International Space Exploration Coordination Group Assessment of Technology Gaps for Dust Mitigation for the Global Exploration Roadmap

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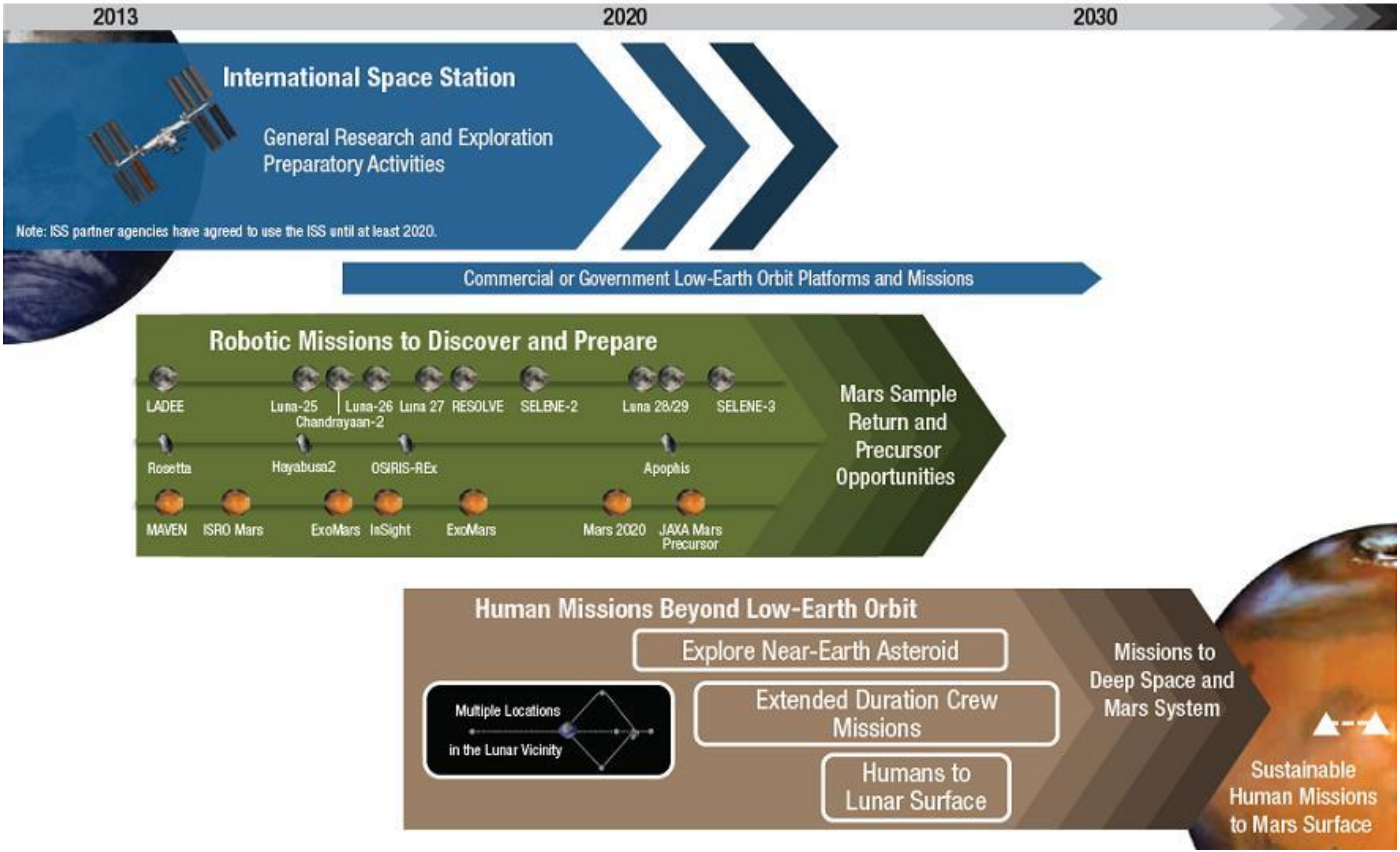
ISECG

