Revisiting Moondust Measurements of Apollo 11 & 12

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Abstract. Data from the Dust Detector Experiments (DDE) put on the moon in 1969 by Apollo 11 and 12 missions were transmitted to Earth for 5 months and 6 years respectively. Later missions contained similar instruments. Simple and matchbox-sized, each DDE held 3 solar cells and 3 thermistors. The history of the DDEs and their data analyses is informative but the lack of quality data archiving and lack of awareness of this historic data in the broader community has strategically disturbing aspects as regards the breadth and depth of technological development supporting future human exploration of the moon and Mars. The DDEs revealed a significant number of phenomena. These included the highly variable effects of the LM ascent, ranging from significant contamination of the DDE (Apollo 11) to actual cleaning (Apollo 12). Significant dust mobilization during sunrise was also noted. There are a number of scientific, technical, and organization lessons of the experiment that are highly relevant to future missions to the moon and Mars.

Keywords: Dust, Moon, Apollo.

1 Introduction

Dr Harrison Schmitt stated after his Apollo 17 flight, "Dust is the number one environmental problem on the moon" [1]. Yet, before Apollo 11, the author's DDE was the only proposed part of Apollo to measure moon dust issues directly over both short and long-term, and initially was widely criticized as unnecessary. It was also only a late (1966), virtually fortuitous proposal.

The magic and historic nature of Apollo 11 and increasing recognition of the importance and multidisciplinary complexity of moon dust make it essential that dust issues be open to public scrutiny. However, much of the data is perceived to be unavailable. For example, a Smithsonian Air & Space magazine web site states that

> "*Many original computer tapes from Apollo experiments, including ones that were never analyzed, can no longer be read. Not only are some of the data formats obsolete, many of the tapes have degraded due to less-than-optimum storage. Some of the data may be permanently lost.*" [2].

In fact, some 200 data tapes have been stored at Curtin University in Perth since 1971. About 100 paper plots are also held in Perth. Such analysis is clearly essential for the planning, science and engineering of future missions to be much more closely synergistic and responsive regarding moon dust, and Mars dust, than during Apollo. In this paper preliminary unpublished findings from the Apollo 12 Dust Detector are discussed and compared with results of both Apollo 11 and from later missions.. Particular attention is given to sunrise effects measured by the Eastwards-facing cell.

2 Historical Background

In the mid-1960s, while Professor of Space Science at Rice University in Houston Texas, I was selected by NASA out of about 90 proponents to be one of the 5 Principal Investigators (PIs) for the Apollo Lunar Surface Experiments Package (ALSEP). These were to be self-powered scientific stations to be left on the moon to measure their environments and transmit the information to Earth for about two years. My experiment was the Charged Particle Lunar Environment Experiment (CPLEE), which subsequently flew on Apollo 13 and 14. This was an upgraded variation of a sophisticated radiation detector code-named SPECS [3] designed to measure electrons and protons in related explorations of the magnetosphere using unmanned rockets and satellites.

Surfaces without effective thermal control on the moon can reach 120 degrees C. So, during a major ALSEP design review in Los Angles, I expressed concern that ALSEP experiments might fail by overheating in lunar day temperatures if the pure white and gold thermal-control surfaces were contaminated significantly by moon dust or debris from the Lunar Module (LM) ascent, or by long-term moon dust creep. With great vigour, NASA engineers and aerospace contractors discounted any likelihood of such effects.

On the plane back to Houston, using my experience in temperature-control of successful satellites I had been involved with, I invented a matchbox-sized Dust Detector experiment (DDE) (Figs. 1 and 2) which would provide information of the degree of contamination of surfaces by dust. The DDE had three solar cells, one each facing East, West and up. Using the Sun as light source, the output voltage of each solar cell measures the absorptivity of the surface, before and after any contamination. This dictates how much input energy, i.e. heating, occurs during lunar day.

