Apollo 17 Lunar Ejecta and Meteorites Experiment (LEAM)

Time-of-Flight (TOF) Sensor Values

The particle Time-of-Flight (TOF) data values (DJ-11 and DJ-22)[1] are 6 bit numbers ranging from 0 to 63. The value is logarithmically, not linearly, related to the time-of-flight (Final Engineering Report for Cosmic Dust Detector, 1970). The time is measured from the time of a pulse on the front (A) film to the time of a pulse of the rear (B) film. Because the particles can pass through the LEAM sensor at different angles, the distance travelled between the front and rear films can vary considerably. The front film covers a 10 cm x 10 cm area, as does the rear film. The films are 5 cm apart. So the minimum distance a particle would travel would be normal to the two films, 5 cm. The maximum distance would be from one corner of the front film to the opposite corner of the rear film, equal to 15 cm. (square root [$10^2 + 10^2 + 5^2$]). However, LEAM descriptions indicate the instrument had an approximately 60 degree square-cone field of view (Berg et al., 1976). A 60 degree half-angle field-of-view would give a maximum distance of only 10 cm traveled (5 cm / cos 60). (Note that the Pioneer Cosmic Dust Detectors were limited to 60 degree half-angle field-of-view because they were recessed 3 cm into the experiment housing. From photos, the LEAM sensors do not appear to be recessed into the housing this far, but we will assume the 60 degree limit on field-of-view.)

LEAM is capable of measuring particle speeds from 2 km/s to 72 km/s. The electronics are design limited to particles having these velocities (Berg and Richardson, 1969, Berg et al., 1973). Therefore, the minimum time a particle would take to travel between the films, i.e. the minimum time measurable, would be a 72 km/s particle travelling 5 cm, which would be 0.7 microseconds. Actually, because the array elements are each 2.5 x 2.5 cm squares, a particle hitting the equivalent elements on the front and back arrays could travel any distance between 5.00 and 6.12 cm, so there is some uncertainty in the distance travelled, an “average” value of about 5.5 cm might be more useful, giving a travel time of 0.76 microseconds. Berg and Richardson (1969, p. 5) note that for low-energy particles travelling between 2 and 10 km/s the deceleration upon hitting the front array is 40%. This would bring a 2 km/s particle down to 1.2 km/s, so this would be the actual travel velocity of an initial 2 km/s small particle. For the maximum distance of 10 cm at 1.2 km/s the time would be 83 microseconds. Since the range of possible detectable velocities is given as 2 km/s to 72 km/s, it stands to reason that the timer can measure times between about 0.75 and 83 microseconds. The clock frequency is given as 4 MHz in the Pioneer Cosmic Dust Detector Experiment (Berg and Richardson, 1969, p. 8), this would give a time resolution of 0.25 microseconds, which would match with a 0.75 microsecond minimum time.

Figure 1 shows a page from Otto Berg’s LEAM notebook with an example of a time-of-flight event. We have marked with a red circle the portion that says “TOF 25 – 12 km/sec”. Presumably this indicates a TOF reading of 25 corresponded to a speed of 12 km/sec. Since the path of the particle: “A” Film 4 ; “A” Grid 2 ; “B” film 4 ; “B” grid 2 - indicates that the particle