Introduction

- International Space Exploration Coordinating Group (ISECG)
  - Established in response to *"The Global Exploration Strategy: The Framework for Coordination"* in 2007
  - Shared vision of coordinated human and robotic space exploration
  - Voluntary, non-binding international coordination
    - Exchange information regarding their interests, plans and activities
    - Work together to strengthen individual exploration programs
    - Devise the collective effort
- Global Exploration Roadmap
  - Strategy for solar system exploration
  - Technology working group critical technology needs
  - **Dust Mitigation** & LOX-Methane Propulsion

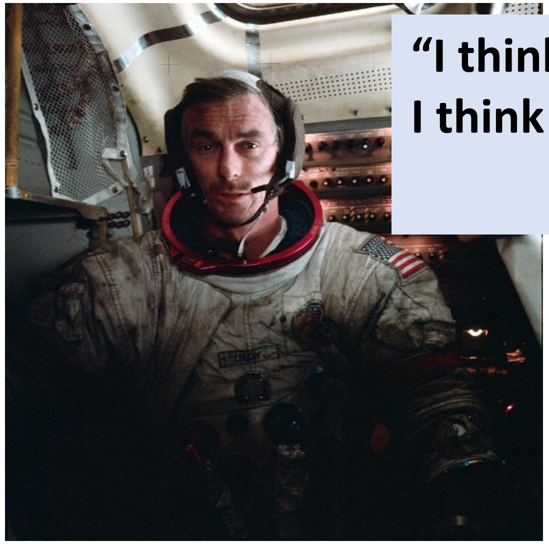
Global Exploration Roadmap



Objectives and Approach

- Technology gap assessment objectives
  - Identify the known dust mitigation challenges
  - Catalog dust mitigation solutions developed to date
  - Assess the gap between known challenges and SOA solutions
  - Identify partnership opportunities
- Assembled an international committee of SME's
  - Scott Vangen (NASA) and Michel Wander (CSA) co-chair
  - Full committee weekly/bi-weekly WebEx meetings
- Presentation made at Feb 2016 ISECG meeting
  - Follow-up, detailed report
  - This summary to introduce to community

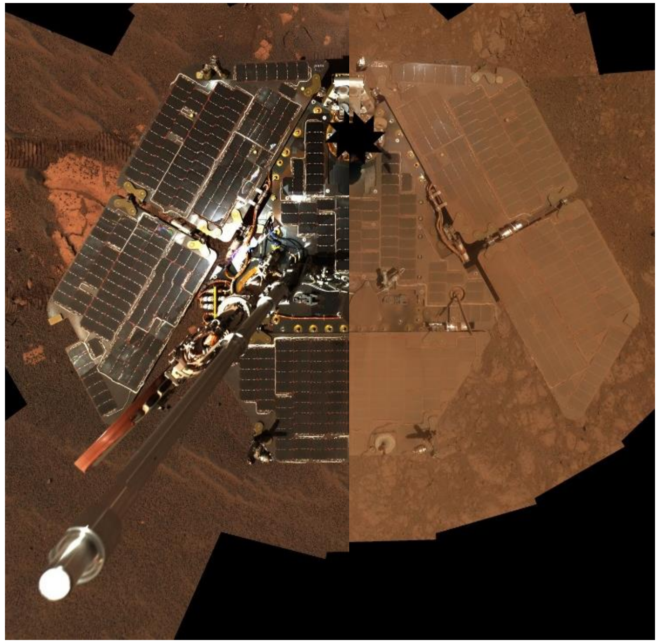
Challenges Posed by Dust



"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."

- Gene Cernan, Apollo 17 Technical Debrief

- 8 dust-sensitive systems were identified
  - Life Support
  - EVA
  - Human health & performance
  - Robotics and mobility
  - ISRU
  - Ascent/Descent vehicles
  - Surface power
  - Thermal control



