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The Effects of Lunar Dust on Advanced EVA Systems: Lessons from Apollo

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"Dust is the number one concern in returning to the moon"

- Apollo 16 Astronaut John Young

July 2004

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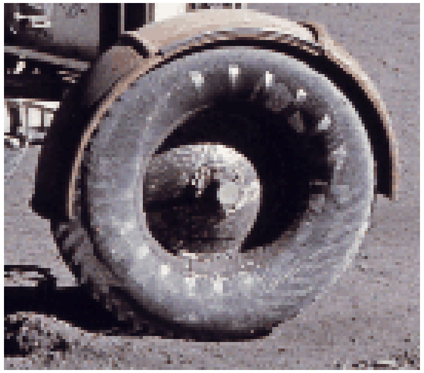
- **NASA's Vision for Space Exploration**
  - Goal advancement of "…U.S. scientific, security, and economic interests through a robust space exploration program."
  - The Vision is based around a spiral development that extends "…human presence across the solar system, starting with a human return to the Moon by the year 2020…"
  - Spiral 2: 4 – 14 day human missions to lunar surface
- **AEVA program has been charged**
  - Develop technology
  - Develop flight hardware
  - Spacesuits, tools, and vehicular interfaces for the lunar surface exploration
- **AEVA Environmental Protection Program**
  - Mitigate risks due to **dust**, radiation, toxicological

Dust Degrades Capabilities

- **Apollo astronauts cited multiple problems caused by lunar dust**
- **Dust degradation effects can be sorted into categories**
  - Vision obscuration
  - False instrument readings
  - Loss of foot traction
  - Dust coating and contamination
  - Seal failures
  - Clogging of mechanisms
  - Abrasion of materials
  - Thermal control problems
  - Inhalation and irritation risks
- ***Lunar dust properties which cause these effects must be understood, simulated, and mitigated if AEVA systems are to operate effectively***

Dust Free



Dust Covered

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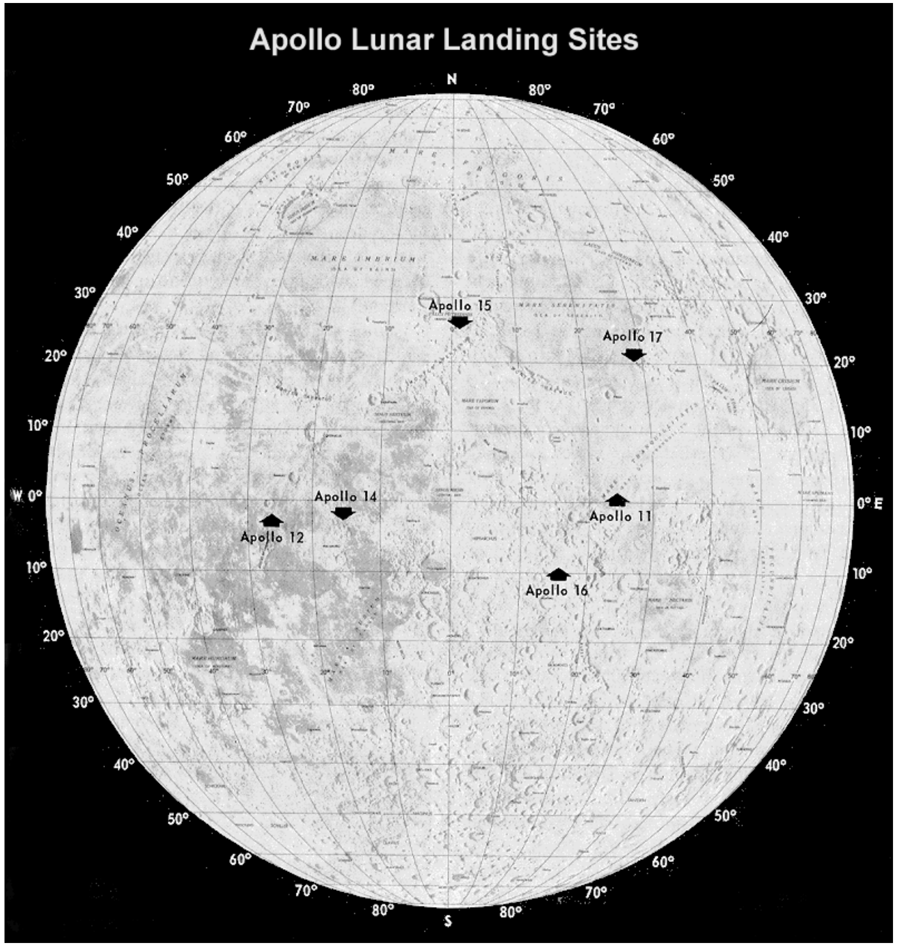
Vision Obscuration Problems

