delayed command sequencer or the timer accept/inhibit logic.

<u>NOTE</u>

SINCE THE TIMER TRANSMITTER TURNOFF FUNCTION CAN ONLY OCCUR ONE TIME, IT IS MANDATORY THAT COMMAND 150 BE SENT PRIOR TO TIMER TURNOFF.

152 HFE HTR STEPS EXP 5 (HFE)

This command (C10) is a 16-state command which advances the heater excitation programer ($H_4H_3H_2H_1$) each time the command is executed. In MODE/G the programer advances but there is no other effect since the probe heater current supply is off. In MODE/LK the execution of Command 152 alternates the heater status between on and off, simultaneously stepping through the eight heaters (current supply in on full time, and heater elements are switched in and out of circuit). In MODE/HK the heater excitation programer (advanced by Command 152) also selects the data to be sampled.

NOTE

HFE commands are executed at the ALSEP 90 frame mark; therefore, there must be 54 seconds delta time between transmission of commands to the HFE.

153 EXP 4 OPER SEL (SIDE/CCGE) POWER DISTRIBUTION UNIT

Command 153 actuates relay K-12, in the PDU, applying +29 Vdc to the SIDE instrument and the SIDE heater.

NOTE

Command 153 is also listed out of numeric sequence following Command 050.