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DUST PROTECTION FOR ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEMS IN THE LUNAR ENVIRONMENT

Susan Fuhs
AiResearch, Los Angeles
and
Jeffrey Harris
Lockheed, Houston

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Abstract

Lunar dust is pervasive, and requirements for dust protection will affect both hardware design and operations planning for lunar surface systems. On Earth, mechanical problems caused by particulates include erosive and abrasive effects, clogging of mechanical equipment, and impairment of seals and bonds. In addition, dust tends to degrade the heat rejection properties of contaminated surfaces. All these effects have been observed on the lunar surface as well.

This paper discusses the potential applicability of current dust protection methods to the problem of dust protection for the enviro˜mental control and life support (ECLS) systems of a lunar base, and highlights areas where development may be necessary. A review of dust problems experienced during the Apollo missions and of additional, ground-based experience with lunar dust provides a baseline for identifying operations and areas where dust may be expected to affect the ECLS systems. Current Earth-based methods of dust protection are identified and the impact of differences between the Earth and lunar environments on these methods is evaluated. Finally, integration of dust protection equipment with ECLS systems equipment is discussed.

Introduction

Lunar dust is pervasive, and poses significant challenges to crew health and to the operation of environmental control and life support (ECLS) systems on the Moon. Techniques for dust control which have been developed for Earth-based applications have varying applicability to lunar scenarios. This paper examines the problems arising from operation in the dusty lunar environment and discusses alternative approaches to solving these problems.

Lunar Dust Problem Definition

Apollo Experience

Dust contamination was one of the major operational hazards faced by the Apollo crews throughout the Apollo missions. Lunar dust clogged latches on extravehicular activity equipment, scratched visors and instrument covers, insulated heat transfer surfaces, and adhered to virtually everything. Although improvements were made in handling dust throughout the Apollo program, the problems had not been fully solved at the time of the last mission. During the Technical Crew Debriefing for Apollo 17, astronaut Gene Cernan commented:

> "Dust -- I think probably one of the most aggravating, restricting facets of lunar surface exploration is the dust and its adherence to everything..."[1]

Lunar Dust

Dust particles are characterized using many different measures, including mass, hardness, morphology, size, conductivity, charge, and color. Lunar dust has significant differences from dust on Earth. Since the Moon has no atmosphere, the lunar surface has been exposed to micrometeorite impacts for centuries. As a result the dust particles have reached a sort of steady state, and are more uniform in size than those on Earth. Without the weathering effects resulting from an atmosphere, the particles remain sharp. Furthermore, without the protection of the Earth's atmosphere and magnetic field, exposure to radiation results in highly charged particles.[(2,3)] The small, sharp, highly charged lunar dust particles attach readily to many surfaces. Table 1 lists relevant characteristics of lunar dust.

Differences between the environment on the Earth and on the Moon result in differences in behavior of dust particles. In general, particle behavior is determined by many factors, including gravity, viscous drag, inertia, electrical forces, diffusivity, and thermophoretic forces. The reduced gravity field and the varying artificial atmospheric conditions in the lunar habitat and airlock will result in subtle differences in particle behavior on the Moon. These differences will need to be carefully considered in the design of equipment for a lunar base. Table 2 highlights differences between the environments on Earth and in the lunar habitat, airlock, and surface.

Effects on Crew Health and on Environmental Control and Life Support Equipment

The Apollo lander had no airlock. As a result, the ECLS equipment was exposed to any dust brought into the lander. In fact, there were indications that the ECLS system was acting as a sort of filter for the air inside the lander. Apollo 15 astronaut Dave Scott indicated:

> "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...but that had all cleaned

out. By the time we got up the next morning things were in pretty good shape."[2]

The crew were also exposed to any dust within the lander; reported symptoms varied in severity from crew member to crew member.[1]

Obviously, for long duration missions, exposure of crew and ECLS equipment to dust must be minimized. Crew health effects include irritation of the eyes, of the pulmonary ventilation system, and of the skin. For example, *Figure 1* shows an experimentally determined collection efficiency curve for particle deposition within the human lung on Earth.[4] It can be seen that the lungs are good collectors of airborne particles, with collection efficiencies ranging from 0.4 to 1.0, depending on particle size. Although some changes in particle behavior are expected on the Moon, this curve will retain its basic shape and deposition of particles in the lung will remain a problem on the Moon.