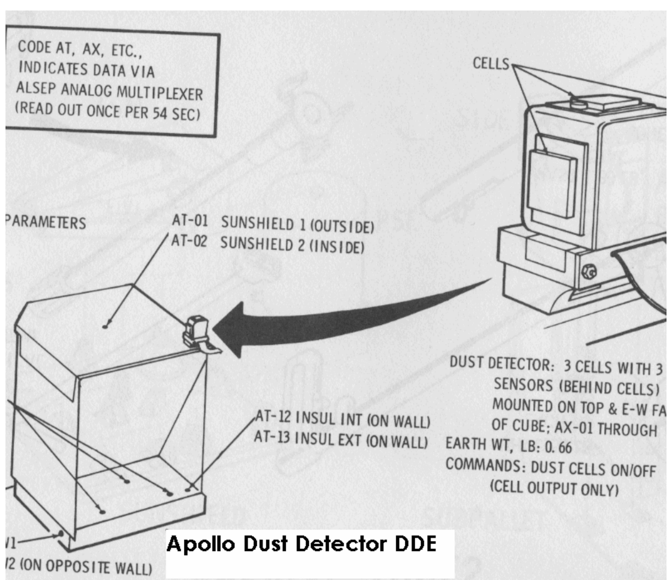


Fig. 1. The original design of the Lunar Dust Detector, as flown on Apollo 12 (**Source**; Bendix Aerospace Corporation, Ann Arbor, 1968).

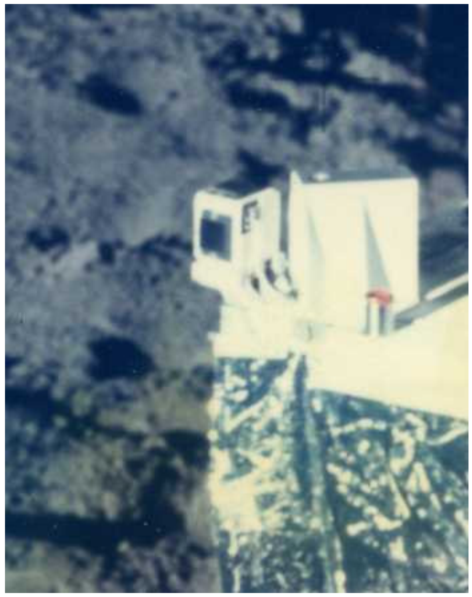


Fig. 2. Apollo 12 DDE on the moon. (**Source**. NASA).

Each solar cell had a tiny thermistor, a bead-like thermometer, behind it to monitor individual temperatures. This temperature, combined with the Stefan-Boltzmann law, permits calculation of the emissivity, or how much infra-red energy is radiated out of the surface into space. From measurement of the alteration of both absorptivity and emissivity of a surface, one can calculate any change to thermal control caused by contamination of the surface. This can be sudden, from Lunar Module ascent blowing moon dust or debris from the Descent Module or discarded rubbish, or an eclipse. Long-term effects could be by creeping dust or impact effects, and operational aspects such as deterioration of the solar cells.

So on 24 January 1966, I formally proposed to NASA that it fly the DDE at least on the first manned lunar landing, Apollo 11 [4]. My subsequent advocacy of the DDE took some physics, vigour, humour and satire, for 2 years, particularly at formal ALSEP Review meetings while reporting as a PI on the CPLEE. Any late addition to the Apollo 11 payload was a interpreted as a challenge, if it implied that the aerospace contractors had omitted a vital system component and that many managers had not detected the omission. The design of the total DDE required only 270 grams versus the Apollo 11 Passive Seismometer mass of 49 kilograms. An advocate merged its telemetry requirements into the existing 90-channel commutated set of house-keeping data. The simplicity of the DDE seemed almost “un-Apollo”. A strong challenge by NASA and Bendix Aerospace Corporation to replace my design with microphones, had to be fended off. Microphones are useful in spacecraft micrometeorite studies, but useless for thermal measurements.

After many vicissitudes, finally NASA agreed it would fly the DDE. However, initially NASA would not call it a Scientific Experiment, but Engineering Experiment M-515. Despite this, the simple little Dust Detector provided unique though primitive moon dust data of strategic, engineering and scientific value, not yet analysed in depth even 41 years after it was first proposed. It does seem a pity that no photo of the Apollo 11 DDE exists.

3 Apollo 11 Dust Detector Data Tape

Amidst concerns about crew safety and reducing stress on astronauts on the moon, the Apollo 11 ALSEP was drastically redesigned in late 1968 and early 1969. Two major scientific experiments and the Radioactive Thermoelectric Power Supply were off-loaded. Only two active experiments remained – the Passive Seismometer to measure moonquakes and the Dust Detector experiment. This Apollo 11 scientific station was called the Early Apollo Scientific Experiment Package (EASEP).

