



Planetary Environmental Simulator/Test Facility Simulating Lunar and Martian Dust Environments

About the Technology

SimulTek Research Company Ltd. in collaboration with the Canadian Space Agency and ITL Inc. has developed a facility for simulation of the effects of the Lunar/Martian dust environments. The simulator is able to provide the following environmental factors:

- ultra-high vacuum or atmospheric conditions;
- Lunar/Martian dust conditions;
- VUV/NUV radiation;
- thermal conditions/thermal cycling; and
- darkness.

The facility can be used for testing and life time evaluation of planetary exploration spacecraft materials and systems, as well as for verification of the effectiveness of dust mitigation strategies and technologies to be developed for the planetary exploration surface systems.

The *basic* lunar environmental simulator/test facility includes the following components:

- thermal-vacuum chamber;
- sample positioning/sample holder system;
- dust particles source;
- VUV/NUV radiation sources;
- motion feed-through and drive systems;
- simple in-situ measurement sensors; and
- support electronics and control software.

The modular design of the facility allows further development for simulation of the conditions of different planetary environments, including the Mars, Venus, and Jupiter planetary environmental factors.

Significance of the Technology

The Planetary Environmental Simulator/Test Facility is an instrument that can be used for development, testing, and life time evaluation of candidate spacecraft materials and mechanical systems, space suits, and planetary mission crew habitats. The *basic* facility contains a number of environmental sources to simulate the planetary surface environments, including dust

particles, UV radiation, temperature conditions and darkness, as well as simple fixtures and test rigs enabling to conduct mechanical testing of planetary rovers components.

The design of the simulator facility allows testing where dust would be the most important environmental factor to verify the operational capability of newly



The image shows the Vacuum Chamber of the Planetary Environmental Simulator/Test Facility

developed planetary exploration hardware, including:

- drive systems;
- deployment systems;
- vision systems;
- mechanical mechanisms;
- seals;
- docking systems.

The main objective of testing would be verification of dust tolerant designs, as well as studying and improvement of the dust and other environmental factors mitigation strategies.

Simulation Technologies

The Planetary Environmental Simulator/Test Facility

Technical Specifications

The simulator facility consists of a stainless steel high vacuum chamber with one of its ends ending as a semi-spherical basis. The sample holder/sample transfer system allows a total displacement of ~12" inside the chamber and allows for heating, cooling, and thermal cycling of the samples.



The Sample Holder/Sample Transfer System

The vacuum pumping system of the simulator facility has an essential requirement of being robust to any dust that would find its way into it. The developed Dust Filter includes five baffle plates with alternating windows at the "top-bottom-top-bottom-top" positions covered with a fine metallic mesh to prevent dust particles from getting into the vacuum pumps.

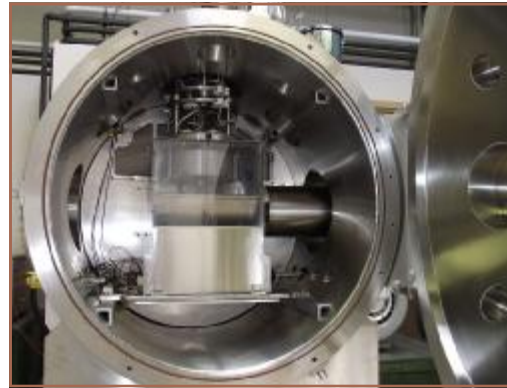


The Dust Particles Source with Housing (left) and an example of generated dust cloud (right)

The *basic* Dust Particles Source includes a Lunar/Martian soil simulant container, a Dust Source Housing, and a funnel-like closed structure in which dust cloud is generated. Dust particles are agitated by a paddle actuator, allowing generating different configurations of the dust cloud. This system is also used to mix the particles in the stage of dust simulant preparation.