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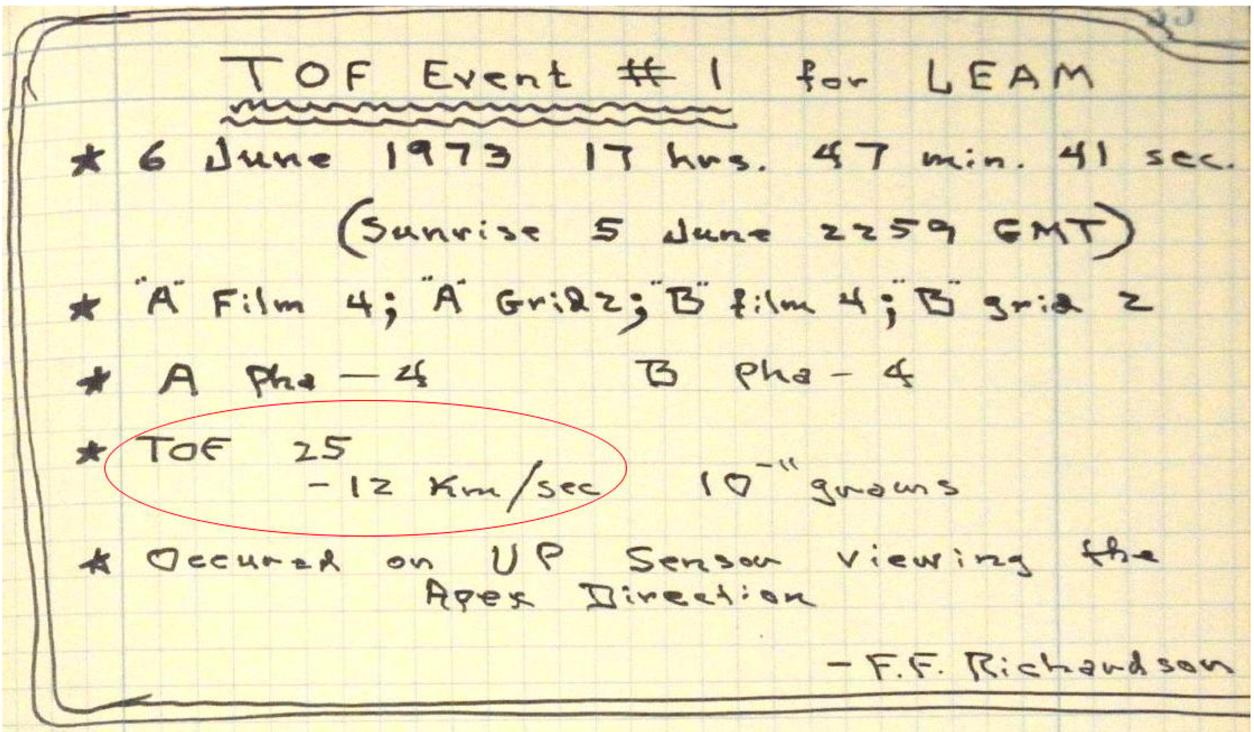
[1] DJ-11 = Elapsed Time for Up Dual Sensor Assembly and DJ-22 = Elapsed Time for East Dual Sensor Assembly according to Table 6-X – LEAM Measurements in Apollo Lunar Surface Experiments Package Systems Handbook: Apollo 17, ALSEP 5 - Array E / Document Change 1 (1972).

hit the same spot on the upper and lower arrays, the flight was normal to the sensor arrays). This means the particle travelled approximately 5 - 6 cm, the distance between the arrays, so the time-of-flight would be roughly: 5.5 cm / (12 km/sec) = 4.58 microseconds.

This is the only concrete example found so far, it appears to pin a reading of 25 to a time of approximately 4.58 microseconds. If the speed in the notebook is given to the nearest km/sec, it could be between 11.5 and 12.5 km/s, giving a time range of approximately 4.4 to 4.8 microseconds.


TOF Event # 1 for LEAM

* 6 June 1973 17 hrs. 47 min. 41 sec.
(Sunrise 5 June 2259 GMT)
* "A" Film 4; "A" Grid 2; "B" film 4; "B" grid 2
* A pha — 4 B pha - 4
* TOF 25
- 12 Km/sec 10^{-11} grams
* Occurred on UP Sensor viewing the Apex Direction

— F.F. Richardson

Figure 1 – Example of time-of-flight (TOF) event from Berg LEAM notebook 1, pg. 35 showing a reading of 25 corresponding to a velocity of 12 km/sec (red circle added).

Figure 2 below shows a curve for the Pioneer Dust Detector, considered fundamentally identical to the LEAM instrument, comparing the binary readout with the time-of-flight in microseconds, on a semi-logarithmic scale. This shows a count of 9 corresponding to 0.5 microseconds and a count of 63 corresponding to 80 microseconds. No explanation is given as to why binary counts below 9 are not included, perhaps at such short times (given the 0.25 microsecond clock time) the counter is not reliable. We have not been able to locate an equivalent plot for the LEAM detector, but given that the limits of the Pioneer plot (0.5 to 80 microseconds) are similar to the 0.75 to 83 microseconds deduced for the LEAM instrument, it would probably be similar. Note that the value of 25 on the Pioneer plot gives a time of approximately 3.8 microseconds, less than the 4.4 – 4.8 microseconds calculated from figure 1 for the LEAM detector. We note if we shift the curve upwards to accommodate this value, it will move the upper part of the curve so 63 counts could be close to 83 microseconds, and the bottom of the curve to higher values.