When EASEP began transmitting from the moon, 27cm-diameter computer tapes of DDE data stripped from the EASEP data stream were flown express to the author, now Visiting Professor at the University of Sydney, hosted at the School of Physics by Professor Harry Messel. The primary analyses were of effects before and after Lunar Module ascents on Apollo 11 and 12.

After the aborted flight of Apollo 13 and after early analysis of the successful Apollo 14 CPLEE operations, the author shipped about 200 tapes to Perth when he became the first Director and Chairman of the Environmental Protection Authority in April 1971. Professor John de Laeter kindly agreed to store the computer tapes in the Dept of Physics at Curtin University. In March 2007 I was advised that he is "*probably the only person who has some of the digitized raw Dust Detector data. Unfortunately the original analog tapes from the individual tracking stations have all been re-cycled (or destroyed) and the digitized versions of those tapes were supposed to have been in 'permanent' storage at the National Space Science Data Centre (NSSDC)*" (J. Bates, pers.comm.). As the NASA Web site states [2], the NASA tapes were misplaced before archiving, and only sampled, plotted data remain at Goddard.

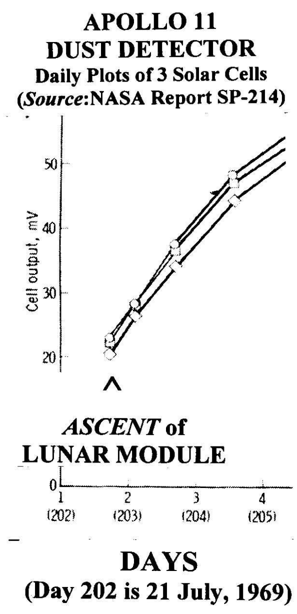
On 8 February 2007 I symbolically presented the Dust Detector data tape for Apollo 11 Days 1 to 4 to Mrs. McClellan, the US Consul-General. With the help of SpectrumData, arrangements are underway with NASA for complete heritage data from Apollo 11 and 12 to be stored at NASA in a form accessible to those planning future missions to the moon and Mars.

4 Effects of Apollo 11 Lunar Module Ascent

The main concern which led to the invention and proposal of the Dust Detector was that the jet exhausts from the Lunar Module Ascent Stage, which used the Descent Stage as its launch pad, could throw moon dust and debris on to ALSEP surfaces and contaminate their thermal control external surfaces. This could lead to overheating and therefore failure of systems or sub-systems. Accordingly LM ascent short-term Apollo effects were analysed and published as highest priorities in 1969. Significant contamination occurred at LM ascent on Apollo 11, because the EASEP was placed only about 17 metres from the Lunar Module [5]. The effects were consistent with the massive overheating of the Passive Lunar Seismometer to 190°F (77.3°C), a full 50°F (8°C) above its planned maximum temperature because of contamination of surfaces by dust disturbed by the exhaust blast of the ascent stage engine. So the DDE had served its original purpose to assist planning of future human missions to the moon.

Whether it was used effectively is another issue and is a long and complex saga in itself. Despite this data, the official Apollo 11 Preliminary Science Report stated that preliminary analysis had shown *no appreciable cell degradation caused by dust or debris from the LM ascent* [6, p.199]. It was not until October 1970 that a peer-reviewed paper showing the full effects could be published [5]. Furthermore, although I corrected the Apollo 11 claims and presented new Apollo 12 data in the 90-day report, the Apollo 12 Preliminary Science Report [7] omitted these data and any reference to the DDE. No explanations for this were made even in personal discussions at Mission Control Centre during the Apollo 13 and 14 missions.

On August 27, 1969, the day when the Apollo 11 Passive Seismic Experiment proved inoperable and was switched off, General Sam Phillips signed his approval for the DDE to fly on all future Apollo landings. A possible explanation for this lies in the fact that selected DDE data were plotted by NASA only once per day as part of the engineering data. Straight lines were then used to join the points and prepare the NASA Preliminary Science Report. Consequently short-duration events such as occur at LM ascent were overlooked. But LM-ascent effects are clear from the author's plotting of the minute-by-minute data. (See comparison of Figures 3a and 3b).



NASA REPORT SP-214

(Apollo 11 Preliminary Science Report)

Page 100: "The ...dust detector ...showed no signs of degradation from the lunar soil ... blown away during the (Lunar Module) ascent."

