



The Effects of Lunar Dust on EVA Systems During the Apollo Missions

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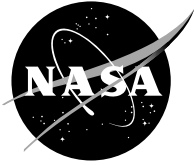
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This printing, numbered as NASA/TM—2005-213610/REV1, April 2007, replaces the previous version, NASA/TM—2005-213610, March 2005, in its entirety. It contains the following changes:

Page 1, “Introduction,” paragraph 3, line 6: Extravehicular Mobility Units (EMU) replaces Extravehicular Mobility Suits (EMS).

Page 5, “Abrasion,” paragraph 1, line 3: The sentence “One or two additional EVAs could have resulted in a pressure failure in the Apollo 12 EMS” has been deleted.

Page 5, “Abrasion,” paragraph 1, line 6: Text has been deleted from sentence so that it reads “Harrison Schmitt’s sun shade on his face plate was so scratched that he could not see out in certain directions.”

Page 7, “Conclusions and Recommendations,” paragraph 6, line 3: The word “its” replaces “it’s.”

Page 11, Table II, “Mission” column, line 12: The word “Apollo” is aligned.

Page 27, paragraph 1, line 1: “Neil” replaces “Niel.”

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Summary

Mission documents from the six Apollo missions that landed on the lunar surface have been studied in order to catalog the effects of lunar dust on Extra-Vehicular Activity (EVA) systems, primarily the Apollo surface space suit. It was found that the effects could be sorted into nine categories: vision obscuration, false instrument readings, dust coating and contamination, loss of traction, clogging of mechanisms, abrasion, thermal control problems, seal failures, and inhalation and irritation. Although simple dust mitigation measures were sufficient to mitigate some of the problems (i.e., loss of traction) it was found that these measures were ineffective to mitigate many of the more serious problems (i.e., clogging, abrasion, diminished heat rejection). The severity of the dust problems were consistently underestimated by ground tests, indicating a need to develop better simulation facilities and procedures.

Introduction

NASA's Vision for Space Exploration has as its fundamental goal the advancement of "...U.S. scientific, security, and economic interests through a robust space exploration program" (ref. 1). The Vision is based around a spiral development that extends "...human presence across the solar system, starting with a human return to the Moon by the year 2020..." The Advanced Extravehicular Activity (AEVA) program has been charged with developing both the technology and the flight hardware required for spacesuits, tools, and vehicular interfaces that will enable astronauts to work on the lunar surface.

In the summer of 2004 the Advanced Integrated Matrix (AIM) Program undertook a study to identify systems on both the lunar and Martian surfaces that would be affected by dust, how they would be affected, the associated risks, the EVA system requirements that need to be developed, and knowledge gaps that need to be filled (ref. 2). The group generated a preliminary list of dust hazards in EVA systems that included those experienced by the Apollo astronauts plus possible electrical problems such as power drains and shorts caused by conductive paths of dust particles. It is essential that the lessons learned during the Apollo program be incorporated into the planning process.

All experience with human EVA systems on the lunar surface comes from the six Apollo missions that landed two-man crews (Apollo 11, 12, 14, 15, 16, and 17) and occurred between 1969 and 1972 (see table I). The records of these missions are a valuable resource as NASA plans for a return to the moon with a more sustained human presence. One of the surprises of the Apollo experience was how troublesome the lunar dust turned out to be. It obscured their vision on landing, clogged mechanisms, abraded the Extravehicular Mobility Units (EMU), scratched the instrument covers, degraded the performance of radiators, compromised seals, irritated their eyes and lungs, and generally coated everything with surprising tenacity. Some of the EMU components were approaching failure at the end of these missions which ranged from 21 to 75 hr on the lunar surface. With the Vision for Space Exploration Spiral 2 missions being planned for the 2015 to 2020 time frame having a mission life of up to 14 days (336 hr), mitigation of the effects of lunar dust on EVA systems clearly must be improved.

This study constitutes a review of the mission documentation and experience with dust from those six Apollo missions. Original documentation such as the Mission Reports, the Technical Debriefings, and transcripts of the voice traffic between astronauts on the lunar surface and Mission Control make up the bulk of the resources that went into the review, though later interviews with some of the principals have also been included.

The dust related hazards could be sorted into nine categories. These categories are: vision obscuration, false instrument readings, dust coating and contamination, loss of traction, clogging of mechanisms, abrasion, thermal control problems, seal failures, and inhalation and irritation. Table II catalogs the references to dust problems in the mission reports and the technical debriefings, sorted by hazard category. The relevant parts of each of the mission documents are reproduced in their entirety in the appendix. The full text of the mission reports and technical debriefings are available on line at <http://www.hq.nasa.gov/alsj/>. In some cases, because of differences in the amount of dust in the local area, problems were only experienced by some of the missions. In some cases later missions were able to lessen the problems by changing operational procedures and, where this was the case, it will be noted herein. But the global lesson is clear—more attention must be paid to the mitigation of the effects of lunar dust if EVA elements are to last through the 14-day nominal mission (ref. 3).

Dust Transport Mechanisms

In order for the dust to cause problems, it must be transferred to sensitive surfaces. A good first-level analysis of the relative importance of different dust transport mechanisms was given by Katzan et al. (ref. 4), and those results will be summarized here. There are two general classes of dust transport mechanisms, natural and anthropogenic. Natural transport mechanisms include secondary ejecta from meteor and micrometeoroid collisions with the surface, and electrostatic levitation of dust at the terminator. None of the natural mechanisms are expected to transport significant amounts of dust over a 14 day period.

Three anthropogenic mechanisms were analyzed and are, in order of increasing importance; astronaut walking, rover wheels spinning up dust, and landing and take-off of spacecraft. By far the most dust is transported by the landing and take-off of spacecraft. Large amounts of dust were seen by the astronauts to be blown about both on landing and on take-off of the Lunar Module (LM). Additionally, parts of Surveyor III recovered by the Apollo 12 crew were totally covered with dust—most of which was probably deposited as the LM landed nearby. Significant dust, though much less than observed on landing, in the Apollo missions was elevated by the Lunar Roving Vehicle (LRV), especially when one or more of the fenders was damaged. Photographs were taken of “rooster tails” of dust thrown up by the rover during its “Grand Prix” performance trial. Dust was elevated by walking, as evidenced by how quickly the EMU around their feet and ankles became dirty. A fourth transport mechanism, not covered by Katzan, is falling. On several occasions astronauts lost their balance and tumbled to the surface, or intentionally went down on one knee to better observe the surface. In all cases, the result was dust adhering to the EMU which could not be brushed off.

It should be noted that the moon has no appreciable atmosphere ($\sim 10^{-12}$ Torr) and, as a result, even submicron particles do not stay suspended. All particles display ballistic motion, falling at the same rate regardless of their size. Thus, there was no enduring cloud of dust when the LM landed, just a racing of particles out radially from the thrust point which settled out almost immediately (ref. 5). This behavior limits the range of dust transport to a strictly local phenomenon.

Pre-Apollo Thermal Testing

Northrop Space Laboratories performed a study sponsored by NASA MSFC in 1967 to try to determine the degradation effects of dust and to establish removal and prevention concepts (ref. 6). They considered the effects of dust on thermal control surfaces, including both a paint (S-13) and a second surface mirror (aluminized FEP Teflon (DuPont)). Sieved and sorted basaltic dust was used as the simulant. It was determined that neither the particle size distribution nor the total mass of the dust proved to be significant parameters and the increase in light absorption, so particle size distribution was not well controlled. However, it was observed that particles larger than 50 μm were easily removed by tapping or low velocity gas jets, so even though the optical properties were independent of particle size, the amount of residual dust contamination depended primarily on the initial amount of particles smaller than 2 μm .

The infrared emittance of the dust (~ 0.88) was similar to that of the thermal control surface (~ 0.83), so it was found that the control surface emittance would not be highly affected by the dust. Thus, radiator performance is degraded primarily by increases in absorption in the UV and visible regions, which raise the temperature of the radiators. It was found that the effect of dust contamination on absorptance was non-linear, with only eleven percent dust coverage resulting in a doubling of the solar absorptance.

Eight different strategies were considered to remove dust from radiator surfaces including brushing, an electrostatic curtain, an electrostatic surface, jet and shield, jet and surface, spinning shield, spinning surface, and vibrating surface. These were prioritized according to system factors and the three that were considered to be the most promising, vibrating surface, jet and shield, and brushing were tested. Preliminary testing was done to remove the dust by nitrogen jet, which proved almost totally ineffective with small particle sizes. Fine dust ($<34 \mu\text{m}$) with an initial dust coverage of 4.5 percent had an initial absorptance of 0.245. After blowing on the sample for 15 sec with 10 psi nitrogen, the absorptance was only reduced by two percent to 0.239. Use of an incompressible fluid (water, benzene, or trichloroethane) did not improve the results much. The results of vibration tests were even worse. Vibration was most effective when the sample was tilted and the vibration was at the resonant frequency, but the fine particles were not substantially removed. Three different brush tests were also carried out, one with a bristle brush, one with styrofoam, and one with cheese cloth. Of these, the styrofoam brush was the most effective.

Final evaluation was done using a functional test where the final temperature of a radiator surface was measured clean, dusted, and with the mitigation strategy employed. Of these trials the jet and plate was the most effective, followed by the mechanical brush, the jet and shield, and finally the vibrating plate. None were completely effective, and the mechanical bristle brush was eventually chosen to fly, primarily due to its lower weight.

Ground-Based LRV Wheel Testing

After Apollo 11 had landed on the moon, but before any LRV had been launched, testing was carried out to determine how the LRV wheels would perform on the moon. There was concern that if the fenders did not contain the dust, that it could cause problems both for the astronauts and for the LRV itself. There had been almost no study about how dust behaved in a vacuum environment under low gravity. In order to study LRV fender design and, indeed, whether they were even necessary, a test rig was constructed in which a LRV wheel could be propelled within a circular vacuum chamber over simulated lunar dust (LSS-4) while being flown on a C-135A aircraft in an arc which would result in a 1/6-g gravitational force (ref. 7). It was found that dust caused as many problems as the most pessimistic predictions, and established the absolute necessity of fenders. It also found that the more complete the coverage of the wheel by the fenders, the less dust was elevated.

The vacuum in which the test apparatus operated was no better than a few Torr. Observation of the mechanics of the dust propelled by the wheel revealed that when the pressure dropped below about 5 Torr

the simulant started to exhibit extra cohesion, as a result of the “clean body effect”.¹ Clumps of the simulant would be thrown up and remain intact until they hit a solid object such as the chamber wall. Under these partial vacuum conditions the dust appeared to travel ballistically, even under reduced gravity conditions, and no suspended particles were observed.

Vision Obscuration

The first dust-related problem experienced by the Apollo astronauts occurred when they landed the Lunar Module (LM). The Apollo 11 crew reported that “Surface obscuration caused by blowing dust was apparent at 100 ft and became increasingly severe as the altitude decreased” (ref. 8). This was even more of a problem for Apollo 12 where there was total obscuration in the last seconds before touchdown to the extent that there was concern that one of the landing feet could have landed on a boulder or in a small crater. In Apollo 14 the landing profile was adjusted to be more steep, and the astronauts reported little difficulty in seeing the landing site. However, this may have been due in part to the Apollo 14 landing site being intrinsically less dusty, because Apollo 15 and Apollo 16 also used the steeper landing profile, and both reported difficulties seeing the landing site in the critical last seconds. Apollo 17 experienced some vision obscuration in the landing of the LM, but they were able to see boulders and craters through the blowing dust all the way to touch down.

The Apollo experience reveals that the extent that vision obscuration as a problem on landing is dependent on the amount of loose dust in the specific landing zone. The record has far fewer references to dust-related problems in Apollo 14 and 17, where there was little obscuration on landing, than in those of the other missions. Thus, it will probably remain a variable as long as spacecraft are landing in unexplored territory. Since vision obscuration is dependent on the depth of loose dust in a particular area, crews may use this as an indicator of how much difficulty they can expect to have with dust during EVA activities.

A related observation is the discoloration of the Surveyor III spacecraft reported by the Apollo 12 crew. Apollo 12 landed about 163 m from Surveyor III with the intent of determining the degradation experienced by the spacecraft after being in the lunar environment for 31 months. The crew expected to find a white spacecraft, but found instead that it was a brown color. Further investigation revealed that the brown color could be wiped off, and was in fact a fine coating of dust. The source of the dust coating was later determined to be largely from the dust kicked up when the LM landed.

In addition to vision obscuration on landing, the dust caused minor problems with photography. The Apollo 15 crew reported problems with a halo effect on the television camera transmission. This was remedied by brushing the dust off of the lens.

False Instrument Readings

In Apollo 12 the landing velocity trackers gave false readings when they locked onto moving dust and debris during descent. The Apollo 15 crew also noted that landing radar outputs were affected at an altitude of about 30 ft by moving dust and debris. But the Apollo 17 crew reported no lock-up onto moving dust or debris near the lunar surface. This again points out the differences in the amount of dust at the different landing sites, with it being high at the Apollo 12 and 15 sites, and low at the Apollo 17 site.

¹When volatile surface films are removed from the surfaces of small particles, the result is stronger electrostatic and Van der Waals forces between the particles.

Dust Coating and Contamination

Dust was found to quickly and effectively coat all surfaces it came into contact with, including boots, gloves, suit legs and hand tools. Consequences included the Apollo 11 astronauts repeatedly tripping over the dust covered TV cable, and a contrast chart on Apollo 12 becoming unusable after being dropped in the dust. This was particularly troublesome on Apollo 16 and 17 when rear fender extensions were knocked off of the LRV and dust “rooster tailed” and showered down on top of the astronauts. Dust coating is the precursor to other problems such as clogging of mechanisms, seal failures, abrasion, and the compromising of thermal control surfaces. In addition, valuable astronaut time was spent in ordinary housekeeping chores like brushing off and wiping down equipment—which often proved ineffective.

Loss of Traction

Neil Armstrong reported material adhering to his boot soles caused some tendency to slip on the ladder during ingress back to the LM. However, this slipperiness was not reported by any of the other crew members, and there are specific references in the Apollo 12 record that this was not a problem for them. It became standard practice for the astronauts to kick the excess dust off of their boots on the ladder before they re-entered the LM in an attempt to keep as much dust as possible out of the spacecraft, and it is likely that this measure was enough to keep slipping from happening.

Although there was concern about the surface being slippery, there are no incidences in the mission record of falling due to slips, though some of the astronauts tripped and fell. In the Apollo experience, loss of foot traction was not a major concern, as long as simple precautions and care were used.

Clogging of Mechanisms

There were reports of equipment being clogged and mechanisms jammed in every Apollo mission. These included the equipment conveyor, lock buttons, camera equipment, and even the vacuum cleaner designed to clean off the dust. Dust made Velcro (Velcro Industries B.V.) fasteners inoperable, and was a particular problem with some LRV indicator mechanisms. The dust also clogged EMU mechanisms including zippers, wrist and hose locks, faceplates, and sunshades. This was particularly troublesome on Apollos 16 and 17 when fender extensions were knocked off of the LRV and showered dust down on top of the astronauts.

The most alarming characteristic was how quickly and irreversibly this could happen. One short ride on the LRV with a missing fender extension, or standing where the equipment conveyor dumped dust on the EMU and difficulties began immediately. With Apollo EMU and equipment designs there was very little room for error. All of the astronauts experienced this to some degree, even those with the shortest stays on the surface. Several remarked that they could not have sustained surface activity much longer or clogged joints would have frozen up completely.

Abrasion

Lunar dust also proved to be particularly abrasive. Pete Conrad noted that the suits were more worn after 8 hr of surface activity than their training suits were after 100 hr and further reported that their EMU were worn through the outer layer and into the Mylar (DuPont) multi-layer insulation above the boot. Gauge dials were so scratched up during the Apollo 16 mission as to be unreadable. Harrison Schmitt’s sun shade on his face plate was so scratched that he could not see out in certain directions. Clearly, if the mission time is to be extended to fourteen days in Spiral 2, these abrasion problems must be solved.

Thermal Control Problems (ref. 9)

An insulating layer of dust on radiator surfaces could not be removed and caused serious thermal control problems. On Apollo 12, temperatures measured at five different locations in the magnetometer were approximately 68 °F higher than expected because of lunar dust on the thermal control surfaces. Similarly, on Apollo 16 and 17 the LRV batteries exceeded operational temperature limits because of dust accumulation and the inability to effectively brush off the dust. John Young remarked that he regretted the amount of time spent during Apollo 16 trying to brush the dust off of the batteries—an effort that was largely ineffective. (This was contrary to ground-based tests which indicated that dusting the radiator surfaces would be highly effective.) This led him to recently remark that “Dust is the number one concern in returning to the moon.” In addition to difficulties with communications equipment and TV cameras, some of the instruments on both Apollo 16 and 17 had their performance degraded by overheating due to dust interfering with radiators.

Seal Failures

The ability of the EMU to be resealed after EVA was also compromised by dust on the suit seals. The Apollo 12 astronauts experienced higher than normal suit pressure decay due to dust in fittings. Pete Conrad’s suit, which was tight before the first EVA, developed a leak rate of 0.15 psi/min after it, and rose to 0.25 psi/min after the second EVA. Since the safety limit was set at 0.30 psi/min, it is doubtful whether a third EVA could have been performed, had it been scheduled. Another indicator is that all of the environmental sample and gas sample seals failed because of dust. By the time they reached earth the samples were so contaminated as to be worthless.

This does not bode well for a long duration habitat where several astronauts will be passing through air locks and unsealing and resealing their EMU routinely. More attention must be directed at ways either to keep dust off of the seals, or to make more dust tolerant seals.

Inhalation and Irritation

Perhaps the most alarming possibility is the compromising of astronaut health by irritation and inhalation of lunar dust. The Apollo crews reported that the dust gave off a distinctive, pungent odor, (David Scott suggested it smelled a bit like gun powder) suggesting that there are reactive volatiles on the surface of the dust particles. Dust found its way into even the smallest openings, and when the Apollo 12 crew stripped off their clothes on the way back to earth, they found that they were covered with it. Dust was also transferred to the Command Module during Apollo 12 and was an eye and lung irritant during the entire trip back. Given the toxicity of particle sizes less than about 5 µm, this points out the need to monitor the concentrations of dust particles within the EMU, the airlock, the habitat, and the spacecraft.

Later Apollo missions were more cognizant of the problem, and dust management strategies such as venting to space and using water to wash down the LM proved to be somewhat effective. But this experience points out that vigilant housekeeping will be required, and as crew sizes and mission durations increase, this will become more of a challenge.

EMU Modifications for Dust Abatement (ref. 10)

The principle concern early on was abrasion caused by sharp rocks. The “super beta cloth” outer covering was not very abrasion resistant, so Chromel-R was woven into the lunar boots and gloves, which

could expect to see the most abrasion. The boots and gloves also used the abrasion-resistant silicone RTV-630 for the soles and finger tips.

A nylon bristle brush was provided to dust off the suits and visors. This was effective for removing the coarse grain material, but not very effective for the fine grain. Since there was only a single brush, there is some thought that in the latter parts of the mission the brush might have transferred nearly as much dust as it removed. Wet wipes were provided for use inside the LM, and these reportedly were effective to clean off skin and equipment. However, they could not be used outside in the lunar environment.