Dust Mitigation Challenges

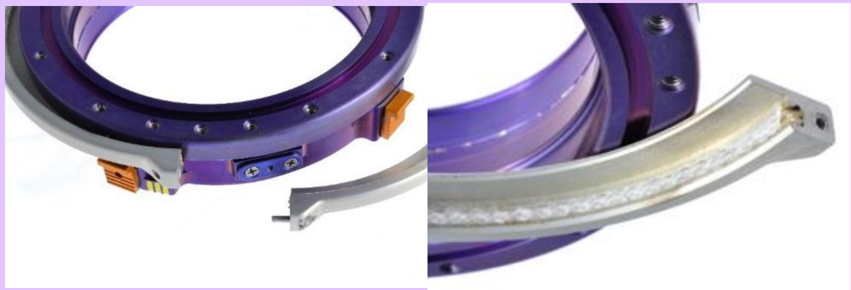
Dust Mitigation Challenges (Requirements Drivers)	Effect due to Dust Exposure	Performance Characteristics
1. Life Support Systems (LSS)	The advanced Life Support System includes atmosphere revitalization, water recovery, solid waste processing, thermal control, and other subsystems. Then each subsystem was further broken into functional…	The LSS must handle a basic particulate load defined in NASA TP-1998-207978, p. 35 and refined by ICES-2014-199 within the concentration limits defined by NASA-STD-3001 for <3 mg/m^3 total dust for particles <100 µm in aerodynamic…
1.1 Atmosphere Revitalization Subsystem	The Atmosphere Revitalization subsystem includes cabin ventilation, trace contaminant control, CO_2 removal, CO_2 reduction, O_2 generation, CO_2 conditioning, and the particulate removal functional elements.	The AR subsystem architecture interfaces intimately with the cabin ventilation architecture. Particulate control is an integral functional component of the cabin ventilation functional element. The core AR subsystem equipment…