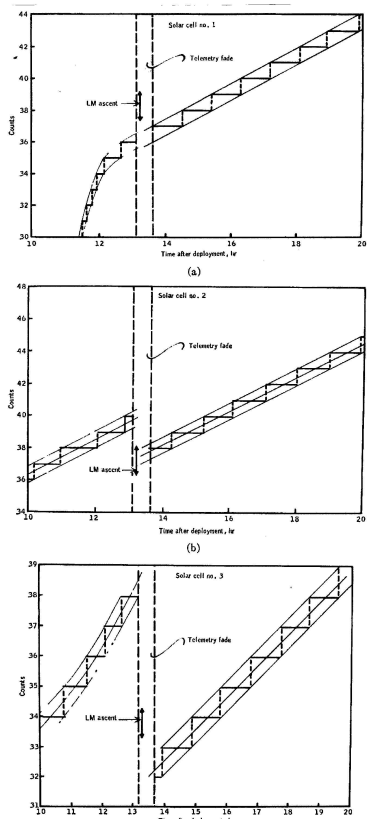
Page 200: "A preliminary analysis of (Dust Detector) data ...showed no appreciable cell degradation caused by dust or debris from the LM ascent." (*see* daily plots, Figure 10-3 in NASA SP-214).

Fig. 3. (a) The reason that the Apollo 11 NASA Preliminary Science Report stated that there was no appreciable cell degradation appears to be because data were plotted only once daily, and straight lines then connected data points. The long-duration effect of the short-duration LM ascent was therefore not detected. [8]. By contrast, when I used the available time resolution of minutes the effect was apparent (see Figure 3b).

Consistent with this explanation, the NASA Website on the DDE was updated in 2006 or thereabouts to state that ALSEP DDE

"*Measurements were made over the course of each lunar day, returned to Earth, and stored on magnetic tape. Selected data were plotted. The original tapes were subsequently misplaced before they could be archived, the only existing data from these experiments are on the plots"* [9].

O'BRIEN, FREDEN & BATES, J. APPLIED PHYSICS, 1970



APOLLO 11 DUST DETECTOR SOLAR-CELL COUNTS THROUGHOUT ASCENT OF LUNAR MODULE

Fig. 3b. The effects of contamination of the Apollo 11 Dust Detector solar cells due to ascent of the Lunar Module are clear in two out of three solar cells when plotted with a time resolution of minutes, not days. The reason why one cell was not affected is presumed to be, but not known to be, because of patchiness of contamination. (**Source**: [5]).

In 1972, NASA Technical Report TN D-6738 found that "*the most probable cause of the overheating [of the Apollo 11 Passive Seismometer] was optical degradation… resulting from contaminants deposited during the LM ascent*." That report omitted reference to the DDE [10]. Whether the results of the little DDE were used to assist planning of future human missions to the moon is another issue. Later ALSEPs were certainly deployed at greater distances from the LM but, given the omission of mention of the DDE in the Apollo 12 Preliminary Science Report meant that the flawed conclusions from the NASA Apollo 11 Preliminary Science Report were the most-commonly available reference source within the relevant widespread community as to the effect of dust mobilization, the decision to deploy the ALSEP further away from the LM may be due largely to commonsense and the need to minimize contamination by the vibrations and outgassing of the LM.

5 Apollo 12

By contrast with Apollo 11, the Apollo 12 DDE showed a small but still measurable effect at LM ascent, when the DDE was located about 200 metres from the LM Descent Stage. Most ALSEP experiments did not overheat [11, 12]. Currently (mid-2007) the Apollo 12 data are being revisited, using about 100 computer-driven "tractor-paper" charts made of selected data at the University of Sydney School of Physics in 1969 and 1970.

These paper charts show Apollo 12 LM-ascent effects with high resolution in time, some sunrise measurements with high and low resolution in time, and coarser time resolution for twelve Lunar days, or about the first calendar year after deployment. The raw data for about 3 hours immediately before and after LM ascent show for the Apollo 12 DDE that:

- The horizontal solar cell output voltage **increased** abruptly at LM ascent by 4 digital units or about 2.5 mV from its previous output of about 54 mV

- The horizontal solar cell temperature temporarily "stalled" at its pre-LM Ascent temperature of about 31°F (-2.2°C) for about half an hour before then resuming its previous rate of temperature increase as the sun rose

- Immediately at LM Ascent the East-facing cell temperature rose by one digital step (about 0.2°F) and stayed there for three successive samples (circa 5 minutes), before returning to the pre-ascent value for 40 minutes before resuming its previous upwards trend.