In between EVA's, the zippers and helmet and glove disconnect seals were cleaned and re-lubricated with Krytox oil and grease. Although this helped, it was not completely effective either to keep mechanisms from clogging or to keep the seals from leaking. The wrist bearings and rotational hardware connectors only had a fabric covering to keep out the dust, and these were not totally effective. When rover operations started with Apollo 15, dust covers that were attached with Velcro were added to the connectors on the front of the EMU (ref. 11).

There also was no concerted effort to keep dust out of the LM, and so the astronauts dragged a lot of dust in when they crawled through the hatch. Part of this dust was redistributed onto sensitive surfaces and even the astronauts' skin in the rest periods between EVA's. There was a small vacuum cleaner in the command module (CM) that was used to try to limit the dust transferred from the LM to the CM on docking, but it had limited effectiveness.

Conclusions and Recommendations

Dust on the lunar surface proved to be more problematic than anyone had anticipated. Gene Cernan in the Apollo 17 Technical Debriefing remarked, "I think dust is probably one of our greatest inhibitors to a nominal operation on the Moon. I think we can overcome other physiological or physical or mechanical problems except dust." All of the Apollo missions were adversely affected by the dust due to included visual obscuration, false instrument readings, dust coating and contamination, loss of traction, clogging of mechanisms, abrasion, thermal control problems, seal failures, and inhalation and irritation.

Simple dust mitigation measures were sufficient to mitigate some problems like loss of traction, but for many such as thermal control problems, adhesion, and abrasion, it is clear that new technologies must be developed. Some mitigation strategies, such as vibration have been tried and found lacking. Others, such as brushing appeared to work much better in ground tests than they did in the lunar environment. Clearly, an important area is the development of better simulation environments than were used in the Apollo era. This may include the use of better simulants, higher vacuum, correlated simulations, and more realistic thermal and illumination environments.

Finally, the pervasiveness of the dust and the problems it causes were summed up by Gene Cernan in his Technical Debrief

"Dust - I think probably 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, whether it be skin, suit material, metal, no matter what it be and its restrictive friction-like action to everything it gets on. For instance, the simple large tolerance mechanical devices on the Rover began to show the effect of dust as the EVAs went on. By the middle or end of the third EVA, simple things like bag locks and the lock which held the pallet on the Rover began not only to malfunction but to not function at all. They effectively froze. We tried to dust them and bang the dust off and clean them, and there was just no way. The effect of dust on mirrors, cameras, and checklists is phenomenal. You have to live with it but you're continually fighting the dust problem both outside and inside the spacecraft. Once you get inside the spacecraft, as much as

you dust yourself, you start taking off the suits and you have dust on your hands and your face and you're walking in it. You can be as careful in cleaning up as you want to, but it just sort of inhabits every nook and cranny in the spacecraft and every pore in your skin.”

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Table I.—Apollo crews

	Mission Commander	Lunar Module Pilot	Command Module Pilot	Launch	Landing Site
Apollo 11	Neil Armstrong	Buzz Aldrin	Michael Collins	07/16/1969	Sea of Tranquility
Apollo 12	Charles (Pete) Conrad, Jr. ¹	Alan Bean	Richard (Dick) Gordon	11/14/1969	Ocean of Storms
Apollo 14	Alan Shepard ¹	Ed Mitchell	Stuart Roosa ¹	01/31/1971	Fra Mauro
Apollo 15	David Scott	Jim Irwin ¹	Al Worden	07/26/1971	Hadley-Apennine
Apollo 16	John Young	Charles Duke	Tom Mattingly	04/16/1972	Descartes Highlands
Apollo 17	Gene Cernan	Harrison (Jack) Schmitt	Ron Evans ¹	12/07/1972	Taurus-Littrow

¹Deceased

Table II.—Apollo dust problems

Hazard	Mission	Specific	Mission Report Page	Debrief Page	
Vision Obscured	Apollo 11	Landing site obscured by dust blown by descent engine	4-9		
	Apollo 12	Landing site totally obscured in last seconds before touchdown	6-1, 9-6		
	Apollo 14	Dust noted during descent but did not obscure landing site	3-15	9-17, 9-18	
	Apollo 15	Dust on lens caused halo effect in TV camera (able to brush off)	95		
	Apollo 15	Blowing dust completely obscured vision below 60 ft on landing	110	9-18	
	Apollo 15	Difficult to see RCU flags even with dust covers	20-6		
	Apollo 16	Vehicle landed before visibility degradation due to dust	9-8	9-9, 9-13	
Apollo 17	Dust was blown around, but could see all the way down		9-7		
Equipment Clogged	Apollo 11	Lunar equipment conveyor clogged by dust	4-12, 11-12		
	Apollo 12	Lunar dust clogged wrist locks and suit hose locks	8-21	10-54	
	Apollo 12	Shovel extension handle mechanism got clogged	9-16		
	Apollo 12	Lock buttons on conveyor jammed with dust	9-16		
	Apollo 14	Dust presented problems for experiments package deployment	9-15, 14-47	9-28	
	Apollo 15	Dust clogged tools and made difficult to operate		10-74	
	Apollo 15	Dust interfered with action of interlocking parts		10-49, 21-5	
	Apollo 15	Needed to lubricate wrist and neck rings		10-30, 13-5	
	Apollo 15	Dust clogged camera mechanisms	30	10-65	
	Apollo 16	Vacuum cleaner failed, equipment and watch clogged	6-13, 9-21, 9-50, 14-78, C-1	13-1	
	Apollo 16	Space suit problems with wrist rings, faceplate	9-36, 9-37, 14-70	10-11, 10-69, 10-74, 11-6	
	Apollo 16	LEVA clogged and stuck due to dust		21-1	
	Apollo 17	Faceplate sunshade mechanism, wrist lock-locks jammed with dust	9-5, 10-14	21-2	
	Apollo 17	Stiffness in rover mechanisms, scooping tool, geopallet because of dust	10-16, 10-18	10-2, 20-11	
	Apollo 17	Velcro hold-down pads became inoperative	15-29	10-6	
	Dust Coated	Apollo 11	TV camera cord covered with dust so hard to see - kept tripping over	4-13, 11-12	
		Apollo 11	Adhesion to boots, gloves, suits, hand tools, and rocks	175, 11-12, 12-7	
Apollo 11		Crew dirty after removing helmets, overshoes, and gloves	12-7		
Apollo 11		Dust in eye easily removed, dust under fingernails not able to be removed	12-7		
Apollo 12		Dust coated objects degraded working conditions, housekeeping	3-34, 8-19, 9-14, 9-21, 9-25	10-18, 10-23, 10-36, 10-54	

Table II.—Apollo dust problems (continued)

Hazard	Mission	Specific	Mission Report Page	Debrief Page
	Apollo 12	Dust covered sensitive measurement equipment	6-1	10-29, 10-31, 10-34, 10-45, 10-51
	Apollo 12	Dust covered camera lenses		10-54,20-12
	Apollo 12	Contrast chart dropped onto surface unusable because of adhered dust	9-19	10-37, 10-39, 10-40
	Apollo 14	Soil adhered extensively to the crewmen's clothing and equipment	3-15	10-38, 10-39,10-42
	Apollo 14	Dust collected in the LM		10-65
	Apollo 14	Extra time required to stow dusty equipment		10-67, 13-3
	Apollo 15	Dirt dumped onto suit when transferring samples		10-43, 10-55
	Apollo 15	Fell and got dust all over suit		10-36
	Apollo 15	Dust coated lower part of suits and was dragged into LM		10-18, 10-27
	Apollo 15	Dust accumulated on LRV after fender knocked off		10-76
	Apollo 15	At high speeds dust was thrown up by LRV onto equipment and crew		20-6, 20-17
	Apollo 16	Equipment covered with dust		21-4
	Apollo 16	Lost LRV fender extension caused dust to cover astronauts, equipment	8-2, 9-41, 14-93	10-93, 20-4
	Apollo 16	Film quality degraded when dust got in cameras		10-60
	Apollo 16	Large amount of dust tracked into LM, clogged Velcro hold-downs	9-35, 9-38, 9-50, 9-60	10-16, 11-3,21-5
	Apollo 17	Dust obscured checklist on hand controller	20-5	
	Apollo 17	Considerable time trying to dust off the suits		10-14
	Apollo 17	Loss of LRV fender extension caused excessive dust accumulation		20-11
	Apollo 17	Dust on central experimental station, lunar surface gravimeter, mass spec	10-22, 10-23	
	Apollo 17	Dust coats and contaminates everything		27-27
Surfaces Slipped	Apollo 11	Dust adhering to the boots caused some tendency to slip on the ladder	11-12	
	Apollo 12	No slippery surfaces noted		10-13
	Apollo 12	Skinny tires would have problems slipping		10-49
	Apollo 15	Traction from LRV wheels was good—10% slippage		20-5, 20-6
Dust Inhaled	Apollo 11	Distinct, pungent odor from lunar material	12-7	
	Apollo 11	Floating particles in Command Module not a problem	12-7	
	Apollo 12	Both spacecraft contaminated by floating dust	6-5, 9-21	12-22, 18-6, 18-7, 19-11

Table II.—Apollo dust problems (concluded)

Hazard	Mission	Specific	Mission Report Page	Debrief Page
	Apollo 15	Smelled like gunpowder when first came in from EVA		10-22
	Apollo 15	Particulate matter floated around spacecraft		13-8
	Apollo 16	Dust in the LM in between EVAs, and in the CM after docking, also in eyes		12-11, 13-3, 13-5, 27-36
	Apollo 17	Kept helmet on to keep inhalation irritation down, still short term irritation		13-1, 19-10, 27-47
Radiators Degraded	Apollo 12	Temperatures measured were approximately 68 °F higher than expected	3-16	
	Apollo 15	LRV batteries ran 68 to 78 °F high because dust accumulation on radiators	94	
	Apollo 16	Instrument performance degraded by overheating due to dust on radiators	4-10, 4-19	
	Apollo 16	Dust on Lunar Rover battery mirrors caused overheating	9-42	10-64
	Apollo 17	Instrument shut down when terminator passing to mitigate dust collection	15-29	
Instruments Fooled	Apollo 12	Velocity trackers lock up on moving dust, debris during descent	8-3	
	Apollo 15	Landing radar outputs were affected by moving dust and debris.	72	
	Apollo 17	No lock-up on moving dust or debris near the lunar surface.	8-2	
Seals Failed	Apollo 12	Higher than normal suit pressure decay due to dust in fittings	8-21, 9-21	10-54
	Apollo 12	Environmental sample and gas sample seals failed because of dust	9-14, 9-19	
	Apollo 14	Measurable leaking of suits	10-65	
Dust Abraded	Apollo 12	Outer material worn through the outer suit layer in several spots.	9-21	10-54
	Apollo 16	Gauge dials scratched so unreadable	9-37	21-4
	Apollo 17	Sunshade on faceplate too scratched to see well	9-5	27-45
	Apollo 17	Cover gloves heavily abraded	9-5	

Appendix

Specific references to lunar dust in:

- Apollo 11 Mission Report
- Apollo 12 Mission Report
- Apollo 12 Technical Crew Debriefing
- Apollo 14 Mission Report
- Apollo 14 Technical Crew Debriefing
- Apollo 15 Mission Report
- Apollo 15 Technical Crew Debriefing
- Apollo 16 Mission Report
- Apollo 16 Technical Crew Debriefing
- Apollo 17 Mission Report
- Apollo 17 Technical Crew Debriefing

MSC00171
Apollo 11 Mission Report
November 1969

References to dust:

Page 4-9: Surface obscuration caused by blowing dust was apparent at 100 feet and became increasingly severe as the altitude decreased. Although visual determination of horizontal velocity, attitude, and altitude rate were degraded, cues for these variables were adequate for landing.

Page 4-12: The initial operation of the lunar equipment conveyor in lowering the camera was satisfactory, but after the straps had become covered with lunar surface material, a problem arose in transporting the equipment back into the lunar module. Dust from this equipment fell back onto the lower crewmember and into the cabin and seemed to bind the conveyor so as to require considerable force to operate it.

Page 4-13: The television presented no difficulties except that the cord was continually getting in the way. At first, the white cord showed up well, but it soon became covered with dust and was therefore more difficult to see.

Page 11-7: The regolith is weak and relatively easily trenched to depths of several centimeters. At an altitude of approximately 30 meters prior to landing, the crewmen observed dust moving away from the center of the descent propulsion blast. The lunar module foot pads penetrated to a maximum depth of 7 or 8 centimeters. The crewmen's boots left prints generally from 3 millimeters to 2 or 3 centimeters deep. Surface material was easily dislodged by being kicked, (see fig. 11-3). The flagpole and drive tubes were pressed into the surface to a depth of approximately 12 centimeters. At that depth, the regolith was not sufficiently strong to hold the core tubes upright. A hammer was used to drive them to depths of 15 to 20 centimeters. At places, during scooping operations, rocks were encountered in the subsurface.

The crewman's boot treads were sharply preserved and angles as large as 70 degrees were maintained in the print walls (see fig 11-4). The surface disturbed by walking tended to break into slabs, cracking outward about 12 to 15 centimeters from the edge of the footprints.

The finest particles of the surface had some adhesion to boots, gloves, suits, hand tools, and rocks on the lunar surface. On repeated contact, the coating on the boots thickened to the point that their color was completely obscured. When the fine particles were brushed off the suits, a stain remained.

Page 11-12: The physical characteristics of lunar surface materials were first indicated during the lunar module descent when the crew noticed a transparent sheet of dust resembling a thin layer of ground fog that moved radially outward and caused a gradual decrease in visibility.

Inspection of the area below the descent stage after landing revealed no evidence of an erosion crater and little change in the apparent topography. The surface immediately underneath the engine skirt had a singed appearance and was slightly etched (fig. 11-14), indicating a sculpturing effect extending outward from the engine. Visible streaks of eroded material extended only to a maximum distance of about 1 meter beyond the engine skirt.

During ascent, there were no visible signs of surface erosion. The insulation blown off the descent stage generally moved outward on extended flight paths in a manner similar to that of the eroded surface particles during descent, although the crew reported the insulation was, in some cases, blown for several miles.

The landing gear foot pads had penetrated the surface 2 to 5 centimeters and there was no discernible throwout from the foot pads. Figures 11-15 through 11-18 show the foot pads of the plus Y and minus Z and Y struts. The same photographs show the postlanding condition of the lunar contact probes, which had dug into and were dragged through the lunar surface, as well as some surface bulldozing by the minus Z foot pad in the direction of the left lateral motion during landing. The bearing pressure on each foot pad is 1 or 2 psi.

The upper few centimeters of surface material in the vicinity of the landing site are characterized by a brownish, medium gray, slightly cohesive, granular material that is largely composed of bulky grains in the size range of silt to fine sand. Angular to subrounded rock fragments ranging in size up to 1 meter are distributed throughout the area. Some of these fragments were observed to lie on the surface, some were partially buried, and others were only barely exposed.

The lunar surface is relatively soft to depths of 5 to 20 centimeters. The surface can be easily scooped, offers low resistance to penetration, and provided slight lateral support for the staffs, poles, and core tubes. Beneath this relatively soft surface, resistance to penetration increases considerably. The available data seem to indicate that this increase is caused by an increase in the density of material at the surface - rather than the presence of rock fragments or bedrock.

Natural clods of fine-grained material crumbled under the crewmen's boots. This behavior, while not fully understood, indicates cementation and/or natural cohesion between the grains. Returned lunar surface samples in nitrogen were also found to cohere again to some extent after being separated, although to a lesser degree than observed on the lunar surface in the vacuum.

The surface material was loose, powdery, and fine-grained and exhibited adhesive characteristics. As a result, the surface material tended to stick to any object with which it came in contact, including the crewmen's boots and suits, the television cable, and the lunar equipment conveyor. During operation of the lunar equipment conveyor, the powder adhering to it was carried into the spacecraft cabin. Also, sufficient fine-grained material collected on the equipment conveyor to cause binding.

The thin layer of material adhering to the crewmen's boot soles caused some tendency to slip on the ladder during ingress. Similarly, the powdery coating of the rocks on the lunar surface was also somewhat slippery (see section 4.0). A fine dust confined between two relatively hard surfaces, such as a boot sole and a ladder rung or a rock surface, would be expected to produce some tendency to slip.

Page 11-20: Data from the dust and thermal radiation engineering measurement were obtained continuously except for brief turn-off periods associated with power/thermal management.

Page 11-21: Data from the dust and thermal radiation engineering measurement went off-scale low at 10:00 p.m. e.s.t., September 16, and remained off-scale throughout the day. The downlink signal strength, component temperatures, and power levels continued to be nominal, corresponding with values recorded at the same sun angles on previous days.

Page 11-22: On August 20, 1969, the McDonald Observatory obtained reflected signals from the reflector. The round trip signal time was found to be 2.49596311 (+0.00000003) seconds, an uncertainty equivalent to a distance variation of 4.5 meters.

These observations, made a few days before lunar sunset and a few days after lunar sunrise, show that the thermal design of the reflector permits operation during sun illuminated periods and that the reflector survived the lunar night satisfactorily. They also indicate no serious degradation of optical performance from flaked insulation, debris, dust, or rocket exhaust products which scattered during lunar module lift-off.

Page 12-7: Although each crewman attempted to clean himself and the equipment before ingress, a fairly large amount of dust and grains of lunar surface material was brought into the cabin. When the crewmen removed their helmets, they noticed a distinct, pungent odor emanating from the lunar material. The texture of the dust was like powdered graphite, and both crewmen were very dirty after they removed their helmets, overshoes, and gloves. The crewmen cleaned their hands and faces with tissues and with towels that had been soaked in hot water. The Commander removed his liquid-cooling garment in order to clean his body. One grain of material got into the Commander's eye, but was easily removed and caused no problem. The dust-like material could not be removed completely from beneath their fingernails.

The cabin cleaning procedure involved the use of a vacuum-brush device and positive air pressure from the suit supply hoses to blow remote particles into the atmosphere for collection in the lithium hydroxide filters in the environmental control system.

The concern that particles remaining in the lunar module would float in the cabin atmosphere at zero-g after ascent caused the crew to remain helmeted to prevent eye and breathing contamination. However, floating particles were not a problem. The cabin and equipment were further cleaned with the vacuum brush. The equipment from the surface and the pressure garment assemblies were placed in bags for transfer to the command module. Before transfer to the command module, the spacecraft systems were configured to cause a positive gas flow from the command module through the hatch dump/relief valve in the lunar module.

The command module was cleaned during the return to earth at 24-hour intervals using the vacuum brush and towels. In addition, the circulation of the cabin atmosphere through the lithium hydroxide filters continued to remove traces of particulate material.

MSC01855
Apollo 12 Mission Report
March 1970

References to dust:

Page 3-2: Output data from the dust detector cells are shown in figure 3-4. All readings are close to expected values and show no evidence of natural dust accumulations. An increase in the cell 2 output was seen at lunar module lift-off. Data from cell 2 show that the sun incidence angle was normal to the cell face about 6 hours prior to actual lunar noon, indicating the package is probably tipped about 3 degrees to the east.

Page 3-16: Temperatures measured at five different locations in the instrument (magnetometer) were approximately 68° F higher than expected because of lunar dust on the thermal control surfaces.