- **First noted on Apollo 11 LM landing**
  - Began noticing at altitude of 100 ft
  - More severe as altitude decreased
- **Apollo 12 even more severe**
  - Concerned LM foot could land on boulder, small crater
- **Landing profile changed, Apollo 14 had fewer problems**
  - Had fewer dust problems of all types
  - Intrinsically less dust site?
- **Apollo 15, 16 both reported problems on landing**
  - Both used higher landing profile
- **No mention in Apollo 17 debriefing**
  - Also had fewer dust problems reported
- **Minor camera problems on Apollo 15**
  - Fixed by brushing off lens



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False Instrument Readings

- **Apollo 12 velocity trackers gave false readings**
  - Locked onto moving dust and debris during descent
- **Apollo 15 landing radar outputs affected**
  - Altitudes less than 30 feet
- **Dust on visors adversely affected Lunar Roving Vehicle (LRV) indicators and gage readings**
- **Apollo 17 reported minimal problems of this sort**
  - Less loose dust at landing site(?)
  - ***Each landing site will be different!***

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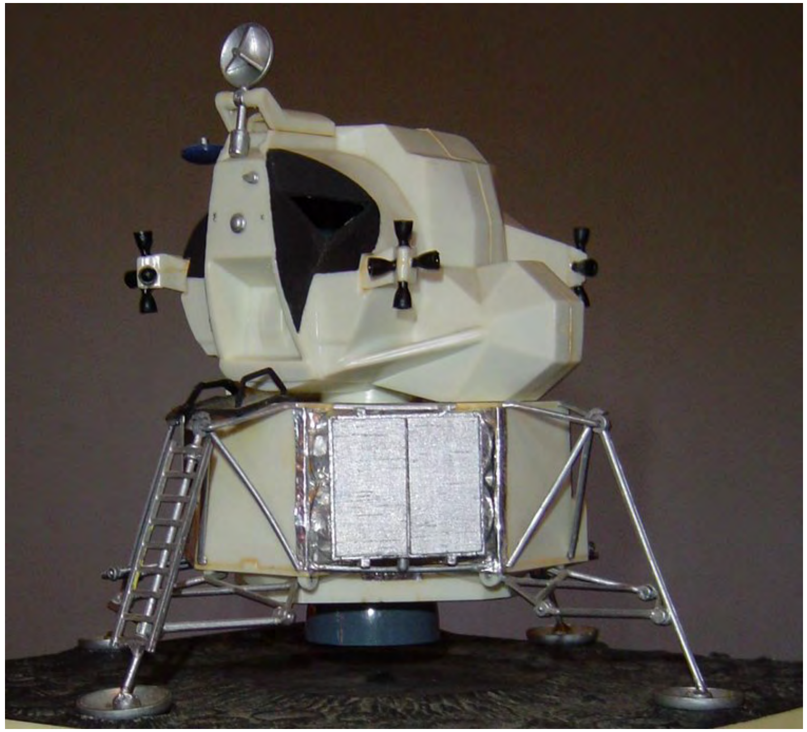
Loss of Foot Traction

- **Neil Armstrong reported material on boot sole made ladder slippery**
- **No other similar reports**
  - Apollo 12 astronauts report specifically there were no problems
- **Astronauts started kicking ladder before ingress**
  - Kept some of the dust out of the LM
  - May have shaken enough dust off to prevent slipping
  - Limited number of egress-ingress cycles
- ***Not thought to be a major concern***