Dust Mitigation Solutions

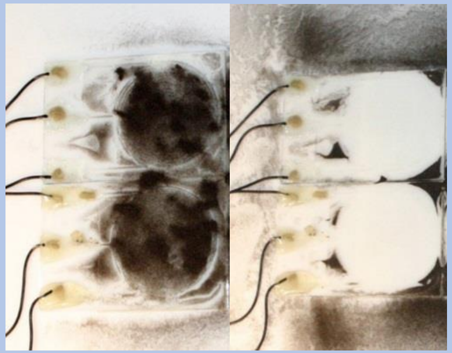
Wide variety of approaches

- Mars and Moon
- Little asteroid work
- Nearly all TRL < 6

Passive Technologies

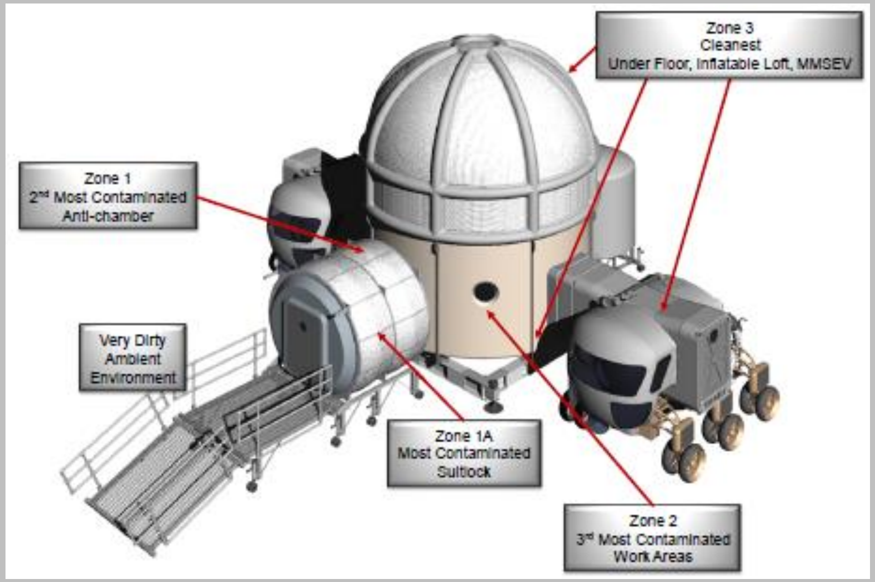


Active Technologies



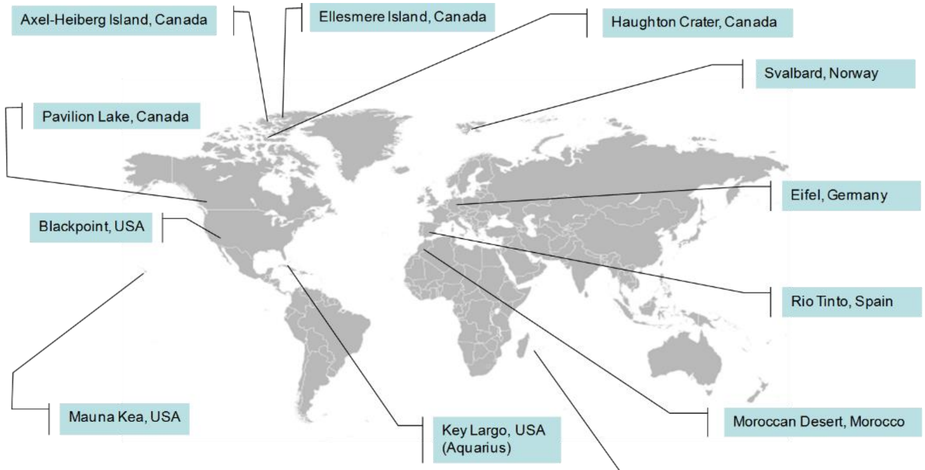
Operational Strategies

Engineering Solutions

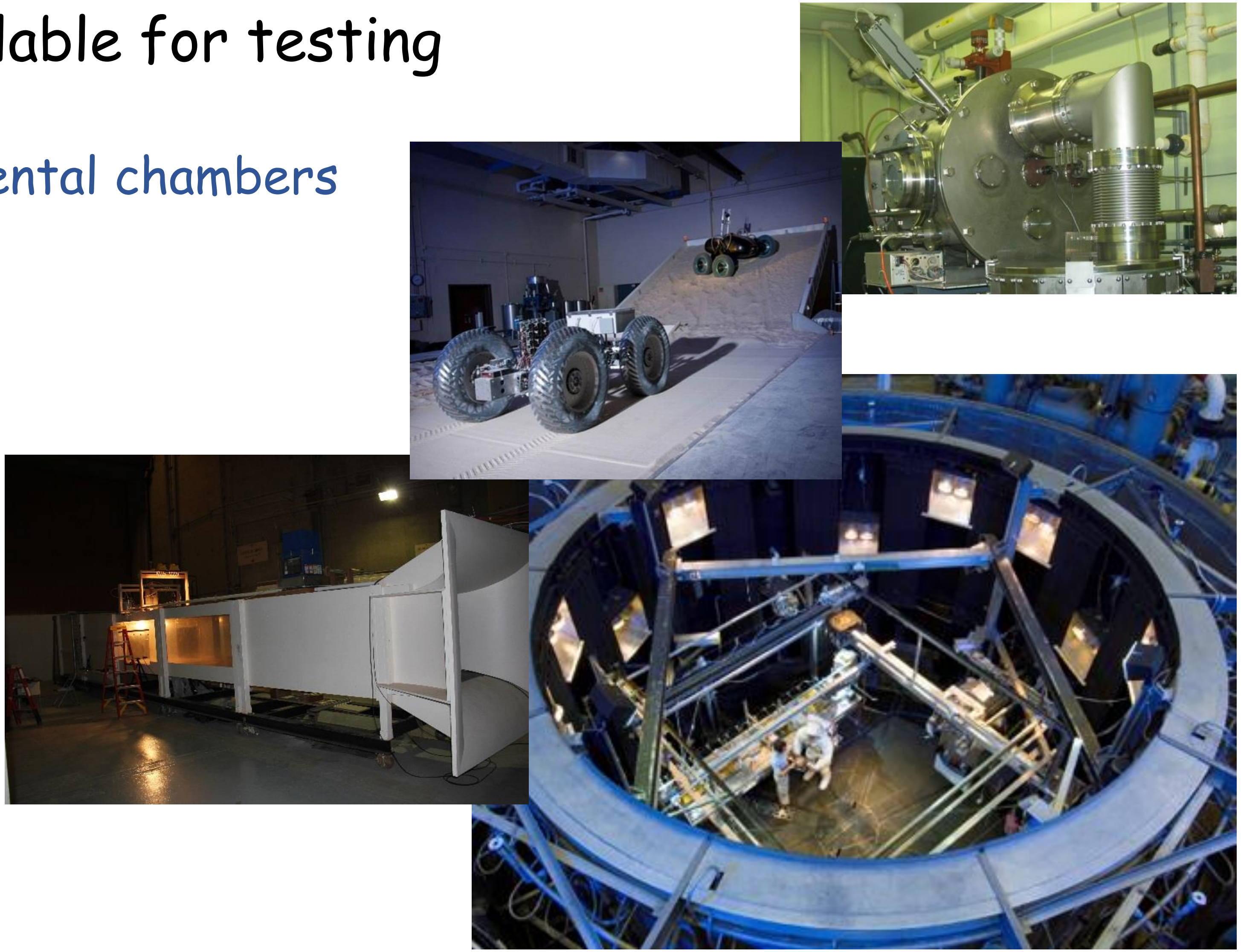


Verification Testing

- Identified facilities available for testing
  - 17 high fidelity simulants
  - 79 high fidelity environmental chambers
  - 5 open air test beds
  - 12 analog sides



The sites listed represent the current range of sites identified by ISECG members. Additional sites are anticipated.
Additional CSA sites have been used but are not shown for clarity



Technology Gap Assessment

- Many systems use similar components
- Identified 13 key technology challenge areas
  - Rotary Seals
  - Linear Motion Seals
  - Static Seals
  - Mating Connectors
  - Filters (Mechanical, Gas Scrubbers, and Other)
  - Human Health (Biological)
  - Thermal Control Surfaces
  - Optical Surfaces
  - Other Surfaces (Performance)
  - Flexible Materials including Fabrics
  - Chemical Contamination and Corrosion/Oxidation
  - Characterization of Dust and Regolith
  - High-Fidelity Simulation Chambers

Technology Gap Assessment

- Identified system components for each challenge area

	Key Technical Challenge Areas	ECLSS	EVA & Airlocks	Mobility & Robotics	ISRU	Ascent/ Descent Vehicles	Systems
1	Rotary Seals	Fans, louvers, pumps	Articulation Joints - Bearings	Wheel bearings, motor bearings, steering & suspension linkages, hinges	Drill & tool bearings, motor bearings, linkages, hinges,	Landing gear, deployment ramps	Fans, Wheels, Antenna

Technology Gap (GER Extended Human Mission)