Page 3-31: Lunar surface erosion resulted from descent engine exhaust gases, and dust was blown from the surface along the trace of the final descent path (see section 6). Examination of sequence-camera film suggests that this erosion was greater than observed in Apollo 11. Further analysis is required to ascertain whether this effect resulted from different surface conditions, a different descent profile, or whether degraded visibility resulted from a different sun angle.

Page 3-34: After an initial acclimation period, the crew encountered no unexpected problems in moving about on the surface. Traction appeared good, and no tendency for slipping or sliding was reported. Fine surface material was kicked up readily and, together with the lunar dust that coated most contacting objects, created difficult working conditions and housekeeping problems on board the spacecraft

(section 6)

Footprint depths were of the same order as in Apollo 11, that is, a centimeter or less in the immediate vicinity of the lunar module and in the harder lunar surface material areas, and up to several centimeters in the softer lunar surface material areas. The least penetration was observed on the sides of Surveyor crater. Penetration of the lunar surface by various handtools and staffs was reported as relatively easy and was apparently easier than reported for Apollo 11. The staff of the solar wind composition experiment was readily pushed to a depth of approximately 111 centimeters and the flagpole approximately 17 centimeters. Trenches were dug to depths of 20 centimeters without difficulty, and the crew reported that, except for limitations caused by the lengths of the tool handles (section 9), they could have excavated to considerably greater depths without difficulty. Vertical sidewalls on these trenches would cave in when disturbed at the top but would remain vertical if left untouched.

Page 3-36: Examination of the photographs taken at the Surveyor III site (figs. 3-23 and 3-24) suggest that the lunar surface has undergone little change in the past 2-1/2 years. The trenches excavated by the lunar material sampling device on Surveyor, as well as the waffle pattern of the Surveyor footpad imprint, appear much the same as when formed on Surveyor landing (fig. 3-25). Many of the Surveyor components (fig. 3-26) were observed to be coated with a thin layer of dust, but some other process could also have discolored them. The results of a detailed postflight examination of the Surveyor components returned to earth will be published in a separate science report (see appendix E). The Surveyor components returned were a cable, a painted tube, an unpainted tube, the television camera, and the scoop.

Examination of returned samples.- Four kilograms of lunar surface material having a grain size of less than 2 millimeters in length was returned and this was much less than the 11 kilograms returned from Apollo 11. The lunar surface samples available for study are: (1) lunar surface material mixed with and

adhered to the rock samples in both the selected and documented sample boxes; (2) five individual documented lunar material samples; (3) the contingency sample; and (4) the contents of four core-tube specimens. A cursory examination of returned samples indicates a very fine, dusty, charcoal-gray lunar material similar to that returned from Apollo 11.

Page 3-43: The lunar terrain over which the lunar module traveled during descent was documented by the 16-mm sequence camera. Lunar surface visibility during descent and the obscuration by dust just prior to landing are illustrated in this film sequence (fig. 6-1). The 70-mm film exposed on the surface, when not affected by sun glint on the lens or surface washout by sunlight, was generally of good quality.

Page 4-23: Figure 6-1 contains a sequence of out-the-window photographs showing the effect of dust on visibility during the final phases.

Page 4-25: Actually, as discussed in the previous section, the unperturbed (automatic) descent trajectory was very close to nominal (170 feet south and 380 feet west of Surveyor), and the crew elected to over-fly the crater to the right side, eventually touching down very near its far rim. The final landing location, which was 535 feet from the Surveyor, was influenced by the preflight consideration that the landing occur outside a 500-foot radius of the target to minimize contamination of the Surveyor vehicle by descent engine exhaust and any attendant dust excitation.

Page 6-1:

6.0 LUNAR DUST

Lunar dust was evident during Apollo 12 in two respects, but in a manner which differed significantly from that observed during Apollo 11. First, the crew experienced total obscuration of visibility just prior to touchdown, and second, because of increased exposure, more dust adhered to surface equipment and contaminated the atmosphere of both spacecraft.

6.1 DUST EFFECTS ON LANDING VISIBILITY

During the final phase of lunar module descent, the interaction of the descent engine exhaust plume with the lunar surface resulted in the top layer of the lunar soil being eroded away. The material particles were picked up by the gas stream and transported as a dust cloud for long distances at high speeds. Crew visibility of the surface and surface features was obscured by the dust cloud.

6.1.1 Mechanism of Erosion

The type of erosion observed in the Apollo 11 and 12 landings is usually referred to as viscous erosion, which has been likened to the action of the wind blowing over sand dunes. The shearing force of the gas stream at the interface of the gas and lunar soil picks up the weakly cohesive particles, injects them into the stream, and accelerates the particles to high velocities. The altitude at which this erosion is first apparent and the transport rate are dependent upon the surface loading caused by the engine exhaust plume and upon the mechanical properties of the local lunar soil. This dependence is expressed in terms of several characteristic parameters, such as engine chamber pressure, exit Mach number, material density, particulate size, and cohesion. Reference 4 develops the fundamental theory for predicting erosion rates during landing and compares the analytical predictions with experimental data. A list of suitable references on this subject are contained in volume II of reference 4.

6.1.2 Visibility Degradation During Apollo 12

Data on the degradation of visibility during landing are derived from crew observations and photographs.

Page 6-3: The first time that dust is detected from the photographic observations occurs 52 seconds before touchdown. This time corresponds to an altitude of about 100 feet. There is no commentary in the voice transcription relative to dust at this point, but postflight debriefings indicate the crew noticed the

movement of dust particles on the surface from a relatively higher altitude. At 180 feet altitude the Lunar Module Pilot made the comment that they could expect to get some dust before long. However, the initial effect of the dust, as first observed in the film or by the crew, indicates that there was no degradation in visibility prior to about 100 feet in altitude. However, the crew stated that dust was first observed at an altitude of about 175 feet (section 9.0). Dust continued to appear in the sequence camera photographs for the next 10 or 12 seconds as the lunar module descended to about 60 to 70 feet in altitude. Visibility is seen to have degraded, but not markedly. Beyond this point, the film shows the dust becoming more dense. Although surface features are still visible through the dust, impairment of visibility is beginning. Degradation of visibility continues until the surface is completely obscured and conditions are blind. The point at which this total obscuration occurs is somewhat subjective. At 25 seconds before touchdown, the dust cloud is quite dense, although observations of the film show some visibility of the surface. From the pilot's point of view, however, visibility is seen to be essentially zero at this time, which corresponds to an altitude of about 40 feet. Therefore, the pilot's assessment that total obscuration occurred at an altitude of about 50 feet is confirmed. The Commander considered visibility to be so completely obscured at this point that he depended entirely on his instruments for landing cues.

Page 6-4:

6.1.3 Comparison to Apollo 11 and Results of Analysis

Compared to the Apollo 11 landing, the degradation in visibility as a result of dust erosion was much more severe during Apollo 12. During Apollo 11, the crew likened the dust to a ground fog; that is, it reduced the visibility, but never completely obscured surface features. On Apollo 12 the landing was essentially blind for approximately the last 40 feet. In order to better understand the reasons for these differences, a detailed analysis was initiated of the factors which affect erosion and visibility. The results of that analysis, although not completed, are summarized here.

First, it was important to establish whether the surface material characteristics were different at the Apollo 11 and Apollo 12 landing sites. The various data sources provide no firm basis for a belief that a significant difference exists between the lunar material characteristics at the two sites. On the other hand, the following evidence indicates that the surface material behavior was essentially the same at the two sites:

- a. The height at which erosion first occurred was essentially the same on the two missions. The Apollo 11 sequence camera photographs indicate the first signs of dust at about 120 feet altitude about 65 seconds before landing.
- b. Photographs taken during the extravehicular activity in the general area of the lunar module revealed that the soil disturbances caused by the descent engine exhaust produced about the same effects on the two missions.
- c. Photographs of the crewmen's bootprints indicate that the soil behaved about the same at the two sites. Although there were local variations in footprint penetrations, such variations were observed at both sites.
- d. Analysis of the returned core tube samples indicates that the lunar soil had about the same density and the same particle size distribution at both sites.

Since the soil characteristics were apparently the same at the two sites, the analysis was concentrated on the aspects of the two flights that were different, that is, the descent profile over the last 200 feet of altitude and the sun elevation level at landing. Results of these analyses indicate that both of these effects contributed to the poor visibility conditions on Apollo 12. The thrust level on Apollo 12 was somewhat higher over most of the final descent and was significantly higher (about 20 percent) at about 30 feet altitude at 15 to 20 seconds before landing. This greater thrust caused a higher surface loading and therefore produced greater erosion rates. More significant, however, was the effect of the lower sun angle (5.1 degrees on

Apollo 12 compared to 10.8 degrees On Apollo 11). For given dust cloud density the combined effects of light attenuation, veiling luminance, and a diffuse illumination on the surface are much more serious at the lower sun angle and can be shown analytically to produce the effects observed on Apollo 12. Analysis is continuing on a parametric variation of the factors which affect erosion and visibility. However, all these analyses are based upon certain assumptions about the optical scattering properties of the lunar dust and upon an idealized lunar model. Thus, these limitations make it impossible to conclusively prove that the effects noted can indeed be attributed to the sun elevation angle. Undeterminable differences in critical soil properties, such as cohesion, could have produced the same effects.

Page 6-5:

6.1.4 Instrument Landing Procedures

Preliminary studies show the impracticality of various means for reducing the dust effects on visibility, largely because of the weight and performance limitations of the spacecraft. The lunar module was designed with the capability to be flown entirely on instruments during the landing phase. The two accomplished lunar landings have provided the confidence that an instrument landing is within the capability of the spacecraft systems. Therefore, on Apollo 13, onboard software will be modified to permit reentry into an automatic descent program after manual modes have been exercised. This change will allow selection or redesignation of a suitable landing site, followed by automatic nulling of horizontal rates and automatic vertical descent from the resulting hover condition, which would occur at an altitude above appreciable dust effects.

6.2 CONTAMINATION OF THE SPACECRAFT ATMOSPHERE

The amount of lunar dust encountered by the Apollo 12 crew appeared to be appreciably greater than in Apollo 11. This condition manifested itself by contaminating the atmospheres in both spacecraft and depositing dust over much of the lunar surface equipment and onboard systems. The cohesive properties of lunar dust in a vacuum, augmented by electrostatic properties, tend to make it adhere to anything it contacts. These properties diminish in the presence of the gas of an atmosphere. Upon attaining gravity, some of the lunar dust floats up in the cabin atmosphere and becomes widely dispersed. This process tends to be continuous, and renders present atmosphere filtration techniques inadequate. The presence of the lunar dust in the cabin of either spacecraft does not detrimentally affect the operation of onboard systems, but the dust could present a hazard to crew health, and at least it constitutes a nuisance. The potential health hazards are eye and lung contamination when the dust floats in zero g. In an effort to minimize this nuisance on future flights, various dust removal techniques were evaluated for cleaning the spacesuits and equipment on the lunar surface prior to ingressing the lunar module.

Page 8-3: At altitudes below 50 feet, the range and velocity trackers are operating on highly attenuated signals resulting from the high discrimination of the receiver audio amplifiers to the low frequency signals at these trajectory conditions. Since the trackers are approaching signal dropout, the velocity trackers are particularly vulnerable to locking up on moving dust and debris generated by exhaust plume impingement on the lunar surface.

Page 8-19: The lunar equipment conveyor satisfactorily transferred equipment into the lunar module, although a considerable amount of lunar dust was picked up during the operation.

Page 8-21: During the last hookup of the suits to the electronic control assembly prior to ascent, the lunar dust on the wrist locks and suit hose locks caused difficulty in completing these connections. In addition, much dust was carried into the lunar module after the extravehicular periods. Dust may have contaminated certain suit fittings, since during the last suit pressure decay check, both crewmen reported a higher-than-normal suit pressure decay. However, no significant difference in oxygen consumption between the two extravehicular periods was apparent.

Page 9-6: A steeper-than-normal descent was made into the final landing site. Dust was first noted at approximately 175 feet in altitude. The approach angle was approximately 40 degrees to the surface slope. A left translation was easily initiated and subsequently stopped to maneuver over to the landing site. The last 100 feet were made at a descent rate of approximately 2 ft/sec. Prior to that time during the landing phase, the maximum descent rate was 6 ft/sec. The dust continued to build up until the ground was completely obscured during approximately the last 50 feet of descent (section 6.1).

Page 9-14: It was impossible to work with the various pieces of experiment equipment without getting them dusty. Dust got on all experiments during off-loading, transporting, and deployment, both as a result of the equipment physically touching the lunar surface and from dust particles scattered by the crewmen's boots during the deployment operation. Because there does not appear to be a simple means of alleviating this dust condition, it should become a design condition.

The environmental sample and the gas sample were easy to collect in the container provided, but there was a noticeable binding of the threads when replacing the screw-on cap. The binding could have been caused by a thermal problem, operation in a vacuum, or the threads being coated with lunar dust. Although the lid was screwed on as tightly as possible, the gas sample did not retain a good vacuum during the trip back to earth.

The Surveyor was sitting on a slope of approximately 12 degrees. All components were covered with a very tenacious dust, not unlike that found on an automobile that has been driven through several mud puddles and allowed to dry. While the dust was on all sides of the Surveyor, it was not uniform around each specific item. Generally, the dust was thickest on the areas that were most easily viewed when walking around the spacecraft. For example, the side of a tube or strut that faced the interior of the Surveyor was relatively clean when compared to a side facing outward.

Page 9-15: The practicality of a pushed or towed vehicle for transporting equipment, tools, and samples over the surface could not be resolved from the work performed in this mission. However, certain constraints, such as the dust which would be set in motion by any wheels, must be considered in the design of such a vehicle. Also, under the light gravity, objects carried on such a conveyance would have to be positively restrained.

Page 9-16: The extension handle was also from 3 to 5 inches too short for optimum use with the shovel. The upper collar that mates with the aseptic sampler is no longer required and could be removed. The locking collar for the shovel or core tube was binding slightly by the end of the second excursion, probably because of dust collection in the mechanism.

Trenching operations were very time consuming. Because of the continuous mantle of dust that coats most of the lunar surface, trenching should be deeper and more frequent on future mission.

The single-strap lunar surface conveyor (fig. 9-5) was easy to deploy and generally performed satisfactorily. The end of the strap resting on the surface collects dust, which is subsequently deposited on the crewmen and in the lunar module cabin. The metal pin that retains the lunar module end of the conveyor was not large enough to prevent it from slipping out of the yoke. By the end of the second extravehicular period, the lock buttons on the two hooks were extremely difficult to operate because of accumulated dust.

Page 9-19: Closing of the sample return containers was not difficult and was similar to that experienced during 1/6 g simulations in an airplane. The seal for the sample return container lid became coated with considerable dust when the documented samples were being loaded into the container. Although the surface was then cleaned with a brush, the container did not maintain a good vacuum during the return to earth.

All shades on the contrast charts could be seen under the conditions tested. One of the charts was accidentally dropped to the surface, and the dust coating rendered it unusable. The other two charts were used to look at the two extreme lighting conditions, up sun and down sun on the walls of a crater.

Page 9-21: Cabin repressurization after each extravehicular period was positive and rapid. Once inside the spacecraft, the dust on the suits became a significant problem. Considerable dirt had adhered to the boots and gloves and to the lower portions of the suits. There were fillets of dirt around the interior angles of the oxygen hose connectors on the suit. The suit material just beneath the top of the lunar boots chafed sufficiently to wear through the outer suit layer in several spots. The dust and dirt resulted in a very pronounced increase in the operating force necessary to open and close the wrist rings and the oxygen hose connectors. The Commander's suit had no leakage, either prior to launch or prior to the first extravehicular activity. Just before his second egress, the leak rate was 0.15 psi/min and, prior to cabin depressurization for equipment jettison, was 0.25 psi/min. If the suit zippers had been operated for any reason, suit leakage might have exceeded the 0.30 psi/min limit of the integrity check. (Editor's note: See section 8.12)

After ascent orbit insertion, when the spacecraft was again subject to a zero-g environment, a great quantity of dust and small particles floated free within the cabin. This dust made breathing without the helmet difficult and hazardous, and enough dust and particles were present in the cabin atmosphere to affect vision (section 6.2). Some type of throwaway overgarment for use on the lunar surface may be necessary. During the transearth coast phase, it was noticed that much of the dust which had adhered to equipment (such as the camera magazines) while on the lunar surface had floated free in the zero-g condition, leaving the equipment relatively clean. This fact was also true of the suits, since they were not as dusty after flight as they were on the surface after final ingress.

Page 9-25: The transfer of equipment between both vehicles was impeded by the large amounts of dust and debris in the lunar module. Therefore, the timeline became very tight in meeting the schedule for lunar module jettison. However, the checklist and the flight plan were completed satisfactorily. On future flights, at least an additional half hour should be allowed for this activity. Lunar module jettison and the subsequent command and service module separation maneuver were conducted in accordance with flight plan procedures.

Page 10-10: The medical aspects of lunar dust contamination are briefly discussed in section 6.

Page 14-19: Initial tests showed the filter was clogged, allowing only about 20 percent of normal flow. Subsequent testing showed the contamination was soluble and as the testing continued, the flow through the filter returned to normal. Analysis indicated the major contamination was urine solids. Only one small particle of lunar dust was detected in the filter.

Page A-2: The following changes were incorporated in the crew provisions as a result of the Apollo 11 experience. Two hammocks were added for increased crew comfort during the lunar-surface stay. The valve, hoses, and large urine bags of the waste management system were replaced with a lighter, less complex system of small urine bags. A condensate collection assembly, having a flow indicator, was added to permit recharging of the water in the portable life support system. The lunar equipment conveyor was redesigned to a single strap arrangement to preclude any possible binding caused by lunar dust. A color television camera was substituted for the slow-scan black-and-white lunar surface camera.

Page A-5:

Central Station

The central station (fig. A-1) is the focal point for control of the experiments and for the collection, processing, and transmission of scientific and engineering data to the Manned Space Flight Network... A dust detector mounted on the central station measures the dust accumulation. The detector consists of a sensor, which has three photocells, and associated circuitry.

Apollo 12 Technical Crew Debriefing December 1, 1969

Page 10-13:

BEAN: I never noticed any slippery surfaces such as Neil and Buzz pointed out. The ground never felt slippery at all to me. ... What do you think about the slipperiness?

Conrad: I didn't notice any slipperiness, ...

Page 10-18:

CONRAD: Our two rock boxes...The only problem was one that was already mentioned. We knew it was going to happen anyway and I really don't see a heck of a lot you can do about it. This problem is that the lower end of the strap got completely covered with dust and I got dust all over my hands and over my suit arms from handling that strap. I really don't see anything you can do about it.

Page 10-23:

BEAN: One thing that continually disturbed us the whole time, particularly Pete, was the fact that the TV cable was right in front of the MESA. Our TV cable laid flat on the ground. It didn't tend to curl up or anything like that; but, because it lays on top of the dust and you feet go beneath the dust, you end up pushing the cable around quite a bit. ... We never fell over it but it was just a constant problem trying to avoid it.