A lunar base life support system will contain many types of equipment. Such a system will comprise, at a minimum: rotating machinery, flow control equipment, chemical process units, and heat transfer equipment. Table 3 identifies typical components which may be found in a lunar base life support system, and identifies effects of dust contamination on unprotected equipment. Dust particles will have major impacts on operation, reliability, and maintainability of ECLS equipment.

Protection Against Lunar Dust

There are several means of mitigating the effects of lunar dust on the crew and on a lunar base ECLS system. These include (in rough order of preference):

1) eliminating entry of dust into the habitat,
2) designing robust equipment which can operate in a dusty environment,
3) reducing exposure to dust by removal of particles from the air,
4) taking steps to retard contamination by dust, and
5) performing direct clean-up of dust in areas that have become contaminated.

Each of these approaches is discussed in the following paragraphs.

EVA operations are the primary source of dust particles within the habitat module. As a result, careful EVA operations planning is required to reduce the amount of dust passing from the airlock into the habitat and thus to reduce the exposure of crew and ECLS equipment to dust. Kennedy and Harris[2] provide a plan for re-entry through the airlock which will minimize the amount of dust brought into the habitat module itself. This plan is presented in simplified form in *Figure 2*. (In addition, selection of appropriate materials for EVA suits/equipment can provide benefits by inhibiting the attachment of particles and/or by facilitating removal of dust. A detailed discussion of materials properties is beyond the scope of this paper, however.)

Where dust entry can not be eliminated, such as within the airlock itself, careful design and development can produce robust equipment which can operate in a dusty environment. For example, degradation of air bearings due to particles in the air passing over the bearings can be eliminated by use of a reverse facing pitot to scavenge particle-free air for the bearings. *Figure 3* illustrates this approach. Other techniques for designing particle resistant equipment include selective use of coatings on surfaces exposed to particle impacts, shielding, or sealing. It should be noted that this type of approach is not adequate to mitigate crew exposure to particulates.

Removal of particles from air streams may be necessary. On Earth, several removal methods are available. Table 4 summarizes current approaches, and *Figures 4-8* describe the techniques.

Unfortunately, most of the approaches used on Earth are only marginally applicable to the lunar environment. For example, the large pressurized volume required for a settling chamber is not readily attainable on the lunar surface. The two most likely approaches to lunar dust removal are cyclones and filters. *Figure 2* shows dust removal capability prior to ECLS equipment in the habitat, providing additional dust protection for ECLS systems.

If removal of particles from air streams is not practical, measures can be taken to retard particle build-up in or on sensitive equipment. Selection of appropriate flow regimes and careful choices of materials can minimize impaction and retention of particles on surfaces[5].

Finally, one must be prepared to clean up dust contaminating the airlock or habitat when necessary. Hand held vacuums or moist wipes provide clean up capability.

Conclusions and Recommendations

Design of ECLS equipment and systems for a lunar base must consider the problems associated with exposure to lunar dust. Dust control strategies will affect mass, volume, power, and performance of ECLS and EVA equipment. As a result, trade studies to determine dust control strategies must be conducted from a system viewpoint. Care must also be taken to protect the crew from exposure to dust. It should be noted that some of the techniques used to reduce the effects of dust on equipment will not mitigate effects on the crew.

Areas requiring further research and development include:

1) improved characterization of lunar dust,

2) more detailed evaluation of particle behavior in the various lunar environments: habitat, airlock, surface,

3) evaluation of the applicability of terrestrial dust removal techniques to lunar requirements,

4) determination (and development if required) of better materials to contact lunar soils, and

5) improved understanding of the physiological impacts of exposure to lunar dust.

References

[1]NASA Manned Spacecraft Center, "Apollo 11 - Apollo 17 Technical Crew Debriefings, 1969-1973." Crew Training and Simulation Division, Houston, TX, 1969-1973.

[2]Kennedy, Kriss J. and Jeffrey R. Harris, "Dust Control Research for SEI." paper presented at SPACE '92: Engineering, Construction, and Operations in Space, American Society of Civil Engineers, Denver, CO, May 31 - June 3 ,1992.

