Apollo 15 ALSEP ARCSAV Heat Flow Experiment Calibrated Gradient Bridge Temperatures Collection (1975-092 to 1975-181)

The Apollo 15 astronauts deployed two heat flow probes as part of the Apollo Lunar Surface Experiment Package (ALSEP) [1a]. These probes operated from July 1971 to January 1977 [1b]. Data obtained from July 1971 to December 1974 were processed by the original investigators of the Heat Flow Experiment (HFE) [2] and are available through PDS [3]. This collection contains the Apollo 15 HFE data for April through June 1975. They were extracted from the original ALSEP raw data archival tapes (also known as 'ARCSAV tapes') [4]. These tapes were recovered in 2010 at the Washington National Records Center [5]. The HFE raw data packets as extracted from these tapes are available as Level-1 raw data products [6].

This collection contains fully processed, calibrated data for the temperature sensors that were collectively called 'gradient bridges'. The nomenclature of the sensors follows that by the original HFE investigators [2, 7]. The same information is also reviewed by [8]. Each gradient bridge included a pair of resistance temperature detectors (RTD), placed at two different depths into the hole in the lunar surface where the heat flow probe was inserted. The heat flow instrument obtained the average and the temperature difference between the paired RTDs of each gradient bridge. Two modes of measurements were used for the temperature difference: low gain and high gain. The low gain mode had a range of ~20 K, and the high gain mode had a range of ~2 K.

For these data products, the temperature values for each RTD have been obtained from the average temperature and the high-gain temperature difference measurements for each gradient bridge RTD pair. When the temperature difference exceeded the range of the high gain mode, the low gain mode was used for obtaining the temperature of each RTD.

These temperature values have been calculated according to the data reduction procedure used at the Johnson Space Center (JSC) in the 1970s, described in [9] and [10]. The accuracy of the processed data have been verified by comparing the temperature values for sensors TG12B and TG22B with those reported in the weekly logs of the ALSEP instruments [11].

The RTD calibration data are also given in [10]. Seven sets of heat flow probes (SN-1 through -7) were fabricated in preparation for the Apollo Heat Flow Experiments, and they were calibrated in 1968 – 1971. Because the calibration work predated the Apollo missions, the calibration reports for these probe sets [10] only refer to their serial numbers assigned by the contractors who fabricated them. These reports do not refer to the actual Apollo flight missions the individual probe sets were on. According to notes left behind by the HFE investigators and the contractors, the serial number for each pair of heat flow probes match up with each Apollo flight as follows.

Apollo Flight	HFE serial number	HFE Flight Model number
Apollo 13	SN-5	2S
Apollo 15	SN-4	2
Apollo 16	SN-6	3
Apollo 17	SN-7	4

The original HFE investigators, based at Columbia University, used a data processing scheme slightly different from the one used at JSC. It is outlined in [12] and [13]. However, these reports did not provide sufficient information for fully reconstructing their data processing procedure for the Apollo 15 heat flow probes. The data provided here were processed by the JSC scheme.

HFE operational status is reported in the weekly logs of the ALSEP instruments [11].

Data Organization

Each of the two heat flow probes deployed at the Apollo 15 site had two gradient bridges, 'TG11' and 'TG12' for Probe 1, and 'TG21' and 'TG22' for Probe 2 (refer to [2] and [5] for the nomenclature; [3] uses the nomenclature 'DTG11' and 'DTG12' for Probe 1, and DTG21' and 'DTG22' for Probe 2). 'TG11' and 'TG21' are the upper gradient bridges, those on each probe closest to the lunar surface. There are four files in this data package. Each file contains data from one of these four gradient bridges.

The four data files have an identical, fixed-width, ASCII tabular organization. In each file, data are organized in six columns. The first column indicates the earth received time, which is typically used as the time of acquisition for analysis purposes. The second column gives the temperature value of the upper RTD of the gradient bridge. The third column gives the temperature value of the lower RTD. The fourth column gives the average of the two. The fifth column gives the temperature difference between the two RTDs obtained in the high-gain mode. The sixth column gives the temperature difference in the low-gain mode. Each row contains the temperature values acquired in one data sampling cycle. All the temperature values are in Kelvin, rounded to the nearest 0.001 K which is the accuracy of the differential temperature measurement [7].

For example, the file for gradient bridge TG11, a15_hfe_1975_l2_arcsav_tg11.tab, is organized in the following manner:

```
time                      TG11A    TG11B  TG11avg   DTH11   DTL11
1975-092T00:04:17.237  255.792  256.071  255.931  -0.280  -0.281
1975-092T00:11:31.948  255.829  256.109  255.969  -0.280  -0.281
1975-092T00:18:46.660  255.792  256.071  255.931  -0.279  -0.281
```

Data Users' Notes

- In the file for gradient bridge TG21, a15_hfe_1975_l2_arcsav_tg21.tab, the temperature differences calculated for the high gain mode, DTH21, differ from the low gain mode, DTL21, by a factor of 10 because values for the high gain mode saturate at ΔT = +3 K. When the real ΔT exceeds 3 K, the DTH values are be smaller than the DTL values:

  ```
  time                      TG21A    TG21B  TG21avg   DTH21   DTL21
  1975-092T00:04:55.153  305.347  275.434  290.390   2.993  29.913
  1975-092T00:12:09.846  305.349  275.431  290.390   2.993  29.919
  1975-092T00:19:24.538  305.298  275.385  290.341   2.992  29.913
  ```

- Although all raw thermocouple measurements, numbered DH-14/24/34/44 for probe 1 and DH-16/26/36/46 for probe 2 [4], were extracted from the ARCSAV tapes and archived [6], the reduced temperatures for the thermocouples are not included in this collection because the data providers [8] were still looking for calibration data as of late 2018.

  Please note two numbering conventions exist in the literature for the thermocouples. This collection follows the nomenclature of original HFE investigators [2, 7], 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 [3], 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.

- The times in the first column of the data files 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.

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