Page 10-29:

BEAN: The first experiment I put out was the passive seismic. It had two anomalies that I know. One was the skirt. The aluminum foil, the skirt, didn't want to lie down. It wasn't that it had a memory. When I placed it near the ground, the many layers seem to separate. The skirt seemed to have some kind of static charge on it that would not allow it to touch the ground. It took quite a little pushing to get it to lie down on the ground. The only way I could make it lie flat was to put a little dirt on it, which I tried. But that wasn't a very good idea because it's difficult to put little clods of dirt on it. I later got some Boyd bolts and made little alignment tubes to sit on it. That worked really well; it held down the skirt pretty well.

Page 10-31:

BEAN: This lid was supposed to be deployed from ground command after we had left the area so that the exposed mirrored surface would be nice and clean and the two detectors would not get dust in them. I'm pretty sure that we did get some dust on the top of it. I hope it's not enough to bother the operation. I've got two other comments. My experience working with Boyd bolts is that you can do them a heck of a lot faster if they don't have those little alignment tubes on them. I don't know how Pete feels about this, but I recommend that you throw those off and just use the Boyd bolts. I could always stick my tool in there a lot faster when there were no tubes, and I can also see when the little bolts jump up a lot better. The second comment; I think we're kidding ourselves if we think there is any way to deploy this experiment without getting a lot of dirt and dust on it. The pictures are going to show this. They just have to be designed to accept dirt and dust. If they can't accept the dirt and dust, then they are going to have to be packaged in some way so they can be deployed completely and then, the last act would be to pull some sort of pin and flip off the covering that would have all the dirt and dust on it, exposing the nice clean experiment.

Page 10-34:

CONRAD: Solar wind spectrometer...The Boyd bolts, as Al pointed out, were no problem; it probably would have been easier if the cups were lower. The bolts should be covered with tape though, because of the dust problem.

Page 10-36:

BEAN: We had talked earlier about just falling over on our faces and catching ourselves on our hands, or getting down on our knees, and inspecting whatever rocks we wanted to look at. When we got there, we could have done this physically, but the problem was, it was just so dirty that you didn't want to do it. I went down on my hands a couple of times, but each time I did, I went down where I would land with my hands on a rock. I would stand there until I saw what I wanted to see, and then do a kind of push-up from the rock. But there isn't always a rock around to do this sort of thing, If we just had some simple...

Page 10-37:

CONRAD: One other item in the first EVA, the colored chart, I took out because I could not bend over, and there was no reasonable way to stick it in the ground. I tried to work it into the ground so that it was perpendicular to the Sun. It didn't work because of the soft dirt. It fell over and became covered with dust. I got it back up and tried to brush it off, but it was impossible. I just made a complete shambles out of it. The dust clung to it so badly that we didn't get a color shot of that.

Page 10-39:

BEAN: I want to discuss number 41 which is the contrast charts. We had three of them. One of them got dropped in the dirt and was completely covered with dust, so it was useless. There was no way to dust it off.

Page 10-40:

CONRAD: We hung them on the corner of the table. We had three of them hanging on the corner of the table. When I removed the first LiOH box on the first EVA to send it up, that one fell off and I had to pick it up out of the dirt. Once it gets in the dirt, forget it.

BEAN: There's no way to dust anything off there, which brings up a good point that we'll be covering in a few minutes concerning when we got back in. I took one chart and put it on the sunny side (and you can see all the different grades of gray), took pictures of it, and reported that over the air. I put the...

Page 10-42:

BEAN: The entire lunar surface was covered with a mantle of broken-up material, fine dust of varying depth. As a result, everything looked pretty much the same – sides of the craters, tops of the craters, flat lands, and ejecta blanket.

Page 10-45:

BEAN: We noticed the Surveyor had turned to sort of a tan appearance, including the white parts, the chrome, and the shiny parts. We looked at it closely and rubbed it. You could rub off this brown color if you rubbed hard enough. It gave you the feeling that it wasn't blown on when we flew down in the LM, or rather that it had adhered to it over the years it had been in the crater. We took enough pictures so that we can document this.

Page 10-49:

BEAN: Although the dust was only an inch deep or something like that, if you had some skinny tires it might give you a little problem. I don't know how big in diameter they ought to be, but they out to be fat things to help it ride along the surface.

Page 10-51:

BEAN: Finally, it did tear about a 6-inch longitudinal rip; and I realized then that it just wasn't flexible enough and didn't want to roll up. So I let it go and let it sort of window-shade all the way around and then tried to roll it up by hand and not get my fingers on the foil. I'm sure I was not able to do this entirely. I expect that there is some dust from my gloves on the foil but I did the best I could. I understand that it is possible to dust that off, bake it off, or something like that and it doesn't bother the experiment.

BEAN: I would like to say something about that camera. We got a lot of dust on ourselves and also on the outside of the camera. We kept looking at the lens to see if there was any dust on it and to see if it was going to degrade the pictures. Neither Pete nor I could see it on each other's camera, although the other parts of our camera were covered with dust. We'll have to take a look at the pictures we returned. If it does turn out to be a problem, we're going to have to come up with some sort of brush we can use to dust off the lens, because I don't see any other way. We were trying our best to keep the equipment clean; but just moving around, trenching, leaning over, and all the other things tend to get dust on the equipment. One other thing, when we go back to the LM, we tried to dust each other off. Usually, it was just Pete trying to dust me off. I would get up on the ladder and he would try to dust me off with his hands, but we didn't have a lot of luck. We should have some sort of whisk broom on the MESA. Before we get back in, we'll dust each other up high. Then the LMP will get on the ladder, and the CDR will give him a dust or vice versa and then will get on in. We are bringing too much dust into the LM. Another possibility is that just as soon as you get in you slip on some sort of second coveralls that fit over the feet on up to the waist, because that's the dirty area. Then you keep it on all the time you're in the LM and take it off just before you get out. The other alternative to this is that you put on a similar something when you're getting out onto the lunar surface. The reason I suggest the former was that I think you want to be as free as you can possibly be when on the lunar surface. Adding another garment over the top of the already existing equipment is going to be restrictive and might give you a few more problems.

CONRAD: I got quite concerned with not only the wear and tear on the suits but the effect of the dust on the suits. On our final hookup back on the LM ECS system for ascent, it was all we could do to get our wrist locks and suit hose locks to work. They were beginning to bog down with dust in them. When you go over these suits later, you'll be able to analyze this. I have no idea what the effects were on the O-rings. Suit integrities did stay good, but there's no doubt in my mind that with a couple more EVA's something could have ground to a halt. In the area where the lunar boots fitted on the suits, we wore through the outer garment and were beginning to wear through the Mylar. I'm sure that with all the wear on the outside surfaces there's bound to have been rubbing of the bladder. I'm sure they will be very carefully inspected to see what these effects were. Al and I had extreme confidence in the suits; therefore we didn't give a second thought to working our heads off in the suits and banging them around – not in an unsafe manner but to do the job in the way we had practiced it on Earth. These suits were worn more than our training suits. We must have had more than a hundred hours suited work with the same equipment, and the wear was not as bad on the training suits as it is on these flight suits in just the 8 hours we were out. I think it is the abrasiveness of the dust.

BEAN: I think that one of the best decisions that we made was not taking the suits off at night. This allowed us to control our temperatures pretty well. We were always able either to turn on the LCG pump and get cool that way or to turn on the vent flow. If we had had the suits opened up, I'm afraid that we would have had a lot more trouble with dust in the zippers, inside the suit, and inside the helmets. It was tough enough on just the wrist rings and neck rings. We tried to wipe them off before we put out equipment back on the next morning but we did notice it (was) harder to put on. I didn't have any leak rate for all the pressure checks prior to launch and at other times, but during the last pressure check that we pulled I had a leak rate of something like two tenths over the minute. So the thing was leaking somewhere and it must have been around the neck and wrist rings because those were the only openings that had changed.

CONRAD: My suit was the same way. I had 0.15 over a minute although I had very little on our first check prior to getting out.

Page 12-22

CONRAD: Tunnel operations were smooth as glass. The LM was filthy dirty and it has so much dust and debris floating around in it that I took my helmet off and almost blinded myself. I immediately got my eyes full of junk, and I had to put my helmet back on. I told Al to leave his on. We left the helmets on and took off our gloves. Once we got stabilized and had the hatches open and everything, the flow system of having the command module more positive than the LM seemed to work. We did not pick up much debris in the command module; very little, if any that was floating in the LM. But, it stayed very good in the LM all the way through our checklist. We tried to vacuum clean each other down, which was a complete farce. In the first place, the vacuum didn't knock anything off that was already on the suits. It didn't suck up anything, but we went through the exercise. It did clean the rock boxes, that much I'll say for it. I don't think is sucked up any of the dust, but it brushed the dirt off the boxes. We put them in their proper containers, and transferred them. Dick brought over LiOH B-5 and 6. We stowed those and it took a long time to get all the gear transferred. Then Al and I, because we and the spacecraft were so dirty, stripped naked and transferred the suits up to Dick. He stowed them under the couch and let us come in dirty and pack our own suits to keep himself and the spacecraft as clean as possible. We packed the two suits in the lower part of the L-shaped bag, and to my knowledge we had very little debris come across from the LM. However, something we found out later and not until we got back to the ship was that the fine dust was on the suits and on almost all of the equipment that was contained inside the bags. The dust is so fine and in zero g it tended to float off the equipment and it must have permeated the whole command module. It floated out of those bags; it floated out of the contingency sample bag. This we could see any time we opened up (which we stopped doing right away) the LiOH container that had the contingency sample in it. The whole thing was just a cloud of fine dust floating around in there. You could actually see it just float out of the bag through the zipper; and you can forget those zippers. They don't hold anything in. When we got all the gear back here and opened it up, back on the carrier, we found that it had all cleaned itself. That was where all this dirt was coming from in the command module. The dirt is so fine I don't think that LiOH filters were taking it all out. It would pump down the ECS system and pump it back out the hoses. This was indicated by Dick's blue suit hose, which we had tied over the left-hand side and was blowing on panel 8 circuit breaker panel. That whole thing was just one big pile of dust that was collected on the circuit breakers. The only reason it's there is the ECS hose was blowing on it. It's got to have taken the dust in through the LiOH canisters and filters and everything and blown it back out the blue hose. So the system is not doing the cleaning, the dust is too fine.

GORDON: I think Pete has probably already commented on this during the LM portion of this debriefing, and to me it was a period of "hustle, hustle." I believe we had a lot more gear to transfer back and forth than did the Apollo 11 crew. Pete mentioned the vacuuming, the futility of trying to vacuum the suits and this sort of thing. He and Al both undressed in the LM and passed the suits over where we put them under the couches for stowage at a later time. It was a continual hustle to get ready for LM jettison. A period of time after we docked, I had the tunnel cleaned out, but they were still busy gathering stuff up in the LM, so I went back and did the VERB 49 maneuver.

Page 18-6:

GORDON: The cabin atmosphere was okay. On the way out, it was clean. On the way back, we got lunar dust in the command module. The system actually couldn't handle it; the system never did filter out the dust, and the dust was continuously run through the system and throughout the spacecraft without being removed.

Page 18-7:

GORDON: The suit circuit performed satisfactorily. There was no problem. The suit circuit was used during launch and undocking prep and was never used again.

We did, of course, use the suit hoses as our ventilation system, and we put screens over the exhaust hoses, which worked satisfactorily. Going out, they were no particular problem. We cleaned the screens approximately once a day on the exhaust hoses and on the suit circuit return-valve screen. On the way back, with all the lunar dust this operation was increased to twice a day for the suit circuit screen and sometimes three and four times a day for the screen on the exhaust hoses. The screens were always covered with gray lint material that we never did seem to get rid of.

Page 19-11:

BEAN: Cabin atmosphere from activation planning was excellent. When we got back inside the first time, in one-sixth g, the atmosphere remained that way although we brought in quite lot of dust. The same with the second time and the cabin jettison depressurization. Once we got into orbit in zero g, there was a lot of dust and dirt floating in the cabin, and we chose to remain in our suit loops as much as possible because of all this dirt, dust, and debris that was floating around.. When we finally got back to the command module and docked with the SCM, we wanted to figure a way to keep this dust and dirt from filling the command module, but we weren't really sure how to do that. I think procedures should be developed so that a positive flow of air is maintained from the command module to the LM, not necessary to keep lunar bugs out of the command module, but to keep all this dust and dirt out of the command module. We were plagued by it when we finally did get back into the command module. Pete and I had to remove our hoses so that we could use them for vacuum cleaners. Incidentally, they didn't perform too well. There wasn't enough vacuum there. We had to remove our helmets from our suits, to keep our eyes from burning and our noses from inhaling these small particles floating around; we just left our helmets sitting on the tops of our heads. This isn't a very good configuration to be in, but we had no other alternatives at the time. I think this is completely unsatisfactory, and there must be some way to clean up that cabin atmosphere so that you can work in a good, acceptable environment when you do get back to the command module. It's possible that you could get up and dock with the command module before you open the upper hatch, dump the cabin down to 3-1/2 psi, and hope it doesn't blow a lot of dirt and debris out there, and then slowly fill the cabin up in the command module and that will keep it filled. There ought to be some way to do this job.

Page 20-12:

BEAN: The thing that worried me most about the cameras was that we were getting a lot of dust on them. I was afraid we were getting dust on the lens, and we had no means whatsoever to clean it off. I think it would be definitely desirable to have a whiskbroom on the MESA. We could use the whiskbroom to dust off the suits, and perhaps the back of the broom could have something so that you could use to dust off the lens of the camera. I suspect that as missions get longer, we're going to get some pretty good dust coverings on the lens of the cameras. Such a dust covering is going to degrade the photographs unless we have some means of cleaning the camera lens off, which we did not have in this case.

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May 1971

References to dust:

Page 3-6: The lunar dust detector of the central station is showing normal outputs from all three photoelectric cells. No changes in the outputs of these cells were observed during or after lunar module ascent, indicating that dust from the ascent engine exhaust did not settle on the central station.

Page 3-9: The suprathreshold ion detector experiment (ref. 2) was deployed southeast of the Apollo lunar surface experiments package central station (fig. 3-2). Noisy data were received at turn-on (section 14.4.2) but the data were satisfactory after seal break and dust cover removal. The experiment is returning good scientific data, with low background rates. Despite a large amount of lunar dust which adhered to one end of the package when it fell over several times during deployment (fig. 3-4), the temperatures throughout the lunar day and night remained within the range allowed for the instrument. Photographs show that the instrument is properly deployed and aligned.

Page 3-12: After lunar module ascent, the charged particle lunar environment experiment was commanded on at 142 hours 7 minutes and the dust cover was removed about 15 hours and 20 minutes later. Operating temperatures are nominal. The maximum temperature during lunar day is 136 °F and the minimum temperature during lunar night is minus 11 °F. The instrument's operational heater cycled on automatically when the electronics temperature reached 32 °F at lunar sunset, and was commanded on in the forced-on mode at 14 °F, as planned.

Page 3-15: Lunar surface erosion resulted from the descent engine exhaust as observed in previous lunar landings. Dust was first noted during descent at an altitude of 100 feet but did not hinder visibility during the final approach.

The lunar module footpad penetration on landing appears to have been greater than that observed on previous Apollo landings. Bootprint penetrations for the crew ranged from 1/2 to 3/4 inch on level ground in the vicinity of the lunar module to 4 inches on the rims of small craters. Lunar soil adhered extensively to the crewmen's clothing and equipment as in earlier Apollo missions. Tracks from the modular equipment transporter were 1/4 to 3/4 inch deep and were smooth.

The Apollo simple penetrometer (also used as the geophone cable anchor) was used for three penetration tests. In each case, the 26 1/2-inch-long penetrometer could be pushed to a depth of 16 to 19 inches with one hand and to the extension handle with both hands. No penetration interference attributable to rocks was encountered.

Page 3-16: The modular equipment transporter stability was adequate during both traverses. Rotation in roll was felt by the crewman through the handle but was easily restrained by using a tighter grip if the rotation sensed was excessive. The jointed legs in the front of the transporter operated as expected in that they flexed when hit and would spring back to the vertical position readily. The smooth rubber tires threw no noticeable dust. No dust was noted on the wheel fenders or on top of the metal frame of the transporter.

Page 9-15: After the site had been selected, the lunar dust presented some problems for the remainder of the Apollo lunar surface experiments package deployment. The suprathreshold ion detector experiment sub-pallet had dust piled up against it and into the hidden Boyd bolt, which must be reached blind with

the hand tool. Several minutes were wasted before the suprathreshold ion detector experiment was successfully released from the sub-pallet.

Page 9-13: The wheels did not kick up or stir up as much dust as expected before the flight. Very little dust accumulated on the modular equipment transporter.

Page 9-11: Dust.- Dust on the lunar surface seemed to be less of a problem than had been anticipated. The dust clings to soft, porous materials and is easily removed from metals. The pressure garments were impregnated with dust; however, most of the surface dust could be removed. The little dust that accumulated on the modular equipment transporter could easily be removed by brushing. The lunar map collected dust and required brushing or rubbing with a glove to make the map usable.

Page 9-10: On previous missions, dust carried into the cabin during ingress was a problem. However, it did not seem to be a problem on Apollo 14, perhaps because there was less dust on the lunar surface, or perhaps, being aware of the problem made the crew more meticulous in contamination control than they would have been otherwise. Care was taken to remove the dust from the pressure garment assembly and other equipment before entry into the cabin. The brush that was used for pressure garment assembly cleaning was adequate. The technique of stomping the boots against the lunar module ladder seemed to help to some extent.

Page 9-8: To provide a soft landing, a delay of about 2 seconds was allowed between acquisition of the contact lights and activation of the engine stop button. Touchdown occurred at shutdown with some small dust-blowing action continuing during engine thrust tailoff or decay. The landing forces were extremely light and the vehicle came to rest within 1 degree of zero in pitch and yaw attitudes, and with a 7-degree right roll attitude (northeast tilt). (Refer to figure 8-2.)

Some lineations were evident in the area of thrust impingement on the surface along the final track and in the landing area. As might be expected, these areas are generally coincident with those in which blowing surface dust was noted at low altitudes. The area in the vicinity of the descent engine after touchdown appeared to have been cratered only to a depth of about 6 inches and, as photographs show, only in a small, well-defined area.

Page 9-7:

The manual descent program was initiated at an altitude of 360 feet at a range of approximately 2200 feet short of the desired target. The lunar module was controlled to zero descent rate at an altitude of about 170 feet above the terrain. Translation maneuvers forward and to the right were made to aim for the point originally targeted. Although this area appeared to be gradually sloping, it was, in general, smoother than the ridge south of the target. The fact that no dust was noted during the translation was reassuring because it helped corroborate the primary computer altitude. Velocity on the cross pointer was about 40 ft/sec forward at manual takeover and this was gradually reduced to near-zero over the landing point. A cross velocity of about 6 ft/sec north was also initiated and gradually reduced to zero over the landing point. The cross pointers (primary guidance) were steady and their indications were in good agreement with visual reference to the ground. Control of the vehicle in primary guidance attitude-hold mode and rate-of-descent mode was excellent at all times. The use of the lunar landing training vehicle and the lunar module simulator had more than adequately equipped the pilot for his task. It was relatively easy to pick out an exact landing spot and fly to it with precise control.