[3]Heiken, Grant H., et al. *Lunar Sourcebook: A User's Guide to the Moon*. Cambridge University Press, New York, NY, 1991.

[4]Friedlander, S. K. *Smoke, Dust, and Haze: Fundamentals of Aerosol Behavior*. John Wiley and Sons, New York, NY, 1977.

[5]Fuhs, Susan E., "Studies of Inertial Deposition of Particles onto Heat Exchanger Elements." Ph.D. thesis, California Institute of Technology, Department of Mechanical Engineering, 1988.

CHARACTERISTICS	DESCRIPTION	REMARKS
SIZE	90% < 1000 MICRONS (1 mm) 70% < 100 MICRONS (0.1 mm)	VERY SMALL WITH HIGH INGRESS AND PENETRATION
SHAPE	ANGULAR/SUBANGULAR SHARP	EMBEDS INTO FABRICS
BULK DENSITY (0–30 cm)	1.58 ± g/cm^3	HIGHER DENSITY DEEPER
HARDNESS	5–7 (MOHS SCALE)	VERY HARD MATERIAL
POROSITY (0–15 cm)	52% ±2%	VOLUME OF VOID SPACE
COHESION (0–15 cm)	0.52 kPa	HIGHER COHESION DEEPER
TOXICITY	PRIMARILY NON-TOXIC	–
CORROSIVENESS	NOT ACTIVE IN VACUUM	NO CHEMICAL REACTION W/O SOLUTION
ELECTROSTATIC	HIGHLY CHARGED	HIGHEST CHARGE DURING LUNAR NIGHT
MAGNETIC	38 ± GAMMAS: APOLLO 15	NOT GLOBAL, LOCAL FIELDS
THERMAL CONDUCTIVITY	0.9–1.3 W/cm°K	GOOD INSULATOR
COMPRESSIBILITY (LOOSE)	0.3 (COMPRESSION INDEX)	TOP 10± cm COMPRESSIBLE

ADAPTED FROM KENNEDY AND HARRIS, "DUST CONTROL RESEARCH FOR SEI"

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Table 1. Lunar Dust Characteristics

	EARTH	LUNAR SURFACE	AIRLOCK	HABITAT
ATMOSPHERE	14.7 PSIA	NONE	VARIABLE	REDUCED PRESSURE OR 14.7 PSIA
GRAVITY	1g	1/6 g	1/6 g	1/6 g
DISTURBANCES	WEATHER, HUMAN AND MECHANICAL ACTIVITY, GEOLOGIC ACTIVITY	HUMAN AND MECHANICAL ACTIVITY, SOLAR RADIATION, MICRO-METEORITES	HUMAN ACTIVITY, PRESSURIZATION/ DEPRESSURIZA-TION AIRFLOWS	HUMAN ACTIVITY, VENTILATION AIRFLOWS

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Table 2. Earth and Lunar Environments

TYPE OF EQUIPMENT	TYPICAL COMPONENTS	POTENTIAL EFFECTS OF DUST CONTAMINATION
• ROTATING MACHINERY	• FANS • PUMPS • COMPRESSORS	• CORROSION • EROSION • CLOGGING • BEARING FAILURES
• FLOW CONTROL EQUIPMENT	• VALVES • METERS	• LEAKS • FAILURE TO OPEN/CLOSE • ERRONEOUS MEASUREMENTS
• CHEMICAL PROCESS UNITS	• SORBENT BEDS • CATALYTIC REACTORS	• PLUGGING • BREAKDOWN • EROSION
• HEAT TRANSFER EQUIPMENT	• HEAT EXCHANGERS • RADIATORS	• FOULING/INSULATION • OBSCURATION OF RADIATIVE SURFACES

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Table 3. Effects of Lunar Dust on Unprotected ECLS Components

	MINIMUM SIZE, μm	EFFICIENCY, MASS%	LUNAR APPLICABILITY?
SETTLING CHAMBER	50	<50	NO
CYCLONE	5-25	50-90	YES
WET COLLECTOR			
• SPRAY TOWER	10	<80	NO
• VENTURI SCRUBBER	0.5	<99	NO
ELECTROSTATIC PRECIPITATOR	1	95-99	POOR
FILTER	0.3	99+	YES