These data are not reproduced here in these Notes, because analyses are not complete. Various explanations are being examined. One preliminary hypothesis is that the LM Ascent actually cleaned the horizontal cell of some pre-existing moon dust, thereby causing its slight increase in voltage output. The Apollo crew observed that:

> "*…there seems to be no way to avoid getting dust on the experiments during unloading, transport and deployment. The experiments got dusty from dust splattered off the lunar surface by our boots, and they got dusty when we put them down on the lunar surface.*" [7].

But an alternative preliminary hypothesis relates to the fact that initial analyses of sunrise on the Second and subsequent lunar days show that the horizontal cell was tilted down towards the East by about 3 degrees. Sunrise had already taken place, of course, on the first lunar day when ALSEP was deployed. So another possible preliminary explanation for the increased output in the horizontal cell at LM Ascent could be that it caused a tilt of the unit on which the DDE was locked. The ascending astronauts *could look down directly at the landing site* as the spacecraft pitched over [7, p.37].

Analyses of these and long-term effects are continuing, together with analyses of measurements during an eclipse. Such analyses will be informed by the analyses and speculations about moon dust reported from hand-to-hand problems encountered by the Apollo astronauts, some visual observations by astronauts and instruments on later Apollo missions.

However, a caveat must apply to such analyses, whether the DDE data are used directly or with other multidisciplinary studies. (see also Concluding comments below).The author cautions that the DDE was not proposed by him to be a scientific analytical device to carry out pure research into moon dust. Instead, it was originally invented as a risk-management device to assist in temperature controls and planning such issues as the distance of deployment of ALSEP from the Lunar Module, planning orientation of ALSEP and other collateral material left on the moon, and the like. The original DDE was invented and designed primarily to measure changes in absorptivity and emissivity of surfaces exposed to effects of LM ascent, and also long-term accretion. It was invented to help plan thermal protection of CPLEE on Apollo's 13 and 14.

6 Apollo 14 and 15

A modified form of the DDE was flown on Apollo 14 and 15. The concept of three solar cells was retained, but it was concluded, prior to Apollo 11, that Surveyor data had shown that the dust accumulation would be much lower than anticipated in the DDE proposal of January 1966. Accordingly, it was decided to use the three cells of ALSEP to measure the long-term degradation effects from thermal effects and ionizing radiation such as cosmic rays and solar protons. See preliminary results in Apollo 14 Lunar Dust Detector Experiment on Web site [14].

The massive overheating of the key Passive Seismometer on Apollo 11 and its DDE findings might have led to a revisiting of the revision to the original concept. However, the revisions to the DDE remained.

One example of a related experiment is the CPLEE put on the moon by Apollo 14 which discovered a variety of phenomena [13]. The first CPLEE unit perished in the aborted Apollo 13 mission. Of particular relevance are CPLEE measurements of the energy spectra of clouds of photoelectrons from the sunlit moon. Energies of electrons were as high as 200 electron volts (eV), far greater than expected if the spectra were simply a thermal distribution around 2 eV.

7 Apollo 17

Only the final Apollo mission, Apollo 17, carried an active and relatively complex dust-related experiment, the Lunar Ejecta and Meteorites Experiment (LEAM), targeting lunar ejecta material [15]. Like the original DDE design, LEAM carried three sensors facing East, up and West. But it experienced temperature anomalies, ie overheating. Findings include an interesting concentration of what is thought to be high-velocity impacts (up to 1 km/sec) from electrostatically-charged dust about the time of sunrise [15].

8 Concluding Comments

The author and his colleague Jim Bates, formerly of NASA in Houston, and others are in discussions about integrating analyses and renewed interest in the Apollo dust data generally, from Apollo 11, 12, 14 and 15. Again, the long period of time that has elapsed since the Apollo missions has made retrieval of many files difficult. Even in 2007, the very existence of some data is uncertain. Despite this, several lessons are clear. Subject to the caveat of using data for scientific analysis that was originally garnered simply for engineering purposes, up-to-date analyses of DDE data will be of scientific and engineering interest to those currently planning future missions to the moon and Mars. Some in the present generation of such planners seem largely ignorant of moon dust data from the early Apollo missions. Yet it is very encouraging that, when the story of the so-called missing computer tapes broke in late 2006, many have expressed significant interest in both the early (circa 1969-70) and more recent (2007) analyses, as-yet unpublished.