Blowing surface dust was first noted at an altitude of 110 feet, but this was not a detrimental factor. The dust appeared to be less than 6 inches in depth and rocks were readily visible through it. A final descent from 100 feet was made at a descent rate of 3 ft/sec, with a deliberate forward velocity of about 1 ft/sec and, essentially, zero cross range velocity. The forward velocity was maintained until touchdown to

preclude backing into any small craters. To provide a soft landing, a delay of about 2 seconds was allowed between acquisition of the contact lights and activation of the engine stop button. Touchdown occurred at shutdown with some small dust-blowing action continuing during engine thrust tailoff or decay. The landing forces were extremely light and the vehicle came to rest within 1 degree of zero in pitch and yaw attitudes, and with a 7-degree right roll attitude (northeast tilt). (Refer to figure 8-2.)

Some lineations were

Page 7-14: A vacuum cleaner assembly and cabin fan filter, used for the first time, along with the normal decontamination procedures eliminated practically all of the objectionable dust such as that present after the Apollo 12 lunar docking. The fans were operated for approximately 4 hours after lunar docking.

Page 14-47: During the first extravehicular activity, the crew deployed the thumper and geophones and attempted to fire the initiators with the following results: 13 fired, 5 misfired, and 3 initiators were deliberately skipped to save time. In some instances, two attempts were made to fire each initiator. In addition, for the first four or five firings, it was necessary to squeeze the firing switch knob with both hands. Subsequently, the excessive stiffness seemed to be relieved and one-hand actuation was possible.

The most likely causes of the problem are associated with the detent portion of the selector switch (fig. 14-31) and dirt on the firing switch actuator bearing surface. The selector switch dial can reposition out of detent in the course of normal handling because of the lack of positive seating in the detent for each initiator position. For an initiator to be fired, the selector switch must provide contact to the proper unfired initiator position. Examination of the qualification unit has shown that the detent is positioned at the leading edge of the contact surface so that any movement toward the previous position will break the contact. Also, the lightening holes in the firing switch knob make it possible for dirt to get onto the Teflon bearing surfaces, temporarily increasing the force required to close the switch (fig. 14-31).

Corrective action for Apollo 16 consists of adding a positive detent mechanism, properly aligned with the selector switch contacts, and dust protection for the firing switch actuator assembly. The thumper is not carried on Apollo 15.

Page 15-1: On previous lunar missions, lunar surface dust adhering to equipment being returned to earth has created a problem in both spacecraft. The special dust control procedures and equipment used on this mission were effective in lowering the overall level of dust.

Page A-2: A vacuum cleaner with detachable bags was added to assist in removing lunar dust from suits and equipment prior to intravehicular transfer from the lunar module to the command module after lunar surface operations, and for cleanup in the command module.

Apollo 14 Technical Crew Debriefing February 17, 1971

References to dust:

Page 9-17:

SHEPARD: I believe that we had less problem with dust than they've had before. I think it's because, as we comment later on, the surface of the general area in which we landed was less dusty, that is, exclusive of the dust around the rim of craters. The general area appeared to have less dust and we certainly had no problems with dust at touchdown. I referred to the cross pointers during the final stages of the descent at less than 100 feet, but only to assure myself that I had the done the best I could as far as cross velocity was concerned. The dust was obvious, but you could also see the rocks through the dust. We had no problems here. I think we had a touchdown that was very light, just a little plop when we hit the ground.

Page 9-18:

MITCHELL: That's what we had practiced because of the dust problems, When we went into the ROD mode, we leveled out on ROD and kept it flying on over until I was sure we were to Triplet and into that area where we wanted to land, and we started on down. I might add that looking at the film of the descent last night the dust problem appears a lot worse on the film than it appeared to me on the window. I thought I could see a lot better.

SHEPARD: You probably would, in any event, because the camera I only looking at one spot and you don't have the more general feeling that your eyeball gives you.

MITCHELL: Right. But just looking out the window you can see the dust is no great problem at all.

Page 9-28:

SHEPARD: There was a lot of dust on one Boyd bolt – the one that is visible – which I was able to knock off and get the tool in there to get that one unlatched. But the one that's blind – the one to which the tool has to pass into a channel to get – was just very difficult to get into. I don't know just what they can do except maybe not put that one on – if they can satisfy the vibration requirements of launch and hold that baby down with only three bolts, all of which are visible and all of which can be cleaned out just by picking up the package up and knocking it a little bit. You can see the dust going out of that thing...

MITCHELL: We just turned it over because it was a two man operation. We turned it over, beat the dust out of it, and held it in the light so Al could see it; and finally he was able to wiggle it.

Page 10-38:

SHEPARD: So we did collect some samples and got back and closed out. We found that the brush that we had planned to use to brush the dust off the suits was effective. It did take off the first layer of loose dust. I would suggest that jumping up and down on the footpad or stomping one's boots on the ladder is just as effective with respect to the boots themselves. Just banging the boots against the ladder is enough to shake off that dust. From the boots on up the lower legs, backs of legs, insides of the thighs, and so forth, the brush did appear to be fairly effective in getting the first layer off.

Page 10-39:

MITCHELL: And effective in the sense that, after the fact, we didn't end up with too much dirt in the LM. Although we had the ETB cable all over the ground, stomping on it, and covering it with dust, when it came up into the LM it didn't have a great deal of dust on it. It didn't shake a great deal of dust in the

LM which was very surprising to me. I don't know why it didn't, but it didn't. Either just the tensions and the vibration of it vibrated most of the dust off, or you shook it off.

SHEPARD: The part that had dust on it never got inside.

Page 10-42:

SHEPARD: We did find that we had to take the boots off because there's so much dust in your overshoes that we did take those off before we went to bed.

MITCHELL: In training, we thought that maybe that was an unnecessary time-consuming step and we'd probably sleep with the boots on, but they were so covered with crud that I didn't want it sifting down in my face during sleep. We took them off.

Page 10-49:

SHEPARD: I really expected more dust to be collected by the tires and thrown up on the MET. That didn't turn out to be the case at all. We dragged it through some fine-grained stuff near the edges of the smaller craters; and although the tires sunk in more, in that fluffy, less dense regolith, it still didn't throw up a lot of dust.

MITCHELL: Dust didn't adhere in any appreciable amount to the rolling surface of the tires. The MET seemed to mash it down, but it didn't adhere. It didn't throw out a rooster tail as we might have suspected.

SHEPARD: Even at fairly good speeds.

Page 10-53:

SHEPARD: I did what I was supposed to do and put it back in the bag. I was surprised that there was little adherence of the surface dust. I expected a little bit more. It didn't adhere very much.

Page 10-57:

SHEPARD: You were making an attempt to do a triple core. It looked as if Ed and I should have changed positions because it was not soft enough for him and it was too soft for me. We practiced digging the trench in the edge of the crater, because it was mechanically and physically easier to dig the trench on the side of the crater. By the side of the crater, the dust just wasn't cohesive enough to get a good sample of soil mechanics. We probably did get a pretty good idea of what the composition of the soil was, because it wouldn't hold more than 60-degree angle in the side of the trench before it all started falling back down in.

Page 10-65:

SHEPARD: We had no problem with recharge, changing out batteries, PLSS feedwater collection, or dust control inside the cabin. We seemed to have a little extra dust on the floor. Other than that, it was not too bad.

MITCHELL: A lot of that dust, I believe, kind of got whipped outside when we did our dump repress. The cabin dust kind of swirled around. A lot of that went out through the relief valve at that point, which might have reduced it somewhat.

SHEPARD: We did clean and lubricate the PGA seals at the neck rings and the wrist rings. I think that was a good way to go. We didn't get an awful lot of dirt, but we did get just enough of a smudge on the wiping cloth to indicate there was a trace of dust there, so I think that's a good way to go. It doesn't take too much time and I recommend doing that.

MITCHELL: Yes, I think it's interesting – I don't know whether that has anything to do with it or not – but my EMU leak rate was less on the second EVA than on the first. That is completely inexplicable to me. The only thing that was different was that we lubricated the rings. Whether that has anything to do with it or not, I don't know. As I recall, I had only 0.15 leak rate on the second EVA – I mean on the pressure check for the second EVA. My leak rate was much closer to specification during the second EVA than during the first.

Page 10-67:

MITCHELL: I think the longer time involved in launch preparation was probably because we know we had a lot of time to do it. It had some bearing on it Deke. We wanted to do a good stowage job. We had the time to do a good stowage job, so we proceeded to do it. In y mind, part of that time was because those weigh bags, the contingency sample, and some of those things were awfully filthy; and I wanted to make sure that they were well stowed out of the way so that we wouldn't have a dust problem when we got into orbit. That was one of the things in my mind when it came to proper storage.

SHEPARD: We had a good stowage there – no question about it. We just took a little extra time to do it. Everything was in the right place. We did have more rocks than we practiced with, those extra bags. We have done that before, and you know it wasn't anything new. It just took longer doing it. We had no hang-ups anywhere - just wanted to get it right.

Page 13-2:

MITCHELL: I think we probably got our suits off a little earlier than the checklist called for. I'd recommend that to future crews: get the suits off as soon as you can. It certainly improved our mobility. One of the first things you do after you get the tunnel open is get those suits off and get them brushed down and stowed. It makes it a lot roomier in the cockpit and gives you easier access to everything in the cabin. We were a little bit hesitant when we planned, in the time line, to remove our suits that early in the game because of the dust problem. But we went ahead, took a chance on it, and wrote it that way. Since we didn't have any dust, it worked out real well.

Page 13-3:

SHEPARD: I don't know exactly why that was, but it did take a little extra time to get those things off. I guess because it's easier to bend the upper torso down and get the V-shape necessary to get your fanny and backside out of the suit under one g. We struggled with those a little more than we had in the past. The vacuuming procedures seemed to be satisfactory. I think with each pass with the vacuum brush, you could see the dust coming off. In other words, you make a pass or two on the side for example, or on the back, and you'd see the loose dust, off the top, that was still there, come off into the vacuum cleaning bag. So that is an effective procedure. At least, you remove just one more layer of dust. Of course, the smudges are still there. I think that, as a general comment, using the procedures that we used, as written, we got very little dust back in the command module. The things that were dirty, the suits, were put away in bags right away. Stu was ready for them and they went into the bags, the L-shaped bag. The rock boxes and so on were in the extra decontamination bags. I thought the command module was remarkably clean. It was a lot cleaner than I expected it to be.

ROOSA: I thought it was exceptionally clean. When you passed the suits over to me, they were dirty, but they weren't dusty. In other words, there was no loose dust coming off the suits. The only dust that came off was when I was shoving them into the bag; but that was not a contact thing. There was nothing floating free at all from the suits.

SHEPARD: We felt the procedures that were suggested, perhaps by Apollo 12, and carried out in our time line, certainly reduced the dust to a minimum.

MSC05162
Apollo 15 Mission Report
December 1971

References to dust:

Page 20: Six days after startup, on August 6, the experiment package was subjected to its first lunar eclipse. This was a total eclipse and the package was closer to the center of the umbra than any previous Apollo lunar surface experiments package during any previous eclipse. During the eclipse, sun shield temperature of the central station dropped from plus 140 °F to minus 143 °F with accompanying rates of change of temperatures up to 260 °F per hour. The central station engineering measurements provided data on the varying solar intensity throughout the eclipse. The instrument measured a lunar surface temperature change of 330 °F during the eclipse. There was no indication of significant dust collection on the instrument's solar cells as a result of the lunar module ascent.

Page 30: The polarizing filter for the Hasselblad electric data camera could not be installed because of excessive dust in the bayonet fitting

Page 72: Landing radar outputs were affected at an altitude of about 30 feet by moving dust and debris.

Page 94: At the beginning of the second extravehicular activity, the battery 1 cover had closed automatically, as expected. Battery 2 apparently had not cooled down enough and the cover was still open. It was closed manually powering up the vehicle. When the vehicle was activated, battery-1 temperature was 68 degrees F and battery-2 temperature was 78 degrees F. The difference was probably caused by the difference in dust accumulation on the thermal mirrors. These temperatures are consistent with predicted cool-down rates with the covers open and warm-up rates with the covers closed. During the second traverse, the battery-1 and battery-2 temperatures increased to 92 °F and 98 °F, respectively. The battery covers were opened at the conclusion of the second extravehicular activity period.

At the beginning of the third extravehicular activity, both covers were open. Little battery cool-down had occurred, probably because of further dust accumulation on both battery mirrors, although the battery covers had been closed for the traverses. The covers must not have been closed tight enough against the Velcro edges to keep dust off the mirror surfaces. Only a small amount of dust on the surface will preclude the desired cool-down. At the conclusion of the traverse, battery-1 and battery-2 temperatures had increased to 108 °F and 113 °F, respectively, which is an acceptable level.

Page 95: Lunar dust on the television camera lens caused a halo effect and sun reflected glints. Improvement in picture quality was restored periodically after the crew brushed the lens.

Page 102: Descent rate reduction was initiated at a height of about 200 feet, and visual reference was maintained by watching several fragments on the lunar surface which were located 30 to 40 meters (100 to 130 feet) west of the selected site. A trace of blowing surface dust was observed at a height of 130 feet with only a slight increase down to 60 feet. Beginning at this altitude, out-of-the window visibility was completely obscured by dust until after touchdown.

Page 110: The vehicle could be maneuvered through any region very effectively. The surface material varied from a thin powdered dust [which the boots would penetrate to a depth of 5 to 8 centimeters (2 to 3 inches) on the slope of the Apennine Front to a firm rille soil which was penetrated about 1 centimeter (one-quarter to one-half inch) by the boot. In all cases, the rover's performance was changed very little.

Acceleration was normally smooth with very little wheel slippage, although some soil could be observed impacting on the rear part of the fenders as the vehicle was accelerated with maximum throttle. During a "Lunar Grand Prix", a roostertail was noted above, behind, and over the front of the rover during the acceleration phase. This was approximately 3 meters (10 feet) high and went some 3 meters forward of the rover. No debris was noted forward or above the vehicle during constant velocity motion. Traction of the wire wheels was excellent uphill, downhill, and during acceleration. A speed of 10 kilometers per hour could be attained in approximately three vehicle lengths with very little wheel slip. Braking was positive except at the high speeds. At any speed under 5 kilometers (2.7 miles) per hour, braking appeared to occur in approximately the same distance as when using the 1-g trainer. From straight-line travel at velocities of approximately 10 kilometers per hour on a level surface, the vehicle could be stopped in a distance of approximately twice that experienced in the 1-g trainer. Braking was less effective if the vehicle was in a turn, especially at higher velocities.

Dust accumulation on the vehicle was considered minimal and only very small particulate matter accumulated over a long period of time. Larger particles appeared to be controlled very well by the fenders. The majority of the dust accumulation occurred on the lower horizontal surfaces such as floorboards, seatpans, and the rear wheel area. Soil accumulation within the wheels was not observed. Those particles which did pass through the wire seemed to come out cleanly. Dust posed no problem to visibility.

Page 267: The vehicle is powered by two silver-zinc batteries, each having a nominal voltage of 36 Vdc and a capacity of 120 ampere hours. During lunar surface operations, both batteries are normally used simultaneously on an approximate equal load basis. These batteries are located on the forward chassis and are enclosed by a thermal blanket and dust covers. The batteries are monitored for temperature, voltage, output current, and remaining ampere hours on the control and display panel. Each battery is protected from excessive internal pressures by a relief valve set to open at 3.1 to 7 psi differential pressure. The circuitry was designed so that if one battery fails, the entire electrical load can be switched to the remaining battery.

MSC04561
Apollo 15 Technical Crew Debriefing
August 14, 1971

References to dust:

Page 9-14:

SCOTT: I could see dust – just a slight bit of dust. At about 50 to 60 feet, the total view outside was obscured by dust. It was completely IFR. I came into the cockpit and flew with the instruments from there on down. I got the altitude rate and the altitude from Jim, and rounded out to 15 feet and 1 foot per second for the last portion. When Jim called a CONTACT LIGHT, I pushed the STOP button, which had been in the plan.

Page 9-18:

SCOTT: I think if you had to move from one point to another, you could do it quite well. I would recommend maintaining an altitude of at least 150 feet so you don't get into the dust problem. I think dust is going to be a variable with landing sites.

Page 10-7:

SCOTT: Maybe a little bit, but at that time, the (LM) cabin wasn't too crowded, nor was it dirty. I think there was another – maybe an advantage for sleeping. We got to sleep the first night (on the surface) in a clean cabin.

Page 10-18:

SCOTT: The first order of business after we got repressed was to go through the checklist and do the EVA post and try and come up with a plan on how to handle all the dirt in the cabin. We were pretty dirty. We had planned prior to the flight to take the jettison bags and step onto them with the suits to keep the lower portion of the suit isolated from the rest of the cabin. Our legs from about thigh down were just completely covered with dirt. I guess the dust brush worked fairly well. I got the most part of it, but we were still pretty dirty.

SCOTT: We could have combined some things as we did do later. We were going sort of slow, feeling our way around the cabin trying to get settled down to some sort of system to control the dirt and stay organized. I think the jettison bags over the legs worked fairly well. I think we kept the majority of the dirt out of the cabin and kept it in the bag. We just cinched the bags up around our legs. It was no problem getting in and out of our suits with the bags on them. We took another jettison bag stuck it up on the midstep, and I stood on that to keep my CWG clean. You stood on one of the OPSs to keep off the floor, which was pretty dirty.

Page 10-22:

SCOTT: When we woke up the next morning, I was surprised how clean the spacecraft was, I think most of the dust had been removed. That's right. It surely had.

IRWIN: That night, it was fairly clean, you know, when we went to sleep. I don't know how all the dust got out of there.

SCOTT: Yes, the ECS does a pretty good job of cleaning the place out. The smell was gone. When you took the helmet off, you could smell the lunar dirt. It smelled like – the nearest analogy I can think of is gunpowder. But that had all cleaned out. By the time we got up the next morning things were in pretty good shape.

Page 10-27:

IRWIN: I don't know. A little bit of that water on the floor there might have reduced the amount of dust on the floor. The floor was always kind of moist.

SCOTT: Yes, that's true. I might comment that lunar dust is very soluble in water. It seems to wash off very easily. I would say if you ever have a connector problem that was really stiff, you could take the water gun and spray it in and loosen it up.

IRWIN: We did not loosen the suit connections for EVA-2 but we did for EVA-3.

SCOTT: It seemed like they were still working pretty well. The connectors got covered with dust – one of mine. One of the primary problems was the LEC. One EVA-1, when I passed you the rock box on the LEC, I just got covered with dirt all down the front. The result was pretty dirty connectors. We tried to brush them off and clean them off. We found that the booties which had been placed over the PLSS connectors were good protection from dirt. A recommendation would be to put booties over all the connectors or some sort of protective device. In the old days they had a bib to keep them clean – or for double protection, I guess. Something like that would surely prevent problems later on and would save time cleaning the connectors. They sure get dirty, and I am just not sure there is any way to prevent them from getting dirty. If you are going to go out there and do the job, you are going to get dirty. If you try to keep everything clean, you are just not going to be able to do the job on time. I think those little booties are a pretty good idea. They were not problem on the donning and doffing.

Page 10-30:

SCOTT: ... We did lubricate all the wrist rings, connectors, and helmet rings on this one, which was easy. I think that little dab of lubrication material works just fine.