	Key Technical Challenge Areas	Technology Gap		
		Moon	Mars	NEOs*
1	Rotary Seals	NASA JAXA CSA	NASA CSA	
2	Linear Motion Seals			
3	Static Seals	NASA	NASA	
4	Mating Connectors	NASA	NASA	
5	Filters – Mechanical, Gas Scrubbers, and Other	NASA	NASA	
6	Human Health (Biological)	NASA ESA	NASA ESA	
7	Thermal Control Surfaces	NASA CSA	NASA CSA	
8	Optical Surfaces	NASA CSA	NASA CSA	
9	Other Surfaces – Performance	ESA	ESA	
10	Flexible Materials	NASA		
11	Chemical Contamination and Corrosion/Oxidation	NASA	NASA	
12	Characterization of dust and regolith	NASA JAXA CSA ESA	NASA ESA	NASA
13	High-Fidelity Simulation Chambers	NASA ESA	NASA	NASA
12	Characterization of dust and regolith	NASA CSA ESA	NASA ESA	NASA
13	High Fidelity Simulants and Environmental Chambers	NASA CSA ESA	NASA CSA	NASA

Legend for color coding:

Confident for extended human mission (1+ month Lunar/1+ year Mars)
Possible TRL 3 solutions for extended human mission
No TRL 3 solutions for extended human mission

Note: Agencies listed are either involved in ongoing research or have already developed solutions in that area.

Experience/Knowledge Gap

	Key Technical Challenge Areas	Experience/Knowledge Gap		
		Moon	Mars	NEOs*
1	Rotary Seals	NASA JAXA	NASA	
2	Linear Motion Seals			
3	Static Seals	NASA	NASA	
4	Mating Connectors	NASA	NASA	
5	Filters - Mechanical, Gas Scrubbers and Other	NASA	NASA	
6	Human Health (Biological)	NASA	NASA	
7	Thermal Control Surfaces	NASA JAXA		
8	Optical Surfaces	NASA	NASA	
9	Other Surfaces – Performance			
10	Flexible Materials –	NASA		
11	Chemical Contamination and Corrosion/Oxidation	NASA	NASA	
12	Characterization of dust and regolith	NASA	NASA	NASA
13	High-Fidelity Simulants and Environmental Chambers	NASA	NASA	NASA

Legend for color coding:

Systems that worked effectively (for NASA during Apollo (3 days) on the moon; Worked effectively on rovers on Mars (> 1 year))
Systems where there is no experience, but active research
Systems that did not work well (for NASA during Apollo (3 days) on the moon; Did not work effectively on Mars (> 1 year))
No comprehensive research past or present

Funding/Research Gap

	Key Technical Challenge Areas	Funding/Research Gap		
		Moon	Mars	NEOs*
1	Rotary Seals	NASA JAXA CSA	NASA CSA	
2	Linear Motion Seals	CSA	CSA	
3	Static Seals	NASA	NASA	
4	Mating Connectors	NASA CSA	NASA	
5	Filters – Mechanical, Gas Scrubbers, and Other	NASA	NASA	
6	Human Health (Biological)	NASA ESA	NASA ESA	
7	Thermal Control Surfaces	NASA CSA	NASA CSA	
8	Optical Surfaces	NASA JAXA CSA	NASA CSA	
9	Other Surfaces – Performance	ESA CSA	ESA	
10	Flexible Materials	NASA		
11	Chemical Contamination and Corrosion/Oxidation	NASA	NASA	
12	Characterization of Dust and Regolith	NASA JAXA ESA CSA	NASA ESA	NASA
13	High Fidelity Simulants and Environmental Chambers	NASA JAXA ESA CSA	NASA	NASA

Legend for color coding:

More than one agency involved in ongoing or anticipated research
One agency involved in ongoing or anticipated research
No agencies involved in research on this aspect

Scheduling Gap

Technology Solutions/Programs	GER Mission Start Dates	CDR Need Dates (est.) (note 1)	R&D Start Dates (est.) (note 2)
Lunar Dust Mitigation (Robotics)	2020	2016	2012
Lunar Dust Mitigation (Human)	2026	2022	2016
Martian Dust Mitigation (Robotic)	2020	2016	2012
Martian Dust Mitigation (Human)	2030+	2022+	2018+
NEO Dust Mitigation (Robotic)	2022	2018	2014

Legend for color coding:

Time to start active research is in the future by at least one year taking into account the GER schedule
Time to start active research is this year (2016) taking into account the GER schedule
Time to start active research has passed, likely contributing to delays in the GER

Note 1: Typical space development program runs 6 – 10+ years
Critical Design Review (CDR) 1 - 2 years after start
Dust mitigation technologies must be TRL 4 by Preliminary Design Review (PDR), and TRL 6 by CDR

Note 2: Assumed that the dust mitigation programs take 4 years to develop viable solutions and techniques.
Where ESA has provided estimates for research programs, those dates were entered.

10 Key Findings

ISECG

- Dust is still a principal **limiting factor** in returning to the lunar surface for missions of any extended duration.
- Viable **technology solutions** have been identified, but **need maturation** to be available to support missions.
- **No single technology** completely solves the challenges of dust, but rather a suite of technologies will be required to address them.
- **Gaps** in existing dust mitigation technologies have been identified and **require strategies for closure** before extended lunar missions are undertaken.
- Situational **awareness** of the dust mitigation challenges **needs to be infused** into all aspects of mission architecture and operations.
- **Investment** in dust mitigation solutions **increases system longevity** and performance (including human-system performance).

Key Findings (cont.)

- **Resources** (power, mass, volume) may be required to implement some of the mitigation solutions, but are **offset** by reduced logistics costs for spares, redundancies, etc.
- **Solutions that work in one environment** may not be fully applicable to other environments or destinations (e.g., chemistry differences, atmospheres, particles, locations on previously explored bodies).
- **Trapped volatile gases** are an additional factor of potential concern, which may require unique mitigation solutions.
- **International cooperation** within the dust mitigation community has already proved beneficial. This is currently limited to sharing information, but further opportunities are expected as commitment to narrowing the technology gap continues.

Summary

- Report will be helpful to organizations within agencies responsible for dust mitigation
  - Technology development program offices
  - Systems engineering groups
  - Exploration architecture teams
  - Program/project-level management
- Points the way for efficient use of the resources of the world's space agencies
  - Available simulants
  - Facilities and analog sites
  - Areas of active research
- Spurs collaboration and cooperation among the agencies
- Attracts prompt and proper attention, support, and work addressing dust mitigation associated with exploration destinations critical to the success of the GER scenario