There are other important lessons from these small blips upon the magic and wondrous achievements of the Apollo missions:

Cultural conflicts: Engineers and scientists may have entirely different cultures, priorities and methodologies in analyses. Indeed, in many sciences, even the physical sciences, such differences may exist and confuse priorities in the setting of goals or missions. The conflict of whether or not the Apollo 11 LM Ascent Stage caused significant contamination was caused directly by different cultural emphases and different methodologies of analyses of DDE data. After discussions, the NASA engineers were co-authors of a paper agreeing there was indeed contamination on Apollo 11 [5]. The pity is therefore not the dispute, but a collateral ignorance in the external Apollo community that the dispute even existed.

Organizational complexity and conflicts can cause loss or under-appreciation of valuable data: An unfortunate side effect in such a highly-complex multi-tasked mission is that there were implications drawn in the Apollo 11 Preliminary Science Report that the moon-soil samples in the vicinity of the LM landing were not "contaminated" by LM Descent effects. One cannot shoot, much less chase down, every false hare that may be raised by intercultural conflicts. Science was necessarily only a hitch-hiker on the first two lunar expeditions. The safety of the astronauts dominated the management decisions which in turn dominated engineering decisions which dominated the science planning.

Old data can remain uniquely valuable: This paper charts of the Apollo 12 Dust Detector data are the only existing and accessible sources of scientific effects occurring at sunrise on the moon and of engineering effects such as variations in performance of solar cells on the lunar surface for twelve lunar days. If a suitable 7-track tape recorder becomes accessible, the 200 computer tapes can be made accessible with far more ease for both Apollo 11 and 12.It is uncertain how many years will pass before such data will be replaced by newly acquired and more broadly based data.

Serendipity can be a valuable tool of scientific research: One cannot guarantee or rely on serendipity, however by developing an experimental culture which increases the likelihood of it, elegantly simple experiments may be developed which allow results which bear fruit in many areas. One such example is the Apollo 12 DDE analysis which is benefiting in two quite different yet interacting ways. First, each ALSEP package was in various eclipses of the Sun by the Earth. All six channels of the Apollo 12 DDE showed responses, in voltages from the 3 solar cells and in temperatures from the three thermistors. These enable significant in-situ tests of response times and the like. Second, on Apollo 14 the author was Principal Investigator of CPLEE. It measured the energy spectrum of photoelectrons, and how they disappeared in both its paired detectors during eclipses. Photoelectrons and electrostatic effects and interactions with moon dust in the complex and variable plasma environments on the moon and above it offer rich new fields to explore (see, for example [16]). One feature is certain from the past history of exploration mysteries of auroras and magnetospheric complexities, and that is that each new discovery will likely lead to more questions.

Changes in data acquisition and storage technologies may make retrieval of historic data difficult: the data records for a particular mission may well be the most modern available at the date of acquisition, such as the 7-track tape recorders in the brief Apollo era, may no longer be operational or available a generation later. That is one reason why the simple paper charts of Apollo 12 are literally irreplaceable. Digital systems mutate quickly, but papyrus is more durably deciphered.

There is no substitute for the primary data: A wise pioneer would be well-advised to research deeply into primary references, and not necessarily accept intrinsic assumptions which may not be known to be as assumptions. Indeed, in many fields, long-held assumptions may not be articulated as assumptions, and may become easily accepted truth, particularly when peer groups meet and exchange congratulations. The saga of the misinterpretation of the Apollo 11 DDE is a salutary example of this problem.

Future directions: indicative recent commentary and research show a diversity of interest in moon dust and associated lunar phenomena [16]. Such studies cover comments by the Apollo 17 astronauts about their observations of "horizon glow" (HG) and "streamers", some Surveyor photographs of HG, and discussions of possible electrostatically-charged dust particles. It is clear that moon dust is not only a severe challenge for any astronaut activities on the moon, with corresponding severe implications for engineering and system designs, health and mobility issues. Hand-in-hand with such challenges are exciting, exhilarating opportunities for scientific research.

Not before time, there is a considerable amount of scientific interest and more inter-disciplinary analyses of moon dust and its properties and behaviours. In his Mission Report on Apollo 17, Eugene Cernan expressed the frustrations of the astronauts with the ubiquitous dust:

> *"….one of the most aggravating, restricting facets of lunar surface exploration is the dust and its adherence to everything no matter what kind of material …. and its restrictive friction-like action to everything it gets on"*. [17].