Mission Support LM Model

Dust Coating and Contamination

- **Dust quickly and effectively coated surfaces**
  - Boots, gloves, suits, and hand tools affected
  - Dust on Apollo 11 TV cord concealed it and created tripping hazard
  - Dropped Apollo 12 contrast chart became unusable
  - LRV fender extensions knocked off, resulting in astronauts and equipment being covered with dust
- ***Coating problems developed into other problems***
  - Clogging of mechanisms
  - Seal failures
  - Abrasion
  - Thermal control

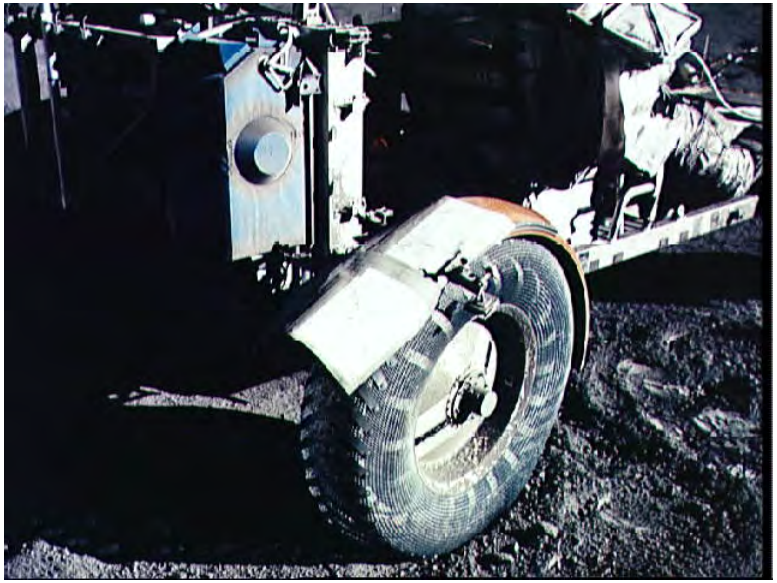
- **Dust created housekeeping problems**
  - Much astronaut time devoted to ineffective brushing off and wiping down equipment

Seal Failures

- ***Ability to seal suits for EVA's compromised***
- **Apollo 12 higher than normal suit pressure decay**
  - Pete Conrad's suit was tight before first EVA
  - After first EVA 0.15 psi/min
  - After second EVA 0.25 psi/min
  - Safety limit was 0.30 psi/min
  - Dust could not be completely cleared off of fittings
- **All Apollo environmental, gas, and regolith sample seals failed**
  - Samples contaminated before reached earth

Clogging of Mechanisms

- **Equipment clogged and mechanisms jammed on every mission**
  - Equipment conveyor to LM
  - Lock buttons
  - Camera equipment
  - Velcro® fasteners
  - Zippers
  - Wrist locks
  - Hose locks
  - Faceplates
  - Sunshades
  - Vacuum cleaner
- **Particularly problem when fender extensions were knocked off LRV**



Apollo 17 Fender Fix

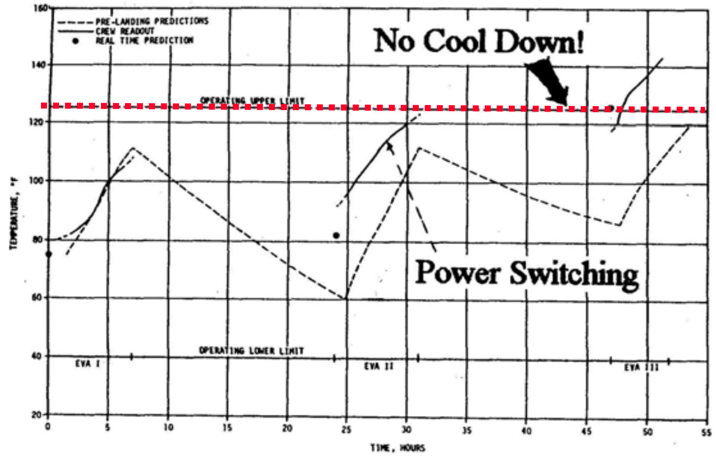
- ***Several crew remarked could not have sustained more surface activity***