ADAPTED FROM FRIEDLANDER, "SMOKE, DUST, AND HAZE"

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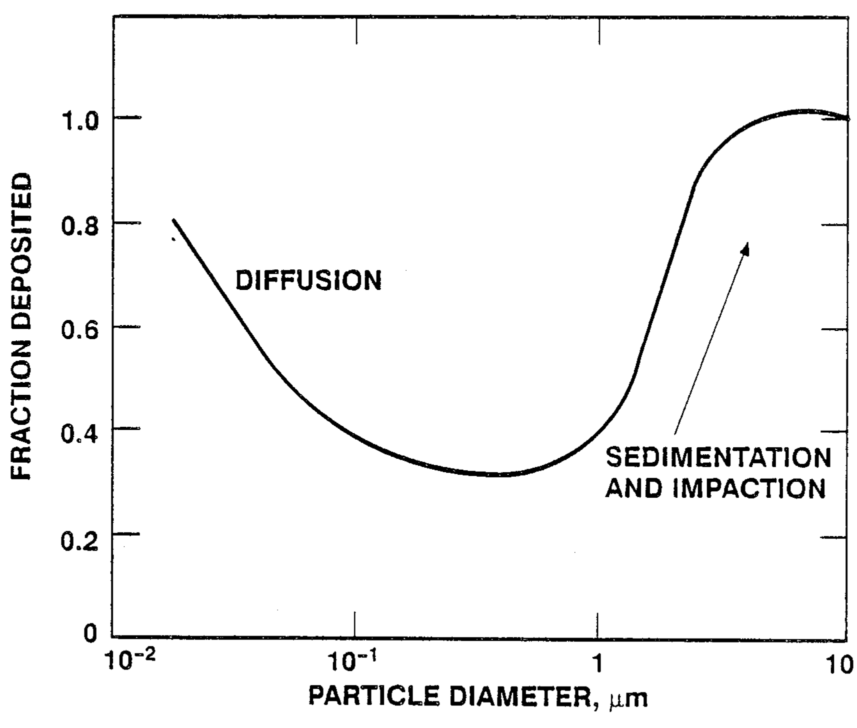
Table 4. Current Approaches to Particle Removal



ADAPTED FROM FRIEDLANDER
"SMOKE, DUST AND HAZE"

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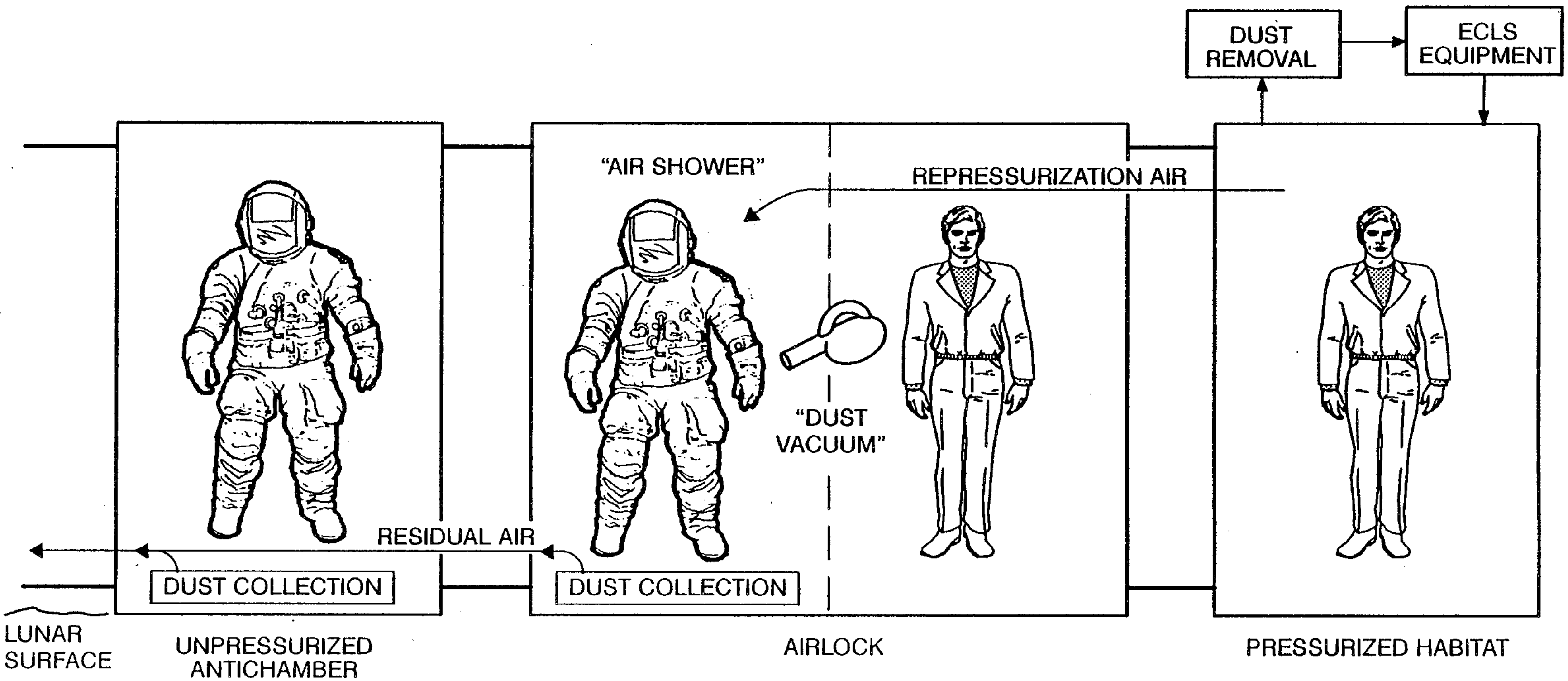
Figure 1. Particle Deposition in the Human Lung on Earth