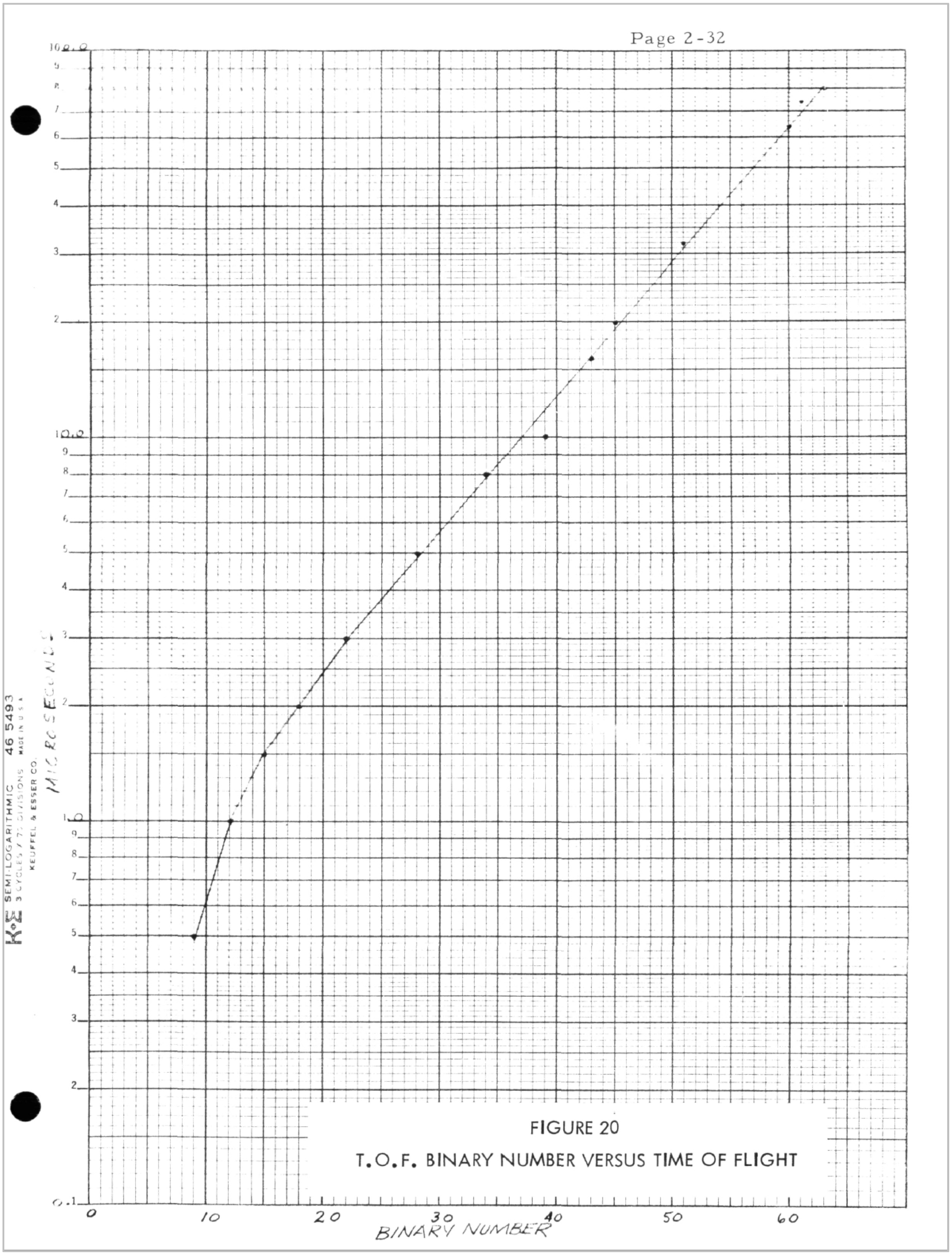


Figure 2 - Plot of T.O.F. binary number vs. time-of-flight in microseconds for the Final Engineering Report for Cosmic Dust Detector, Figure 20, p. 2-32, 1970.

References

Apollo Lunar Surface Experiments Package Systems Handbook: Apollo 17, ALSEP 5 - Array E / Document Change 1, Unnumbered, NASA Manned Spacecraft Center, Houston, Texas, published 8 August 1972, revised 6 October 1972.

Berg, O.E., and F.F. Richardson, The Pioneer 8 Cosmic Dust Experiment, NASA Technical Note D-5267, NASA, Washington, D.C., July 1969.

Berg, O.E., F.F. Richardson, and H. Burton, Apollo 17 Preliminary Science Report, Chapter 16, NASA SP-330, NASA, Washington, D.C., 1973.

Berg, O.E., H. Wolfe, and J. Rhee, Lunar Soil movement registered by the Apollo 17 Cosmic Dust Experiment, In: Elsässer H. and H. Fechting (eds), Interplanetary Dust and Zodiacal Light, Lecture Notes in Physics, Vol 48, Springer, Berlin, Heidelberg, 1976. (doi: 10.1007/3-540-07615-8_486)

Berg, O. E., D. R. Williams, and M. Gaddy, "Apollo 17 Lunar Ejecta And Meteorites Experiment Calibration Notebook Bundle", NASA Planetary Data System, ID: urn:nasa:pds:a17leamcal, 2017. Digital reproduction of one hand-written laboratory notebook, "LEAM Notebook 1", of calibration analysis for the Apollo 17 Lunar Ejecta And Meteorites (LEAM) Experiment detector which was identical to the Pioneer 8 and 9 Cosmic Dust Detectors (CDD).

Final Engineering Report for Cosmic Dust Detector Model ML 309-1 and Cosmic Dust Detector Ground Support Equipment Model ML 310-1, prepared for NASA/Goddard, Technical Staff, Time-Zero Corporation, NASA CR-110703, 1970. (Available from NASA Technical Reports Service Registered website, https://ntrsreg.nasa.gov for NASA-registered users.)