Abrasion of Materials

- **Conrad and Bean's suits worn through above boot**
  - Micrometeoroid protection layer breached
  - Several layers of Kapton® multi-layer thermal insulation breached
- **Brushing dust off scratched indicator dial faceplates**
  - Made some LRV indicators unreadable on Apollo 16
- **Obscured vision**
  - Harrison Schmitt's visor sun shade so scratched he could not see in certain directions
- **Apollo 17 astronaut cover gloves for core drill were worn**
  - Worn through after drilling cores on two (of three) EVA's
- ***Abrasion caused some of the most serious problems***

Thermal Control Problems

- **LRV batteries exceeded temperature limits**
  - Losing fender extensions increased dust exposure for dust covers and radiators
  - Power switching required on Apollo 16



Battery No. 2 Temperature

- **Communications, TV camera, experiment radiators also adversely affected**
  - Surface Electrical Properties (SEP) experiment failed

- **Valuable EVA time spent trying to clean radiators**
  - Limited effectiveness

- ***Ground-based tests for dust removal by brushing were inadequate and misleading***
  - Need high quality thermal/vacuum test facility
  - Need "believable" testing of prevention and mitigation methods, correlated with actual system models

Astronaut Brushing Radiator

Inhalation and Irritation Risks

- *Dust could compromise astronaut health*
- **Apollo 11 reported dust gave off distinctive, pungent odor**
  - Suggests small particle sizes were suspended in spacecraft
  - May have reactive volatiles on the surface of the dust
  - Dust irritated eyes, but was easily removed
  - Dust under fingernails was persistent
- **Apollo 12 reported eye and lung irritation on return trip**
  - Contaminated the CM after docking with LM
- **Apollo 12 crew reported dust got in everywhere**
  - Conrad and Bean covered with dust when they removed space suits
- **Harrison Schmitt reported hay fever-like symptoms from dust**
  - Lasted much of the return trip

Advanced Integrated Matrix Program

- **Wide range of experts generated a report that identified:**
  - Systems that would be affected by dust
  - How those systems would be affected
  - Risks associated with each system so affected
  - Requirements that need to be developed
  - Knowledge gaps
- **Resulting list of potential problem areas in EVA systems**
  - Those culled from the Apollo experience
  - Possible electrical problems such as power drains and shorts

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AEVA Systems Evaluation

- **TRL 6 development for Spiral 2 surface suit, other AEVA components by 2009**
  - Testing requirements now being developed
  - Realistic testing facilities identified or built up
  - Requirements for appropriate simulants being developed
- **How well they hold up in the dusty environment**
  - Evaluation of candidate suit materials that would be exposed to the dust
    - New mitigation strategies will be tested at this level
    - Effectiveness quantified
  - Component-level testing
    - Particularly important for joints and connections
    - Evaluate new designs and materials identified in the first stage
  - Full-up suit and system tests
    - Identify system problems that are not obvious from the component tests.

Lunar Regolith Simulants

- **Functional properties of dust are key**
  - Optical properties
  - Abrasive properties
  - Adhesion properties
  - Thermal properties
  - Tribological properties
  - Electrical properties
  - Magnetic properties
  - Other properties?
- **May use different simulants to test different properties**
  - The fewer that can be used, the better
  - Must not compromise fidelity in properties to minimize number of simulants

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AEVA Simulant = ISRU Simulant?

- **Required characteristics of the lunar simulants yet to be defined**
- **AEVA simulant(s) properties driven by requirements**
  - Goal is to reduce risk of AEVA failure due to dust
- **ISRU simulant properties driven by requirements**
  - Goal is to develop resource utilization technology
- ***Since the goals are different, the simulants might also differ***
  - Communication between the AEVA and ISRU teams must be maintained
  - The more commonality of simulants, the better
  - Fortunate coincidence if simulants required by both efforts are the same.