IRWIN: It was easy and I think it paid off because it was very easy to make the connections.

SCOTT: We never had a problem with the zipper at all. Both zippers worked very good throughout the flight. I don't remember ever having your zipper hang up.

Page 10-36:

IRWIN: ...I was pulling on the lanyard with one hand (to try to release the LRV from the LM) and trying to take pictures with the other. And of course I fell down there once because I tripped backing up in that soft soil.

SCOTT: Yes, but you recovered gracefully.

IRWIN: Well, you helped me up.

Page 10-43:

SCOTT: Well, I didn't have any problem getting up and I could get to the first rung with a leap with my bag, with a good spring. And another problem I found with the LEC was when we transferred the ETB at the end of EVA-1, the LEC line had been in the dirt and that's the dirtiest I got, I think, in the whole trip. It just spread dust all up and down the front of me as the thing went up and I guess I could have grabbed that one handle and held it, but that would have been putting an awful lot of force on you and I think that the effort expended by the guy in the cabin to hold that stuff up is not worth it. I'd recommend just taking up the bags one by one manually, putting them on the porch.

IRWIN: How about the pallet? We never transferred a pallet, I don't believe.

SCOTT: No. And I thought about that afterwards too. If you want to free your hands completely, you can have a small wrist tether with an elastic band on it just like in the command module and hook it to the wrist tether, and it wouldn't be any problem at all taking it up, with both hands free to hold on the rail. It would save a lot of time, a lot of dirt, and a lot of effort.

Page 10-49:

IRWIN: Then I attempted to take the SIDE out. I had trouble with the UHT locking into the SIDE. I didn't realize this until I got it just about out to the station, and I was about to put it down when it dropped off the UHT. I hope it didn't interfere with the experiment itself. I tried to engage the UHT again and again had problems. It fell off the UHT about three times there. It was very frustrating. I don't know, maybe there was some dirt on the UHT that interfered with the engagement. We got the screen down, got the SIDE positioned, pulled the safety pin, checked its level, and aligned, reported to Houston, went back to the central station, and pressed the shoring switch. I couldn't really check the amps zero because there was just too much dust on the gauge. Might make a comment here that that the dust covers that were put on the various experiments really paid off, because we were in probably the worst situation I have seen as far as dust and soil, but they kept all the Boyd bolts clear of any dust.

Page 10-55:

SCOTT: I think this is the point at which I transferred the LEC and SRC with the LEC and got all dirty.

Page 10-65:

SCOTT: ...and I guess the problem with the camera – we brought it back for people to look at – I think the problem is definitely dirt in the drive mechanism. I fiddled with it that night and got it going. The next day, it hung up again. After we got into orbit, we worked on it some more, and you could see that the wheel exposed by the Reseau plate was hanging up. If you put your fingernail in there and triggered it, it would get going. I think with the amount of dirt that you have, and the fact that the camera is level with the area in which you work when you roll up the bags, you get dirt, in the camera. I think we ought to put some little Beta booties over the top of the camera to keep it clean, at least over the joint there where the film mag goes on. They were getting so dirty that every time we reset our f-stop and lens, I had to brush mine off with my finger. I had to wipe it off, because I couldn't see the settings on the camera, it got so dirty. I'd recommend maybe Velcro tabs and a little piece of beta right up on top of the camera to keep that mechanism clean.

IRWIN: Dust accumulation also gave a problem as far as removing the film mag from the camera. There were several times where it was very difficult to release it.

SCOTT: I think the camera would be better off if we'd protect it a little bit better. We used the lens brush on the cameras, and they were very good.

IRWIN: On the TV also.

SCOTT: On the TV also. The lens brush is really a good brush. It cleaned it off very well. The dust brush, to clean off the suits seemed to work pretty good. It got the gross dirt off. It didn't get everything. I guess it also worked quite well on the LRV and the LCRU mirrors – cleaned them off pretty well.

Page 10-74:

SCOTT: This summarizes tool operation – mechanically – how they work. They all work just fine. When my palms got dirty, I had a difficult time manipulating the handle squeeze and the opening and closing because of all the dirt in the tongs. And so, about half way through EVA-2, I switched to the other set of tongs which were clean. That helped quite a bit.

Page 10-76:

IRWIN: I guess we commented on the general dust condition on the Rover. We just took a series of pictures of the dust accumulation on the Rover after the EVA.

Page 13-5:

SCOTT: Everybody checked their connectors and plugs. I might add that my restraints were pretty dingy at that time. We all had dirt on those things. They were getting a little tough to work. That was prior to the hatch operation.

Page 13-7:

SCOTT: The vacuum cleaner worked pretty good I thought. We brought the vacuum cleaner over to the LM and just turned it on and let it run. It did a pretty good job of clearing the dust out. We were pretty dirty.

WORDEN: The vacuum cleaner is a big bulky piece of gear, we were all surprised at how effective it was in flight. It really worked out well.

SCOTT: I thought it did too. We stowed the CDR and the LMP suits in the L-shaped bag, to get the dirt out of the cabin.

Page 13-8:

SCOTT: We left Al's suit out because of the bulk. Al's suit was still clean. We put the filter on the cabin fans and turned the cabin fans on. We already talked about the foreign object in the cabin fan which we heard periodically. When the cabin fan was running with that filter, I thought it did an excellent job of cleaning the cabin. You could sure see the particulate matter floating around there after we finished the transfer.

WORDEN: When we got up the next morning, the cabin was as clean as it was before the initial separation.

Page 20-5:

SCOTT: I think the wire wheels worked very well relative to traction. The only wheel slippage that we noted occurred in hard turns at high rates where the momentum of the vehicle would keep it going straight until the speed slowed enough for the wheels to catch. One time we had the wheels spinning in the soil; they were digging in opposition.

Page 20-6:

SCOTT: It was really deep there, wasn't it? The wire wheels are excellent. They picked up very little dust. We did have an accumulation coming up under the fenders. I think the fenders are well designed and quite adequate. It seems to keep the dust off pretty well. You had a chance to see if there was a rooster tail behind the Rover when I drove. Did you see much?

IRWIN: One time I did comment on the rooster tail. I guess it was on the Grand Prix.

SCOTT: How much was it?

IRWIN: It kicked up, I'd estimate 15 feet in the air. We had one over your head and it impacted in front of you.

SCOTT: I didn't notice it looking forward.

IRWIN: It was really impressive. Too bad the sequence camera didn't operate.

SCOTT: I didn't notice, when we were driving at higher rates, any dust or dirt coming into our view.

IRWIN: I think at that particular time, you were just doing a max acceleration, and that's when it kicked up the rooster tail.

SCOTT: Auto max acceleration. I don't remember at any time feeling a particular wheel slippage. I think the vehicle accelerates very well, probably as we expected and very similar to the centrifuge runs we had under one-sixth g simulation. The braking is more responsive than I expected. When I did that little Grand Prix exercise and put the brakes full on, it came to a stop I would say comparable to the one g trainer. I expected to slide more. The braking was excellent.

Page 20-17:

SCOTT: The LCRU battery was fine. Electrical-mechanical connections all worked well. Dust generated by the wheels – we'd have to say that the dust was minimum. We did have to dust off the mirrors quite a bit, but it was far less than I expected to see.

IRWIN: Yes. I don't know whether all that dust was created by the wheels. It could have been the dust created by us just getting on and off because we kicked a lot of dust, you know.

SCOTT: Yes, that's right. I really didn't see much dust going forward from the wheels. I could see it hitting the fenders, and it seemed like the fenders did very well. I really didn't see anything going forward.

IRWIN: No. That's why I had difficulty accounting for the dust that was on the mirrors.

SCOTT: Yes. Except it could have been very fine over a long period of time that we couldn't see. The dust accumulation was minimum. It was fine dust. The little decal with the procedures, just forward of the hand controller, was almost completely covered most of the time. If I used it, I had to brush it off.

IRWIN: There was one mirror that was broken on the TV camera. Cracked. One of the small squares was cracked. I don't know when that occurred.

Page 21-5:

SCOTT: PLSS PGA operations. Everything connected and disconnected all right, except when we got dust and dirt. Then, sometimes it would stick, but in general, I thought it worked great.

Page 20-6:

SCOTT: ...I think it was a good idea that they put that plastic plate over the flags in the RCU, because that sure got dirty.

IRWIN: I had some difficulty seeing my flags with the visor down.

SCOTT: I did too. I found that it was the dust accumulation.

IRWIN: I had to actually strain against putting my nose against the visor to look down and see the flags. I guess, also, I felt that when I was getting out of the LM when it was in the shade, I preferred to have the visor up so I could see better. Then I put the visor down after I got out.

SCOTT: I did the same thing. As a matter of fact, with the visor down in the shade, you couldn't see at all.

MSC07230
Apollo 16 Mission Report
August 1972

References to dust:

Page 4-10: The passive seismic experiment (S-031) was deployed as planned. All elements of the experiment have functioned normally with the exception of the thermal control system. Two days after activation, the temperature increased markedly beyond the controller set point and eventually exceeded the range of the sensor, 61.4 ° C. The temperature stabilized at night to 52.2 ° C. Photographs of the instrument show the shroud skirt to be raised at several places (fig. 4-5); further, dust was inadvertently kicked onto the skirt after the photographs were taken. These factors are believed to be responsible for the abnormal temperatures. The temperatures are not expected to affect instrument life or seismic data, but will degrade the tidal data.

Page 4-19: The plastic in all panels of the [cosmic ray detector] experiment was degraded by heating above the design limit of 54° C, at which temperature degradation begins. The high temperature was most likely caused by a film accumulating on the thermal control surface, in addition to lunar dust. Analysis of the film has not been completed.

Page 4-21: The solar wind composition experiment (S-080) for this mission differed from those of previous missions in that pieces of platinum foil were attached to the specially prepared aluminum foil used to entrap noble gas particles. This was done to determine whether or not the platinum foil pieces could be cleaned with fluoridic acid to remove lunar-dust contamination without destroying rare gas isotopes of solar wind origin up to the mass of krypton.

Page 6-13: The vacuum cleaner failed after becoming clogged with dust. The vacuum cleaner was cleaned postflight and it operated properly. The design of the vacuum cleaner is such that lunar dust can clog the impeller.

Page 8-2: On the second traverse, the attitude indicator pitch scale fell off, but the needle was still used to estimate pitch attitudes (see sec. 14.6.4). Incorrect matching of switches caused a loss of rear-wheel drive. Correct switch configuration returned the vehicle operation to normal. The crew noted that the forward wheels tended to dig in when attempting to climb slopes without rear-wheel power. The right rear fender extension was knocked off and, thereafter, dust was thrown up from the right rear wheel and covered the crew, the console, and the communications equipment. Midway through the second extravehicular traverse, the ampere-hour integrator for battery I began indicating about four times the normal battery usage. Because of higher-than-desired temperatures on battery I, a series of procedures were initiated to lower the load. These procedures probably caused the inadvertent removal of drive power from a pair of wheels, thereby losing two odometer inputs and the associated static range, bearing, and distance displays (see sec. 14.6.3). The problem cleared when the normal switch and circuit breaker configuration was restored.

Page 9-18: The lunar module velocity was decreased rapidly as Double Spot Craters were passed. The Commander controlled the lunar module with the attitude hold control mode at about 250 feet altitude and maintained a very slow forward velocity. The rate of descent at this time was about 11 feet per second, and this rate was quickly reduced to 5 feet per second. From 200 feet altitude to the surface, the Commander did not look inside the vehicle. Small traces of dust were evident at approximately 80 feet, and the dust increased all the way to touchdown; however, the vehicle had lunar contact before the visibility obstruction due to dust prevented the Commander from seeing craters or small boulders on the surface.

Page 9-21: Subpackage 2 was laid flat on the surface so that the radioisotope thermoelectric generator could be serviced. The subpackage was then reoriented in order to provide the Lunar Module Pilot a clear access path to the radioisotope thermoelectric generator housing. The reorientation may have forced dust into the locking collar which, later, could have prevented the Lunar Module Pilot from making a positive lock-on to the carrying bar. The radioisotope thermoelectric generator was fueled and then the hike to the Apollo lunar surface experiments package deployment site was begun. About half-way out, subpackage 2 separated from the bar and fell to the lunar surface. The subpackage was examined and, when no damage was found, it was reconnected to the bar and carried to the deployment site.

Page 9-35: The major concern with housekeeping, on post-extravehicular doffing of the pressure garment assemblies, was dust in the cabin. A jettison bag was placed over both legs of the suit and the suits were laid on the engine cover as prescribed. There was a considerable amount of dust on the suits around the neck, around the helmet, on top of the oxygen purge system, and on the back of the portable life support system. Most of this dust ended up on the floor of the lunar module. The dusty floor was cleaned by wetting a rag, caking the dust into mud, and picking it up in the rag; however, there was no way to remove the dust from the Velcro on the floor. Since the Velcro does not restrain the crew to the floor in zero gravity, it is not needed.

Because of the dust problem, the lower limbs of the liquid-cooled garments were dirty. Each crewman had to help the other crewman remove his suit. Consequently, there was appreciable dust on each crewman's hands and up to the elbows of the liquid-cooled garments. There is no way to avoid this problem; the crewmen's hands could not be cleaned while on the lunar surface after the first extravehicular activity.

The dust was always a major cause of concern in that the crew never knew when dust might get into some equipment and compromise the lunar module or extravehicular mobility unit environmental control systems. A program to improve housekeeping procedures must be actively pursued to reduce the amount of dust in the spacecraft as rapidly and as simply as possible.

Page 9-36: The crew had a continual problem of donning and doffing the gloves because there was dust in the wrist ring pull connectors (see sec. 14.3.4). Even though the connectors were blown out repeatedly and appeared to be free of dust, it was extremely hard to pull the wrist ring devices in or out and, in fact, rotate the glove on or off. Some type of wrist dirt seal over these connectors is necessary.

Page 9-37: The extravehicular mobility unit visors provided excellent protection from the sun and shielding during the S-band lunar communications relay unit antenna alignment. On the third extravehicular activity, the Commander's extravehicular mobility unit overvisor would not retract; this was due to dust that had accumulated on the helmet as a result of the loss of a rear fender from the lunar roving vehicle.

Because of extensive dust coverage, the Commander's remote control unit was difficult to read. An attempt was made on the surface to dust it off with a glove and the abrasive dust badly scratched the remote control unit face. After the remote control unit oxygen gage was scratched, it was impossible to read oxygen quantity on the lunar surface and it could be read only marginally inside the lunar module. A scratch resistant material should be used to cover the remote control unit face.

Page 9-38: Because of the loss of the rear fender, both of the extravehicular mobility units, (the oxygen purge system, the top and sides of the suit, and the front of the connectors) were covered with small dust clots. The only method discovered to satisfactorily remove the dust from the pressure suits was to beat the appendages of the suit against a surface area such as the lunar roving vehicle tool pallet, the lunar module

landing gear struts, or the lunar module ladder. Dusting with the brush caused a coated layer of dust. Therefore, dusting with the dust brush should be the last resort in cleaning the suits.

The sample collection bag attachment to the tool harness was unsatisfactory. On one occasion, one half-full bag of rocks fell off the tool harness and, fortunately, lodged between the rear fender and the frame of the lunar roving vehicle. Because the Velcro is subject to clogging with dust, the manner in which it is used to attach the bags to the portable life support system tool harness will not assure positive retention of the sample collection bags on the portable life support system tool harness. This is discussed further in section 14.4.8.

Page 9-41: The right rear fender was lost at station 8. Subsequently, the right rear wheel produced a shower of dust over the vehicle which appears in the 16-mm motion picture photography as falling snow. However, a great deal more dust was actually produced by the wheel than shows up in the film. The crew and the front of the vehicle, particularly the instrument panels, were covered with dust. The instrument panel and the start, stop, and closeout decals had 1/4 inch of dust over them at the completion of the third extravehicular activity.

Page 9-42: The battery covers were opened at the completion of each extravehicular activity. Opening the battery covers threw dust onto the battery mirror surfaces; therefore, the mirrors were completely brushed after each extravehicular activity and were brushed twice at final rover parking after completing the third extravehicular activity. Even though the mirror surfaces were brushed as well as possible, battery 2 temperature caused the actuation of a caution and warning flag while driving to station 11/12.

Page 9-50: During the equipment transfer, a large amount of dust had begun floating around and much of it was transferred to the command module cabin. The vacuum cleaner failed after it had been used for about 20 minutes. Therefore, all the dust could not be collected. Most of the sample collection bags were free of dust and debris and the only things that really needed cleaning were the deep core sample and the big rock bags. Dust particles in the lunar module cabin atmosphere did provide some hindrance to the crew during the unsuiting and the dry-out period.

Page 9-60: Once the transfer of equipment from the lunar module began, the command module cockpit became noticeably dusty with quite a few rock chips floating around. The dust could be found on almost all surfaces although there was never any problem with floating dust.

The cabin fan filter was installed on the first day of the flight. After rendezvous, the cabin fan was turned on prior to opening the lunar module hatch and ran continuously until after transearth injection when it made a very loud moaning noise and was turned off (sec. 14.1.11). The cabin fan inlet screen was generally covered with a great deal of trash. After the fan was turned off, a piece of paper was taped over the cabin fan inlet screen in an attempt to retain the dust within the ducting. There was no problem with dirt coming out of the duct, even when the fan filter was removed for entry.

Page 14-21: When the spacecraft was received for postflight testing, the cabin heat exchanger inlet duct screens were blocked with lint and debris with paper taped over the screens. However, this had no effect on the operation of the fans. Operation and sound level were normal and the fan current was within specification. Visual inspection of the fans did not show any nicks or indications of interference. Two small pieces of gray tape, approximately 1/4 inch in diameter, and dust were found on the cabin fan exhaust filter (which is installed by the crew after leaving earth orbit).

Page 14-70: Postflight inspection of the wrist disconnects showed that lunar dust in the clearance areas caused the problem. Rubber dust covers for the ring disconnects which will afford better protection from contamination will be added for Apollo 17.

Page 14-78: At depressurization, just prior to the third lunar extravehicular activity, the Lunar Module Pilot noted that his chronograph crystal was gone. The chronograph hands and face were not hit. However, about 12 minutes later the movement stopped. Most likely, warpage caused by thermal cycling allowed the differential pressure across the acrylic crystal to pop it out of the case. The exposure to and penetration of lunar dust contamination about the Lunar Module Pilot's sleeves probably caused the failure of the chronograph movement,

Page 14-93: The sample collection bag essentially consists of a Teflon bag on a metal frame (fig. 14-62). The bag opening is covered by a Teflon lid on a hinged metal frame. Attached to the metal frame on one side of the bag, about 2 inches below the lid, is a 3/8-inch-wide stainless steel strap with offsets to accommodate the two hooks on the tool carrier. About 1 inch from the bottom of the same side is a 1-inch-wide Teflon band, sewn to the bag, with an offset loop approximately 1 inch by 5 inches to accommodate the Velcro strap from the bottom of the tool carrier. The Velcro strap, when tightened down, keeps the bag from floating or bouncing off the hooks. During the lunar roving vehicle operations, the Velcro strap sometimes loosened because of the entrapped lunar dust so that the bag could come off.