Figure 2. Prevention of Lunar Dust Entry into the Habitat



1. STOMP, SHAKE, AND BRUSH OFF DUST
2. REMOVE ANY COVER GARMENTS
3. USE REPRESSURIZATION AIR AS AIR SHOWER
4. USE DUST VACUUM TO FURTHER CLEAN SUIT
5. TAKE OFF SUIT AND MATE TO SERVICING EQUIPMENT
6. "ASSISTANT" FURTHER CLEANS SUIT AND AIRLOCK
7. CREW MEMBERS ENTER HABITAT DUST FREE

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NOTE: COLLECTED DUST WILL VENT WITH RESIDUAL AIR ON NEXT AIRLOCK OPENING

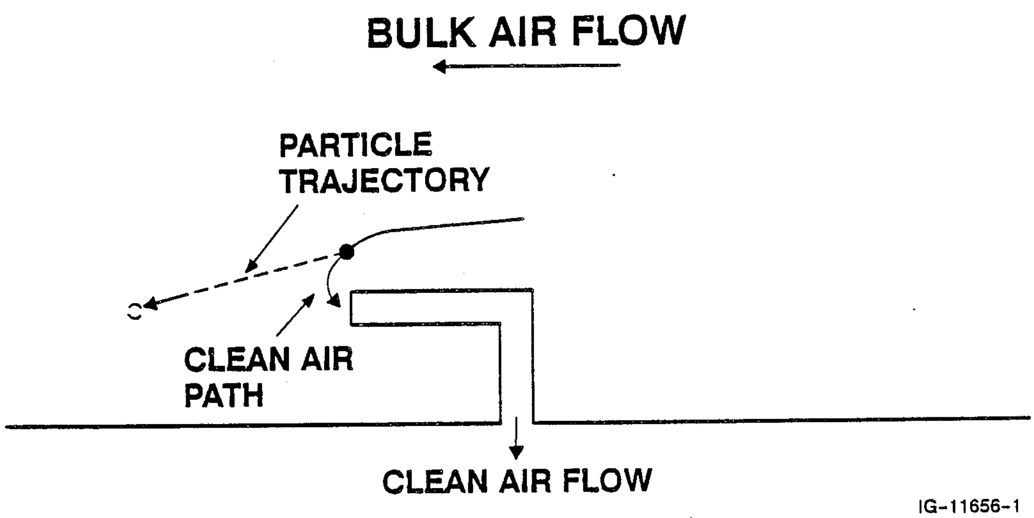


Figure 3. Use of a Reverse Facing Pitot Tube To Scavenge Clean Air Flow for Air Bearings