An overarching, essential lesson for the future is that planning, science and engineering must be more multidisciplinary, closely synergistic, strategically co-ordinated and reactive in issues such as moon dust than they were, or could be, during the first pioneering Apollo missions. This is especially the case as longer duration missions are considered, with multiple visits to the same site.

Personal notes: In 2007, almost 40 years after the events, I still find great pleasure that the original Dust Detector design was flown on Apollo 12. I find gratification in that the "Engineering Experiment M-515" became accepted as the "Dust Detector", part of the scientific package of each of the Apollo missions except the final two. I personally find it magic that this tiny invention, the Apollo 12 Dust Detector, holds the record as the longest-operating active experiment put on the moon of this Spaceship Earth by human hands. In the clear Perth atmosphere, night and day the moon is a close and welcome friend. I sketched the original design of this record-setting DDE on the back of a National Airlines' coaster that came with my Scotch as I flew from Los Angeles. I refined the design on the white napkin that came with the nuts. The next morning in Houston I formally submitted the proposal to NASA. Three years later I was analyzing data from two Dust Detectors on the moon, one on the Sea of Tranquility and the other on the Ocean of Storms. Oh, for the simplicity of days past.

But I now look forward to some ingenious, multidisciplinary, plasma-related dust experiment breaking that record, or at least starting afresh, as quickly as may be. It must be remembered that the moon is swept not only by the solar wind and thermalised solar wind but also by the long tail of the Earth's magnetosphere, containing for examples electrons and protons similar in energies to those found by CPLEE's poorer relatives, SPECS instruments in rockets through auroras and satellites above them. That is why the ALSEP was a happy hunting ground for CPLEE. It is also why I wanted two CPLEEs in action, to sort out spatial from time effects.

I am delighted that Google searches and other publications already reveal some early candidates to solve a specific identified problem or just to explore the unknown or both. But for how many years must such thirsty and eager candidates wait for their keen-edged concepts to send them data from the moon? How long must they endure intellectual frustration?

Acknowledgments. This paper spans a large segment of my professional career, but a segment that began in 1964, when I first lectured to the latest intake of astronauts, whose autographed thanks I treasure, and whose efforts I so admire. Most of them later flew on Apollo missions, beginning with Buzz Aldrin and Mike Collins on Apollo 11 and ending with Gene Cernan on Apollo 17. Colleagues at various NASA centers are too numerous to list. My particular thanks go to Dave Williams, Dick Moke and Jim Bates as we try to bridge the time gaps. I was apparently the first to win a PhD in Physics from the University of Sydney, and I thank Professor Harry Messel and his successors for their willing help and enthusiasm. I thank also Russell Keys for his skilful handling of the giant computer tapes expressed from NASA through the pornography-aversive staff of the Redfern Mail Exchange and then through the Silliac computer systems. My wife Avril deserves, and gets, very special thanks for her willingness to ferry two hundred large computer tapes and three small children from Sydney to Perth in 1971 on a very slow train. Her help for almost 50 years is magnificent. Emeritus-Professor John de Laeter and his Laboratory Manager Glen Dawson in the Department of Physics at Curtin University deserve general thanks and congratulations for storing safely unwieldy boxes of tapes for 36 years, seemingly without a known future. What they stored so carefully is now proven to be indeed of world heritage, of unique value to future exploration of space. I share with various Australians, with Miriam Baltuck at the Deep Space Centre in Canberra and with colleagues and former staff at Honeysuckle Creek and elsewhere, whose enthusiastic search for the missing high-definition tape of Neil Armstrong's first small step lifted general interest. Most recently I thank Guy Holmes and his skilful team of young enthusiasts at SpectrumData, whose care and expertise will ensure future safekeeping of the Apollo computer tapes. In time, with good fortune, they will compress all the Dust Detector data into one single disc that can be made available to the world community through David Williams and the NASA NSSDC facilities at Goddard Space Flight Center in Greenbelt Maryland. And I thank with great delight the US Consul-General, Mrs Robin McLellan, who so graciously and symbolically received in Perth on 8 February, 2007, the catalogue of tapes and the Dust Detector data tape for Days 1 to 4 of the wondrous, magical Apollo 11 mission on the moon.

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