To adjust the azimuth to the proper dial reading, the camera is rotated on a 12.5-inch diameter ball-bearing ring (fig. 14-63). The bearing is not sealed; however, the crew did not observe any lunar dust on the bearing.

Page 15-1: Lunar dust and soil continues to cause problems with some equipment although procedural measures have been taken and equipment changes and additions have been made to control the condition.

Page A-5: The extravehicular mobility unit was modified to improve its operational capability, safety, and to provide increased dust protection. Significant changes were as follows:

Dust protectors were added to the oxygen purge system gas connectors and portable life support system water connectors.

Page A-6: Velcro was added to the battery covers to provide increased protection against dust. Reflective tape was added to provide more radiative cooling.

New underseat stowage bags with dust covers were provided.

Page A-7: In addition to the normal repackaging of the central station (fig. A-2) to accommodate the specific experiments for Apollo 16, one minor change was made. This change consisted of increasing the rear-curtain-retainer release-pin lanyard strength from 50-pound test material to 180-pound test material to prevent the breakage problem experienced on the previous mission. Also, the lunar dust detector was removed from the central station.

The active seismic experiment mortar box cable was lengthened from 10 feet to 50 feet for greater separation distance from the central station. Also, a subpallet was added for the mortar box (fig. A-2) to provide greater stability during firings and for ease of alignment when initially erecting the experiment. The thumper selector switch was modified to provide a more positive detent and all openings around the thumper selector knob and arming and firing knob were covered with dust protectors.

Page Table C-1:

Investigate apparent vacuum cleaner failure

Inspect, operate, and analyze.

Excessive dust deposits caused impeller jamming on restart.

MSC06805
Apollo 16 Technical Crew Debriefing
May 5, 1972

References to dust:

Page 9-9:

YOUNG: When Charlie says you stopped and you're hovering, there wasn't any doubt in my mind that I was hovering. I could look out the window and see the we're hovering just like a helicopter. We were well into the dust, maybe 40 or 50 feet off the ground, when we're doing that.

Page 9-13:

YOUNG: Hovering and Bowing dust. We did a hover for a short period of time there at about 40 feet off the ground, and the rates were practically zero and there was blowing dust.

DUKE: It started at 80 feet, John.

YOUNG: Yes, 80 feet. Certainly it started there and it got a lot worse, but you could still see the rocks all the way to the ground. The surface features, even the craters and with something like that – which really surprised me. I was expecting two things: either the dust would be so bad we couldn't see anything, or there probably wouldn't be as much dust as there was. Possibly, it's the 15-degree Sun angle that did all that. Because there's certainly plenty of dust down there to blow, and there's nothing thin about the regolith around the LM.

Page 10-11:

YOUNG: Every time we took the suit off – it's real handy that the thing is standing up by itself in one-sixth gravity. It's really handy for you to close the zipper up to lube the pressure zipper and get those connectors before you put the thing away for the night. On the second and third EVA, because everything was really getting dirty, and I don't know whether it's a real problem or not or an imaginary problem, we were really getting concerned about whether we were going to be able to do things like fasten the connectors. So we were taking special care to lube everything and, therefore, we ran out of lube.

DUKE: We had one left for the zipper on EVA-3.

YOUNG: I think you should have some more lube in case you do get to a situation where as you're doing your last donning, something is not working right and you need to go back and lube it again to make sure.

DUKE: No. Not only did we use the lube but we used water and the towels to wipe around the outside of the connectors. And the wrist rings – it wasn't the O-ring part that was so stiff – it was the mating surface between the suit and the sliding ring.

YOUNG: Yes. That's been remarked on before. Somebody said they taped their wrist ring but that seems to be like a kluge. I think they should come up with something that keeps the dust out of the wrist rings. Maybe an overflap that you Velcro on the other side of it to keep the dust out of there because I just don't think you should have a problem donning and offing. We really got a lot of dust and I don't see really any way out of it when you're picking up a bag on the Moon and your holding a bag and Charlie's dumping dirt in there, the dust goes all over the place and it's just as easy for it to go down your shirtsleeve as not. The fact is we had both dirt and rocks underneath the flap that you raise to get the glove open.

Page 10-16:

MATTINGLY: Did you have a lot of stuff come out of the hatch equalization like we had?

DUKE: No, we saw a few dust particles fly out but that was all. To do the actual depress we used the overhead valve and just left it open. I never noticed much floating that way. The LM was extremely clean. You know how many little screws and little washers and things we found floating in the command module. I guess maybe on the whole flight we found five in the LM the whole time.

YOUNG: It was extremely clean until after the first EVA, and then from then on it was really dirty.

MATTINGLY: Yes, I was thinking more about the subsequent depress. Did you have a lot of rocks and crud flying through there?

YOUNG: No, actually it cleaned the floor off pretty good. When I opened the door, the dirt would go "zip" right out.

SLAYTON: Do you think one-sixth g is enough to keep that stuff from going out that top hatch?

YOUNG: You all know that Velcro on the floor, it just gets caked with dirt. You can't stand on the floor. I guess it didn't hurt anything, but I know when we donned the suit, we had our jettison bag down to stand on like everybody said, but our feet and our hands and our arms were all full of dust when we put the suit on. So it was all going into the suit. And it didn't seem to bother anything. You don't know how much it's going to bother. You don't have a feel for whether it's going to give you a problem or not. There's just no way to avoid it. The second EVA, we had in places that much dirt and dust on the floor and that's after cleaning each other real good.

DUKE: The place where most of the dirt came from in the place you can't clean was the strap-on pockets we had.

YOUNG: We got smart after EVA-1, and before we got in, we closed the flap. But the first time, I got in with the flap open, and my pocket caught on a hatch sill and when I came in with that right leg, the dust just flopped out. You had a pocketful - you had a contingency sample right there in your pocket.

Page 10-60:

DUKE: The cameras worked nominally, even though we got them real dusty and it was hard to see the setting after the EVAs. We wiped them down with a wet cloth inside and changed the film outside. When we changed the film they were extremely dusty and yet the camera never quit.

YOUNG: Not only that, I guess according to the photo guys, we got some dust inside the reseau. The camera still worked although it left a couple f streaks across the film. If ruins the PR value of the things, but it sure doesn't hurt the data. But the thing worked.

Page 10-62:

YOUNG: It was real easy and I'm glad we went to that LEC because once we got adjusted, we never got any dirt in the cockpit from it. Although we got so much other dirt, I don't know if it made a lot of difference.

Page 10-64:

YOUNG: When we were opening the battery covers, of course, we had to dust the LCRU (they got dusty all the time), the LCRU did badly when they opened the battery covers. We had to park the LRV such that it was rolled into the sun a little. That may have given them a thermal problem they didn't know about.

We parked in at the right heading, but when we opened the battery covers the dirt just flew up in the air and came right back down on the batteries. I could see why they got dusty. There's hardly any way to avoid it. That was the first EVA before we lost any fenders. We were relatively free of dust in the front of the vehicle other than what we accumulated on the front as we drove.

Page 10-69:

YOUNG: PGA doffing was the usual problem of getting the PGAs off. As we said before, we lubricated the zipper when we got the PGA off and then fastened the zipper, and pulled the seals down tight. It was right after EVA-1 that we noticed the wrist rings were getting clogged with dust. There should be some way to cover those wrist rings (the things that snap in and out), the sliders that keep them from getting full of dust because it makes them practically impossible to work. After EVA-1 we experienced a little stickiness with the helmet. Not a great deal so we didn't pay any attention to it. When we took the suits off, they were all dust covered, up to our knees, even though we kicked our boots off as we came up the ladder. We took the suits off and put them into a jettison bag, pulled the jettison bag up over the legs, and laid them on the couch like everybody else has done. We put a bag down on the floor to stand on, but that did not keep us from getting dust all over the place. One of the problems is that we had dust on the bottom of the PLSSs even though we wiped it off, and dust on the side of the OPSs for some reason. They were lying on the floor. As a result when we got in our LCGs, we were sort of standing around, like I had one foot on OPS and one foot on the midstep and was sort of leaning back against the shelf on my side. Charlie was sort of standing with his foot on the ETB and one foot on the midstep, and we were up out of the dirt. Our hands were black when we started taking each other's wrist rings off. We got our hands dirty and I didn't get the dirt off my hands until after we'd landed. Washed them up good. I don't think Charlie did either. We managed to get dirt on the bottom of the LCGs, on our sleeves, and on our hands that got into the suits. It was just a little dust. I don't know what problem it entailed, but it sure looked like it might become a problem. The only thing I can say is we stayed out of the dirt as best we could. It was all over the floor. Just hardly any way to get off of it. We even had some on the midstep where we'd laid the ETB up there. It was dust covered too from dropping in the dirt because the LEC was too long to keep it off the ground.

Page 10-74:

YOUNG: Donning was hard. I'll tell you, pulling that restraint zipper was really rough. After we got the dust in the zipper, closing the zipper and locking it was pretty, pretty bad.

DUKE: Give me a new restraint zipper.

YOUNG: Restraint zipper and, also, closing the gloves and locking once we got the dust in there was really bad. It didn't hurt wrist mobility, but it sure was hard to get them closed.

Page 10-93:

YOUNG: I think it was station 8 where we lost the rear fender and that was because I fell over it. I was coming out to help you and I tripped over the thing and it fell off. Avoid those fenders if you can. Every time the wheel came off the ground and went back in and dug in, it was just like we were watching rain. Dirt came over it, covered up the battery cover, and the instrument panel so bad you couldn't read the POWER DOWN or POWER UP decals. When we got back to the lunar module, I brushed off not only the camera, but the batteries and the instrument panel as well. And that made the problem of dusting me and Charlie off even worse too. We had a lot of dust on top of our OPSs, had dust all over the place, dust on the helmet, dust around the neck ring, what a mess.

DUKE: Raining dust.

YOUNG: Yeah. The message is don't trip over the fender. It didn't bother us any apparently, but it sure was dusty.

Page 11-3:

YOUNG: EVA 3 Past Activities. The repress was normal. Again we tracked in a lot of dirt with us. Weighing and stowage was normal. I don't remember any problems we had stowing any of the boxes.

Page 11-6:

DUKE: We started a little bit early on the helmet and gloves because of the wrist ring problem.

YOUNG: I'm glad we did, because we had a problem. Every time we put the wrist rings on we didn't know if we were going to get them on, and then once we got them on we didn't know if we could get them off again. We knew we were going to get 'em off, but it sure wasn't the normal click click, push pull. I think we need some protection against dirt getting into those wrist locks.

Page 12-11:

DUKE: We did one thing procedurally at insertion. We had a lot of dust and pebbles floating around in the cockpit with us. We did turn on the cabin fan and left helmets and gloves on until docking, because we had so much dust in there.

YOUNG: That didn't clear any dust out because you have to open the inflow valve to get any of that stuff in the suit loop to clean it out. It just circulates it around. It has a filter behind it.

DUKE: Does it have a filter behind it? Well, it didn't clean much of the dust out.

Page 13-1:

MATTINGLY: After docking, we went through out transfer items even though we know we were going to be retaining the LM and going to bed. From my side, the time line entering the LM was a little bit slower than I had anticipated even though I pressurized the cabin prior to rendezvous. Taking things out and finding a place for them just seems to take little bit longer. Perhaps that was because I'm methodical about it. The first thing we did was pass in the vacuum cleaner. I had checked the vacuum cleaner operation only to the extent that I turned it on and it worked and I turned it off. I didn't try to vacuum clean anything. I didn't try to verify that it really was sucking anything up. There's some question in my mind whether the vacuum cleaner really ever worked properly.

DUKE: It did. The screen was covered with dust. It probably was so covered that it stalled out, and that's what failed it.

MATTINGLY: In any event, sometime later, I went into the tunnel to get something, and the vacuum cleaner was lying there making some funny little noise. I noticed the switch was on, but it didn't sound like it was running, so I turned it off. It didn't interest me enough to see if it was still working. I think it had probably failed then. We tried it later and it wouldn't start after that; it would just make this little hum. I suspect it failed at the time I found it the first time. That was within an hour of the time we started it.

Page 13-3:

MATTINGLY: The command module filled up with LM dust and rocks and things almost immediately. Within an hour, it was very noticeable that there was a coating of dust on all the instrument panels and all the surfaces. You'd see little rocks float by in front of your nose. I was surprised how rapidly that stuff all had diffused in. It came over as soon as we brought the first bag or the first suit, or whatever it was. That stuff was just coming off of everything and it never stopped. The command module fans were on at the time of docking. I turned them on right after docking and before removing any tunnel hatch equipment.

They were working properly at that point with the cabin fan filter on. They failed some time EVA morning. The material we brought in we just stashed away.

DUKE: We tried to vacuum the suits and some of the bags that were dirty like the big rock bags and found it was almost totally worthless. You could do a little bit, but the best method was to take a damp towel to wipe things down. We were able to get some of the dust off this way. Fortunately, most things that were dusty went over in DCON bags. That was a lifesaver. Once we opened one of the DCON bags just a little bit to see what bag was in there. The dust floated out and we closed that in a hurry. That was a real mistake. I think Apollo 14 did the same thing. The samples did not need to be vacuumed except on bag before I put it in the DCON bag. That was the big rock bag. Everything else was in good shape.

Page 13-5:

DUKE: John and I both doffed the suits in the LM. I thought it was quite a hazard over there floating through the LM with all the dust and debris. A number of times I got my eyes full of dust and particulates. I felt like my right eye was scratched slightly once.

Page 20-4:

YOUNG: Dust generated by the wheels: We've got plenty of photography of what happens when you lose a rear fender. And the Grand Prix says what's going on the rest of the time.

There's plenty of dust on the radiators just from opening the battery covers. It's very difficult for me to reach across there to close the battery covers. I would think that the next time anybody designs a vehicle, they'd just put the opening and closing mechanism on the outboard side, instead of on the inside radiator. I was always afraid that I was going to end up falling right in the middle of the batteries.

Page 21-1:

YOUNG: LEVA Operation. It was okay, except I didn't mention previously that I got it stuck on the last EVA and couldn't get it off for ingress – undoubtedly due to the dust.

Page 21-2:

YOUNG: We said we needed some more lube in there for the surface operation and the dust.

Page 21-4:

DUKE: The RCU got dusty due to our dust fender problem. I had a tough time reading mine even though it had the plastic over it. They really did a good job putting that plastic over the top of the whole thing or we never would have been able to read it.

YOUNG: They told us to give a PLSS check, and I couldn't read my RCU numbers because I made the mistake of reaching up with my finger and tried to wipe the dust off. Apparently, the dust acts like an abrasive as it just completely clobbered the RCU and I couldn't read what percent oxygen I had from then on. I think they ought to do something about that.

DUKE: I dusted mine all the time. It got dusty.

YOUNG: I couldn't read mine.

Page 21-5:

DUKE: I would like to see the Velcro taken off the flight floor, because it got dusty.

YOUNG: Sure did.

DUKE: Made it terrible to clean. If you took the Velcro off you could take a damp cloth and swab the floor.

YOUNG: Get all that dust and throw it in a jettison bag.

DUKE: But with the Velcro there, you couldn't do that.

YOUNG: For the short time you'll be in zero-g, you could use the tie-downs. ...I don't thin you would lose anything by getting rid of the Velcro, but you sure would get rid of a lot of dirt.

Page 27-36:

DUKE: It was dusty when we got back into orbit, we've already commented on all that stuff.

YOUNG: I don't think it was any problem.

DUKE: I got one piece in my eye – a little something when I was over in the LM that gave me problems, but it was okay; it cleared right up, watered it out.

JSC07904
Apollo 17 Mission Report
March 1973

References to dust:

Page 4-12: The lunar atmospheric composition experiment (S-205) deployment is shown in figure 4-3. All activities associated with the deployment were completed as planned. The dust cover was opened on December 18 at approximately 0420 G.m.t. after the last lunar seismic profiling experiment explosive package was detonated. After allowing the radiator temperature to decrease from a peak of 340.8 °K (before cover removal), to 327.5 °K, nine hours of ion source outgassing was accomplished the following day with a temperature of 523 °K having been reached.

Page 4-13: The measurements indicate that the detected number of lunar ejecta particles compare within an order of magnitude to the number of primary particles. The measurements are verifying that the bulk of cosmic dust material comes from the general direction of the sun which agrees with the results obtained from similar instruments carried on Pioneer 8 and 9.

Page 4-16: The cosmic ray detector experiment (S-152) was deployed by pulling the slide cover open and hanging the cover in the shade while the box was in the sun on the lunar module. In both cases, the nuclear particle detectors faced outward from the lunar module. The detectors were exposed to the lunar environment for approximately 45.5 hours. No degradation of any of the detector surfaces was found. Microscopic examination of the detector surfaces showed very little dust. The maximum temperature of approximately 400 °K (as shown by temperature labels) was well below the critical limit .

Page 4-41: Surface texture, dust generation, cohesiveness, and average footprint depth indicates soil properties at the surface comparable to those at other Apollo landing sites.

Page 8-2: Landing radar performance was normal during powered descent. Velocity acquisition was obtained at an estimated altitude of 42 000 feet, prior to changing the lunar module yaw attitude from 70 to 20 degrees. Range acquisition was obtained during the yaw maneuver, at an altitude of approximately 39 000 feet. Antenna position and range scale change occurred at the predicted time and tracking was continuous to lunar touchdown. There was no lock-up on moving dust or debris near the lunar surface.

Page 9-5: The Lunar Module Pilot encountered some difficulty in operating the sun shade of the lunar extravehicular visor assembly because of lunar dust in the slide mechanism. Dust and scratches on the outer gold visor prompted the crew to operate with the outer visor in the partially raised position during part of the third extravehicular activity.

Both crewmen used the special cover gloves (provided for drilling operations) throughout the first two extravehicular activities, and noted that the gloves were extremely worn. The cover gloves were removed and discarded at the beginning of the third extravehicular activity.

Page 10-3: The optics dust covers were jettisoned in daylight and could be seen under reflected sunlight. There is an associated noise that is apparent with the jettisoning . No stars were ever seen through the telescope in the daylight; however, no attempt was made to become fully night-adapted. The pick-a-pair routine worked well with the stars visible in the sextant; however, in the daylight, there was no detectable illumination of the sextant reticle. The sextant cross-hairs showed up as black lines against a light blue background.

Page 10-12: During the final phases of landing, the Commander divided his attention between looking out-the-window and in-the-cockpit. Inside, the velocity crosspointers and attitude display were monitored. This technique was used in the lunar module simulator and in the lunar training vehicle. Dust was first observed at 60 to 70 feet altitude, as indicated on the tape meter.

Page 10-14: Suit donning and doffing was accomplished essentially as planned. Particular care was exercised in the cleaning and lubrication of zippers and other dust sensitive portions of the extravehicular mobility unit. The dust protectors on the wrist lock-locks were used on each extravehicular activity, but it is difficult to determine how much protection these provided. The conservative approach was to use them; however, by the end of the second extravehicular activity and certainly by the end of the third extravehicular activity, the wrist lock-locks had stiffened considerably. However, the moving part of the extravehicular mobility unit seemed to be usable for an indefinite number of extravehicular activities providing that proper care was given to them.

Page 10-15: Prior to ascent from the lunar surface, the cabin activities included covering all holes in the lunar module floor into which dust had collected or could be swept. Although considerable dust appeared in the cabin upon insertion, taping the holes definitely prevented a major dust problem in zero-g.