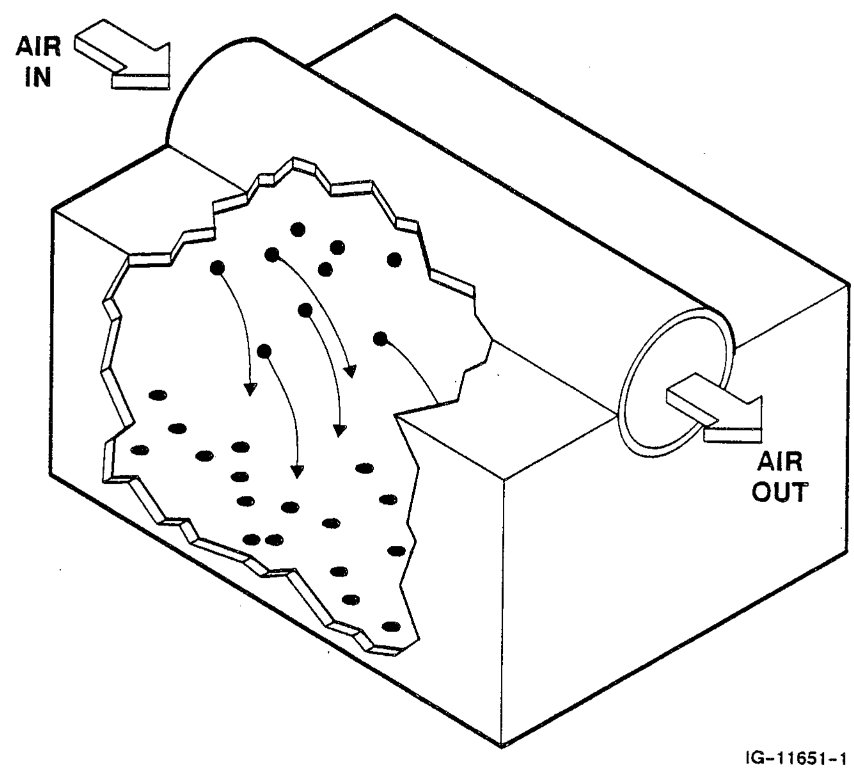


Figure 4. Settling Chamber for Dust Removal. Advantages Include Low Pressure Drop, Low Maintenance, and Simple Design. Disadvantages Include Large Volume and Low Efficiency.

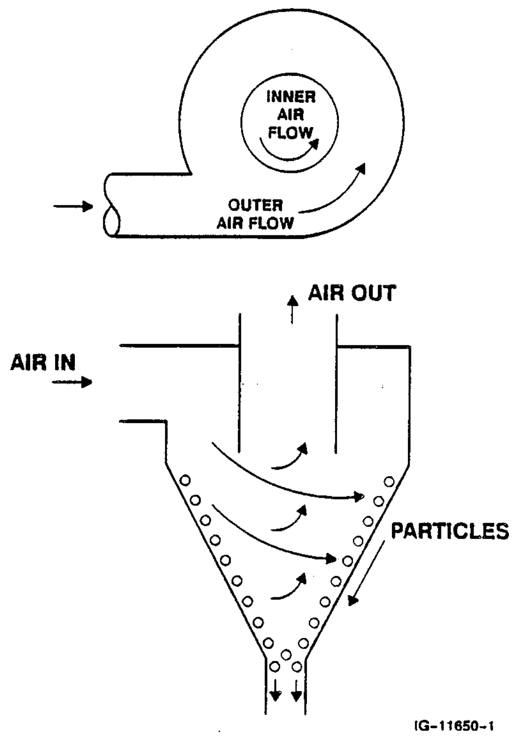


Figure 5. Cyclone for Dust Removal. Advantages Include Simple Design, Low Maintenance, Medium Pressure Drop, and High Load Capability. Disadvantages Include Large Volume and Medium Efficiencies.