Page 10-16: At the end of the second extravehicular activity, the Lunar Module Pilot returned to the lunar surface experiment deployment site for additional verification on the deployment of the lunar surface gravimeter. The second extravehicular activity duration was 7 hours and 37 minutes during which time the lunar roving vehicle traveled approximately 20.4 kilometers. A total of 60 samples were collected with an accumulated weight of approximately 75 pounds. At the end of the extravehicular activity, all hardware systems were operating as expected, except for a noticeable difficulty in the movement of some mechanical parts because of dust permeation.

Page 10-18: The lunar surface scoop was the primary sampling tool used by the Lunar Module Pilot and it worked well. However, by the beginning of the third extravehicular activity, dust in the scoop-locking mechanism prevented extensive use in any of the multiple detents. Only the 45-degree position was used during most of the third traverse.

For special sampling tasks, the Commander used the tongs effectively and the Lunar Module Pilot used the rake, as required. The Lunar Module Pilot auxiliary staff, used for mounting maps, and the lunar roving vehicle sample bag, both worked as planned and fitted the desired position exactly. The rover sampler met all requirements for utility in sampling from the rover, and in auxiliary sampling while walking in the areas of the Apollo lunar surface experiments package and surface electrical properties transmitter. The dust brush was probably one of the most often used pieces of equipment. It was employed on the rover thermal surfaces and reflectors, for cleaning the television camera lens, and by both crewmen in an attempt to minimize the dust carried into the cabin.

The geopallet was used as planned for the first two extravehicular activities. By the start of the third extravehicular activity, most of activities, most of the moving parts of that pallet had begun to bind because of dust permeation along interfacing surfaces.

Page 10-20: Prior to the second extravehicular activity, a temporary fender was made from maps and taped and clamped in to position, where it worked satisfactorily. Loss of the fender created concern that the dust problem would severely limit the crew's operation and the capabilities of the rover systems, not only thermally, but mechanically.

Page 10-22: Leveling of the central station was difficult because of the presence of about 3 to 5 centimeters of very loose topsoil at the deployment site (fig. 10-6). The leveling was finally

accomplished by working the south edge of the station down to a level below this layer of top soil and placing a large, relatively flat rock under the northwest corner. In the process of leveling, about 30 percent of the upper surface of the station sunshield was covered with a thin (approximately 0.5-mm) layer of dust, and no attempt was made to remove this dust. Also, soil became banked against the southeast and southwest corners and against the south edge of the station. Later, upon request from ground personnel, this soil was removed by clearing a 15- to 20-centimeter wide moat around those portions of the station. Some dust and soil still adhered to the sides of the station, but the white thermal coating was visible through most of this dust.

Page 10-23: Lunar surface gravimeter.- There were no known anomalies in the deployment of the gravimeter (fig. 10-7) that would account for the problems encountered upon the commanded activation of the experiment (see sec. 15.4.1). The gimbal was observed to be free swinging after the initial release and after all subsequent jarrings and shakings. A small amount of dust fell off the universal handling tool into the gimbal housing during the final jarring of the gimbal, but all final alignments and leveling by the crew were normal.

Lunar mass spectrometer.- The deployment of the lunar mass spectrometer (fig. 10-8) was as planned. A small amount of dust (approximately 0.1-mm thick) covered about 30 percent of the north-facing surface of the experiment.

Page 10-42: The post-docking activities in the lunar module and the command and service module were accomplished as planned with the checklist as an inventory list and as a backup to common sense. The vacuum cleaner was operated continuously in the lunar module to remove dust floating in the cabin. As a result of this operation and the special attention paid to the bagging and sealing of the samples prior to transfer, the command module remained remarkably dust free. During vacuum cleaner checkout, a main bus B undervoltage light was illuminated; however, there were no caution and warning lights when the vacuum cleaner was used for the lunar module post-docking activities. Preparation for lunar module jettisoning was normal through hatch closure.

Page 15-27: The receiver was protected by a multilayered aluminized Kapton thermal bag (fig. 15-20). The thermal bag had two flaps which protected the optical solar reflector (mirror) on top of the receiver from lunar dust accumulation. A dust film of about 10 percent on the mirror surface could result in the indicated degradation of thermal control and a film of this amount may not be apparent to the crew.

Page 15-29: Velcro pile pad [on the surface electrical properties experiment receiver] was bonded to the Kapton bag and the Velcro hook strap was bonded to the Kapton flaps. The bond of the Velcro pads for both flaps had already failed before the Lunar Module Pilot configured the receiver at the end of the first extravehicular activity, thus resulting in dust accumulation on the mirror surface under both flaps. The bond of the Velcro pads to the Kapton failed, leaving no trace of the adhesive on the Kapton, and the pads remained attached to the straps. The polyurethane FR-127 A and B bonding material used was acceptable and recommended for bonding Velcro to Kapton. The failure most likely resulted from a weak bond caused by improper bonding preparation or procedure. The mixing and timing of the bonding application and mating are critical, as well as maintaining the surface free of contamination.

The temperature of the lunar ejecta and meteorite experiment was higher than predicted during the first and second lunar days (fig. 15-21). The high temperatures occurred with all combinations of experiment modes: on, off, and standby, with all dust covers on, with only the sensor covers on, and with all covers off. Whenever the experiment was in the "operate-on" mode, the science data indicated normal operation of the experiment. The maximum allowable temperature for survival of the electronic components has not been exceeded, however, it was necessary to command the experiment from "operate-on" to "off" at a sun angle of about 153 degrees during the first lunar day and at a sun angle of about 16 degrees during the

second lunar day. Following sunrise of the second lunar day, the temperature rose from 0 °F at 0° sun angle to about 1-68 °F at 15° sun angle (fig . 15-21). The instrument was commanded to standby and then to off because the temperature continued to rise. In the off mode, with no power to the instrument, the temperature rise rate was lower.

Page 15-29: The experiment temperature was cooler during the morning of the third lunar day as compared to the second. This could be attributed to the procedural change which turned the experiment off for 11/2 hours through sunrise and sunset. Data from the suprathreshold ion detector and charged particle lunar environment experiments, deployed on previous Apollo missions, indicate that a flux of -100 to -750 volts can occur near the optical terminator (before optical sunrise and after optical sunset). During the lunar day, the surface is stable with photo electron layering at +10 to +20 volts. It is postulated that when the experiment is on (sensor film at -3 volts and suppressor grid at -7 volts), the charge differential observed at these times may result in an accretion of lunar dust on the east and west sensors. Based on this, the experiment was turned off each sunset and sunrise after the second lunar day. The presence of dust on the sensor film and grid would degrade the thermal control system and result in higher experiment temperatures during the lunar day.

Page A-2: [Extravehicular Mobility Suit] Dust covers were added to the wrist rings on the pressure garment assemblies

i. One of the two sets of spacers, which were subject to galling from dust, were removed from the lunar extravehicular visor assembly.

Page A-4: Apollo lunar sample return container: The Apollo lunar sample return container was made of aluminum with exterior dimensions of 19.0 inches in length, 11.5 inches in width, and 8.0 inches in height (fig. A-1). The interior volume was approximately 1000 cubic inches. The major components of the container were the handle and latch pins, seals, seal protectors, York-mesh liner, and strap-latch system. The two latch pins operated from a central lever which also a carrying handle for the container. The pins and linkage system supported the container in the lunar module and command module stowage compartments under all vibration and g-force conditions. A triple-seal arrangement maintained a vacuum during translunar and transearth flight. Seal protectors were also provided to prevent lunar dust from getting on the seals. The strap-latch system consisted of four straps and two cam latches. When closing the container, the crewman engaged the cam latches, thus tightening the straps over the lid.

MSC07631
Apollo 17 Technical Crew Debriefing
January 4, 1973

References to dust:

Page 9-7:

CERNAN: I kept a good rate of descent down through 200 feet, slowed it down at a little bit over 100 feet to 1 or 2 feet per second, and then started it on down again. We started to get dust somewhere around 100 feet.

SCHMITT: In my window, I didn't see dust until about 60 or 70 feet.

CERNAN: The dust layer was so very thin that I could definitely see through it all the way down. It didn't hamper our operations at all.

Page 10-2:

CERNAN: We actually, each individually in almost all cases, put our own glove dust covers and ring dust covers on. Maybe we had to help each other once in a while. And contrary to some of our initial desires, we decided to go ahead and put those dust covers on for every EVA. After the first EVA, we found out what the dust problem really was.

SCHMITT: One of the tabs on the LMP's dust covers did break off on the first prep.

CERNAN: But besides that, we never used that donning lanyard that we had available. We never needed it. I can't really say anything else except that the doff and don went pretty much as we both expected it to. We obviously took extreme care of our suits - the best we could - because we had to use them several times. I think that care paid off because even at the integrity check of the CM/EVA, the suits were tighter than a drum. I think the wrist connectors, even with the dust covers, were tending to get a little bit stiff.

SCHMITT: Yes, mine were very stiff.

CERNAN: But nothing ever really froze up on us.

Page 10-6:

SCHMITT: I lost a block. It just came off the Velcro. I may have hit it with my leg. Really the dust was so deep and soft that the blocks were relatively ineffective, and I ended up putting a rock underneath one corner.

Page 10-14:

Probably the most difficult job of all the closeouts was trying to dust the suits. a difficult and awkward position. It's hard to make fast sweeping movements in a stiff suit. We did our best, and I think probably the time spent was well spent. But I think also it was a bit more time than we had anticipated. The real-time transcripts will show just how much time and effort was spent in dusting. Both of us found that our lower limbs and boots could probably be better dusted by jumping up and down on a ladder or clapping your feet together on a ladder, which, incidentally, the CDR had to do in every case because he was the last one in. His feet were always in the dust prior to getting on the ladder. But I think that worked out pretty well.

Page 13-1:

CERNAN: Postdocking Check and Pressurization - The general comment I want to make about the postdocking operations is that both pilots in the LM took their helmets off to keep the dust off, primarily. The commander took off his gloves almost immediately after insertion, and flew the entire rendezvous that way. Jack took his off some time later.

SCHMITT: I kept mine on for some time. I can't remember exactly when I took them off. I did most of my preinsertion work with the gloves on, because I didn't want to take the time. I wanted to get that initial AGS solution. I could get that fairly rapidly with the gloves. I didn't take the gloves off until maybe 10 or 15 minutes after insertion. I kept the helmet on all the way through most of the transfer, just to avoid breathing the dust. I had the sinus irritation on the surface.

CERNAN: The commander kept his helmet on throughout the rendezvous and docking. I took my gloves off after insertion and left them off. As soon as we were hard docked, the commander took off his helmet. As I look back at that, because of the dust debris in the LM spacecraft, I'm sorry I did. I could have left the helmet on, and I would have had a lot less eye and mouth type of irritation. You knew you were in a very heavily infiltrated atmosphere in the LM because of the lunar dust. I don't know how much lunar dust previous flights had, but I think we saved a great deal of grief by sweeping all the dust we could find on the floor into the holes and putting our tape covers over those holes. I think that had to help a great deal. There was an awful lot of dust on the floor that we didn't see.

Page 13-3:

SCHMITT: The suits were noticeably cleaned by the vacuum cleaner. You could tell you were pulling stuff off them, although they were still dirty. Every subsequent time we handled them, we got our hands dirty. I think most of the free dust was taken care of.

Page 13-4:

CERNAN: Cleaning control in the command module was excellent, considering all the dust and dirt that just seemed to adhere to everything in the LM. When we got back in the command module, with the exception of the suits, and LMP and CDR, everything was clean. Everything was clean because everything was bagged before we brought it over - bagged and zipped. We never did open anything once we got it zipped up. So the command module stayed exceptionally clean throughout the remainder of the flight.

Page 19-10:

SCHMITT: Cabin atmosphere was good, good ventilation, good odor clearing. The dust clearing was remarkably good, considering the amount of dust that we had. It was within a couple hours after ingress. Although there was a lot of irritation, at least to my sinuses and nostrils, soon after taking the helmet off, about 2 hours later, that had decreased considerably.

Page 20-1:

CERNAN: Mounting and dismounting was simply a case of getting acclimated as to know how to mount and how to dismount. The biggest problem with mounting and dismounting was to be able to mount without kicking dust all over the LCRU.

Page 20-5:

CERNAN: Crew Restrictions, Limitations, and Capabilities - Displays - I could see and read all displays all the time except when we got dust on the checklist down in front of the hand controller. Then that display became effectively unreadable until I could get off the Rover at the next stop and dust it.

Page 20-11:

SCHMITT: Geology Science Site Response - You've covered pretty well how the Rover performed on various kinds of terrain. Gene, why don't you describe the fender? That was the major dust problem.

CERNAN: With the loss of one of the fender extensions, any one of them, the dust generated by the wheels without fenders or without fenders extensions is intolerable. Not just the crew gets dusty, but everything mechanical on the Rover is subject to dust. Close to the end of the third EVA, all the mechanical devices on the gate and on the pallet in terms of bag holders and pallet locks and what have you were to the point that they would refuse to function mechanically even though the tolerances on these particular locks were very gross. They didn't work because they were inhabited and infiltrated with this dust. Some could be forced over center. Others just refused to operate even after dusting, cleaning, and a slight amount of pounding trying to break the dust loose. I think dust is probably one of our greatest inhibitors to a nominal operation on the Moon. I think we can overcome other physiological or physical or mechanical problems except dust.

SCHMITT: What we're really saying is that in any future operation, mechanical joints or levers and this sort of thing are going to have to be protected.

CERNAN: They should be sealed or protected. We had absolutely no dust problem with the wheels, and those are sealed units. Dust accumulated on the radiator.

SCHMITT: That goes for tools too. The only tools we had locks on were the scoop and the rake, and those were getting stiff and wouldn't lock. They wouldn't relock once you adjusted them.

CERNAN: The period of time when we had lost the rear fender just put a solid coat of gray dust over everything. Once we got the fender repaired, the dust problem was at a minimum. After the long traverse rides, the radiators all required a good amount of dusting. That required X amount of time. That's going to be required again any time we have a lunar surface operation.

SCHMITT: I'm sure we'll get into this in the system experiments, but as a general comment for any radiator surfaces that need to be protected, you need to have more than just a cursory design on the protection of those radiators. The SEP is the case in point, and that was a completely inadequate design to protect those radiators. If we ever do it again in a dust environment, you must have clear and very tight protection of your mirrors and radiators for driving.

CERNAN: Something else that dust penetrates that I don't think has been mentioned before is that it penetrates and deteriorates the capability of Velcro. I could see it on the LCRU covers and the SEP covers. The Velcro pulled off to keep the SEP covers closed, but the Velcro that kept them open didn't pull off but it was deteriorating. If you want to use tape on the lunar surface after what you're taping has been exposed to the dust, you first have to clean that surface off with a piece of tape or something and get the mirror dust off before the tape will even begin to adhere to the surface you're trying to apply it to.

Page 21-2:

SCHMITT: LEVA operation - I did have the sticky visor problem, and it was dust. We could force it closed, once we got it off. We tried once on the surface, and we couldn't get it closed.

Page 21-5:

CERNAN: Connectors and controls were good on the PLSS throughout the flight. They are the one thing that did not seem to get affected by the dust. They might have gotten a little stiffer, but I could not tell it.

Page 27-27:

CERNAN: Dust - I think probably 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, whether it be skin, suit material, metal, no matter what it be and it's restrictive friction-like action to everything it gets on. For instance, the simple large tolerance mechanical devices on the Rover began to show the effect of dust as the EVAs went on. By the middle or end of the third EVA, simple things like bag locks and the lock which held the pallet on the Rover began not only to malfunction but to not function at all. They effectively froze. We tried to dust them and bang the dust off and clean them, and there was just no way. The effect of dust on mirrors, cameras, and checklists is phenomenal. You have to live with it but you're continually fighting the dust problem both outside and inside the spacecraft. Once you get inside the spacecraft, as much as you dust yourself, you start taking off the suits and you have dust on your hands and your face and you're walking in it. You can be as careful in cleaning up as you want to, but it just sort of inhabits every nook and cranny in the spacecraft and every pore in your skin. Although I didn't have any respiratory problems, I think the LMT, which he can comment on later, had some definite local respiratory problems right after the EVA – due to dust in the cabin.

CEFNAN: In sputum - I didn't spit up anything. I didn't feel any aerosol dust problem at all until after rendezvous and docking when I took off my helmet in zero-g and we had the lunar module cabin fan running the whole time. I did all the transfer with my helmet and gloves off, and I'm sorry I did because the dust really began to bother me. It bothered my eyes, it bothered my throat, and I was tasting it and eating it and I really could feel it working back and forth between the tunnel and the LM. Ron, did you feel any effects of the dust when we docked and rendezvoused, particularly?

EVANS: Only when I stuck my head up in the LM. When I climbed up in the tunnel I could definitely tell there was a lot of dust up in the LM and you could smell it. It's a difference, so I think you noticed it from that standpoint, but there never really was dust in the command module. The only time you ever got any dirt in the command module was when you touched something that had dirt on it. But as far as dust floating around in the command module - I don't think it ever did.

CERNAN: After rendezvous and docking - After the CDR and LMP had been living with this dust for 3 days on the lunar surface, there was a compelling urge on both of our parts to get clean. We spent about 2 or 3 hours prior to going to bed doing nothing but effectively taking soap and water and trying to wash as much of our body as we could to get free from what is really sort of a dirty feeling due to the dust. Even with soap and water it was sometimes very difficult to get clean, and the dust would get under your fingernails and other places on your body.

Page 27-45:

SCHMITT: Eye irritation during photos - I did not notice any. Helmet visor reflections I guess have been very well covered. With the dust and scratches on the helmet, of course, you needed to shade the helmet more and more in order to see with the Sun directly on the helmet.

Page 27-47:

SCHMITT: Dust - We'll just talk about in-cabin dust. After the first EVA, there was considerable dust in the cabin. It would be stirred up by movements of the suit and the gear that we had. Almost immediately upon removing my helmet, I started to pick up the symptoms that you might associate with hay fever symptoms. I never had runny eyes or runny nose. It was merely a stuffiness in the nose and maybe in the frontal sinuses that affected my speech and my respiration considerably. After about 2 hours within the cabin, those symptoms gradually disappeared. By morning of the next day they were gone completely. After the second and third EVAs, although I'm sure the dust was comparable, the symptoms were not nearly as strong as after the first EVA. That was as if I either developed a mucous protection of the affected areas or had some way or another very quickly developed an immunity to the effects of the dust.

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14. ABSTRACT Mission documents from the six Apollo missions that landed on the lunar surface have been studied in order to catalog the effects of lunar dust on Extra-Vehicular Activity (EVA) systems, primarily the Apollo surface space suit. It was found that the effects could be sorted into nine categories: vision obscuration, false instrument readings, dust coating and contamination, loss of traction, clogging of mechanisms, abrasion, thermal control problems, seal failures, and inhalation and irritation. Although simple dust mitigation measures were sufficient to mitigate some of the problems (i.e., loss of traction) it was found that these measures were ineffective to mitigate many of the more serious problems (i.e., clogging, abrasion, diminished heat rejection). The severity of the dust problems were consistently underestimated by ground tests, indicating a need to develop better simulation facilities and procedures.					
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