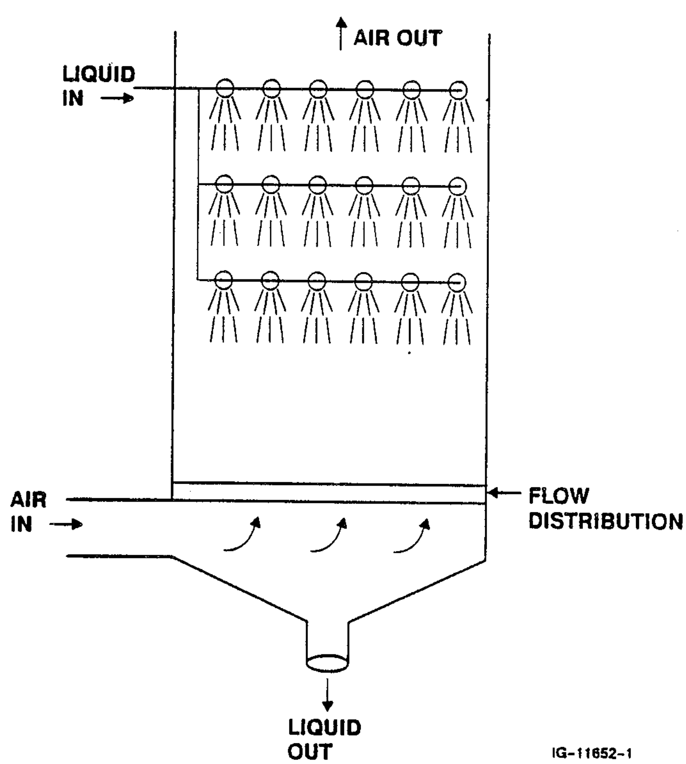


Figure 6. Wet Collector for Dust Removal. Disadvantages Include Need for Water Post-Treatment, Corrosion, and Resupply of Water to the Moon.

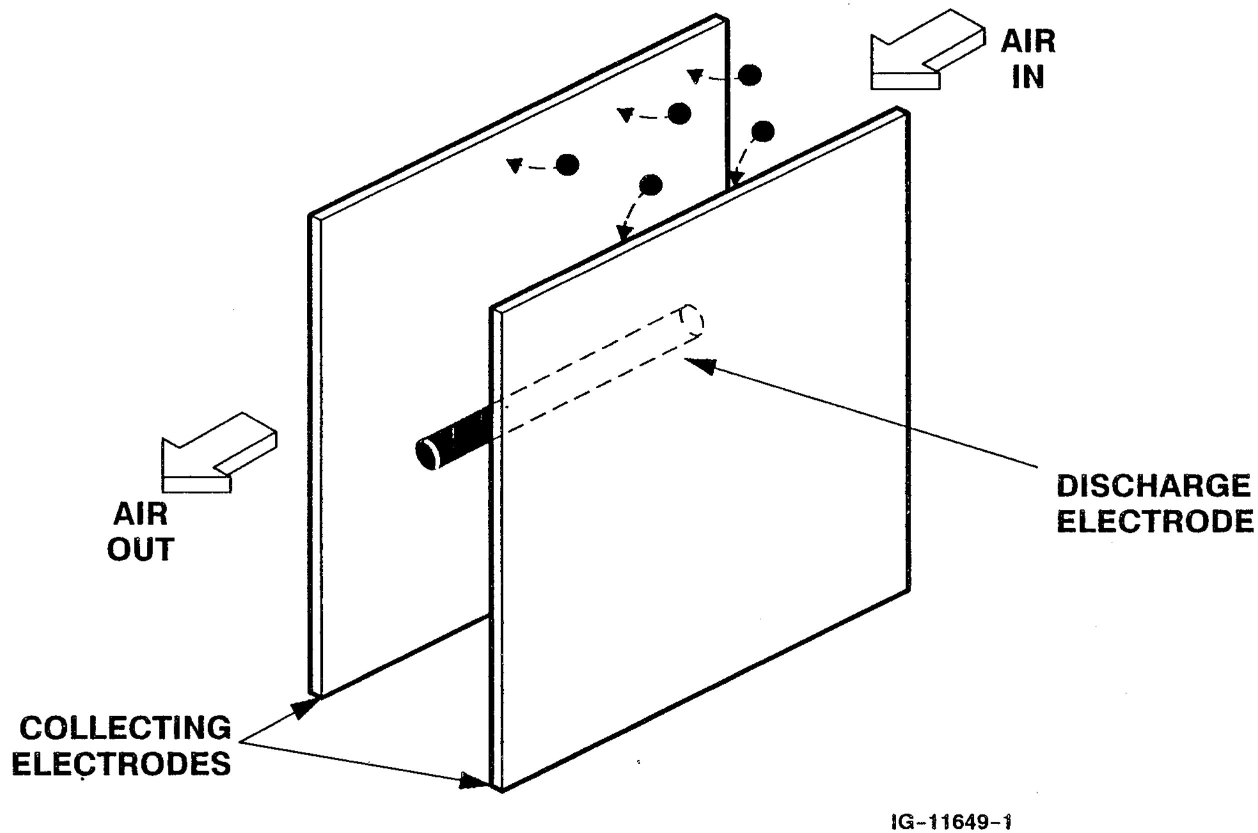
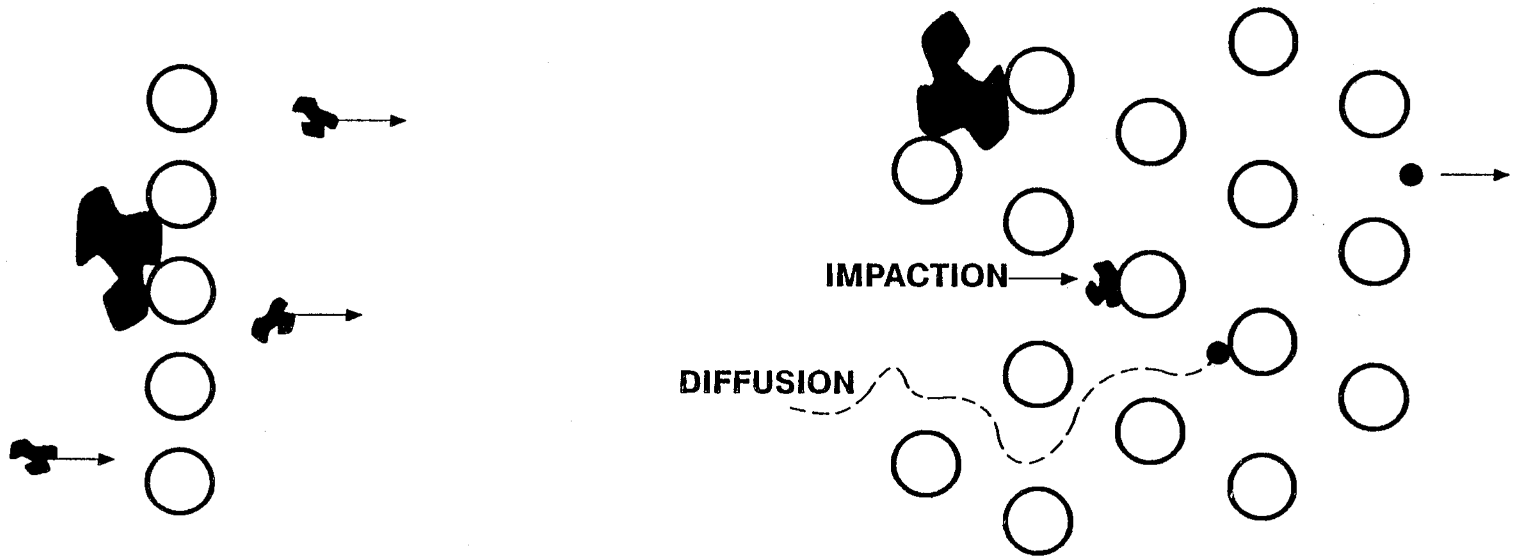


Figure 7. Electrostatic Precipitator for Dust Removal. Advantages Include High Efficiencies and Low Pressure Drop. Disadvantages Include High Voltage, Difficulties in Retaining Some Particles, and Requirements for Periodic Cleaning.



BARRIER FILTER

MEDIA FILTER

ADAPTED FROM RAUBENHEIMER:
"SELECTION AND OPERATION OF
GAS TURBINE AIR FILTERS"

Figure 8. Filters for Dust Removal. Barrier Filters Provide Absolute Size Cuts and Can Be Cleanable, but Have High Pressure Drops. Media Provide High Efficiency and Low Pressure Drops, but are Difficult to Clean, Necessitating Resupply of Media to the Moon.

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