	Parameter	Value
Vacuum System	Volume, m ³	~0.7
	Pumping speed (N ₂), l/s	2,050
	Basic vacuum, Torr	< 2×10 ⁻⁷
Dust Source	Lunar soil simulant	JSC-1AF
	Dust thermal conditioning	RT/+200
	Dust activation	VUV
Sample Holder/ Sample Transfer System	Holder size, cm ²	314
	Temperature range, °C	-180/+200
	Mechanical testing	Rotary or translational
VUV Source	Type of VUV Source	Hamamatsu L2D2 lamp
	Wavelength, nm	115-200

Testing in simulated conditions of Lunar/Martian dust requires a methodology for appropriate preparation of the lunar soil simulant (JSC-1A or similar). Once activated by VUV or other alternative methods (RF plasma, electrons/protons), dust can be applied to a sample and the coverage, adhesion of dust



The Dust Source Assembly Inside the Simulator Chamber

particles to the surfaces can be determined. A number of physical properties and parameters of the lunar dust simulant can be used to control the dust particles activation process.

Lunar Environment Simulator System

SimulTek Research Co. based on its previous accumulated experience and associated with it methodology has developed and manufactured specific environmental testing equipment to be used for ground-based simulation of the harsh conditions of the Moon in a more efficient way.

The Lunar Environment Simulator System (LESS™) is a new generation lunar planetary simulation facility designed that can be used for routine testing the lifetime and performance of various mechanical components of the lunar surface exploration equipment. The simulated lunar environment can include high vacuum, extreme temperature, UV radiation for dust charging, and lunar dust. The improvements over the previous simulator system consist in using better lunar soil simulants, creation of more efficient ways of interaction of dust particles with the samples, higher vacuum, better correlated simulation scenarios, more realistic thermal and illumination environments, and addition of a source of charged particles (protons) to simulate the possible effects of the solar wind, an environmental factor that is also present on the Moon surface.

The LESS™ system includes a vacuum chamber that can provide the simulated lunar environment. The vacuum chamber is able to accommodate either a test rig (a Sample Holder / Thermal Platform) with feedthroughs to achieve linear and rotational motion, or a large-scale structure (when the test rig is removed) along with its accessories and mechanical and electrical interfaces, etc. Lunar dust simulant, such as JSC-1AF or similar, will be used to create a dust cloud simulating the

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Lunar dust environment. The facility is equipped with a data acquisition and data analysis system. The data acquisition system is able to perform real-time, *in situ* measurement of the vacuum pressure in the vacuum chamber, heat sink (cold shroud) temperature, intensity of UV radiation, basic lunar dust properties, etc. The LESS™ system is equipped with the system operation support electronics and is operated through SimulTek-developed computer control software.

Basic Configuration

The lunar planetary conditions are simulated in the proposed LESS™ simulator system that includes the following main components:

- Main vacuum chamber;
- Dust simulation unit;
 - Dust preparation module;
 - UV dust charging unit;
 - Dust cloud forming unit;
- Vacuum pumping system;
- Experimental Test Rig/Sample Holder Box;
- PLC-based electronic control system;
- Data acquisition and analysis system.



The LESS™ simulator system

Vacuum Chamber and Pumping System

Based on the criteria produced to laboratory simulation of the lunar planetary environment and on the previous ITL/SimulTek company's experience, the vacuum chamber is manufactured from stainless steel with vacuum connections (flanges) providing for high-vacuum conditions. The vacuum chamber has the maximum possible axial symmetry of all flanges, thus facilitating alignment of the influence from various sources for simultaneous simulated exposure and installation of various analytical equipment.



The Vacuum Chamber with the Test Rig/Sample Holder Box

The vacuum system includes three high performance Agilent Turbo-V 3K-G pumps with a 2,200 L/sec pumping speeds each. In order to prevent dust getting into the turbo pumps, a dust filter was specially designed to ensure that no dust gets into the clean compartment, virtually without affecting the pumping performance the pumps. To clean the filter from contamination accumulated due to adsorption, the filter system includes its own controlled heating system.

To prevent unnecessary dust contamination during the initial pumping stage, a three-stage pumping system for the dust preparation system was developed. Initially, pumping is performed through a custom valve having a very small through-hole (2-3 mm). This allows for a small (less than 0.01 L/sec) pumping capacity from the dust preparation system. Once the vacuum of approximately 10^{-1} Torr is reached, the pumping system automatically switches to the standard fore-vacuum pumping mode followed by turbo pumping to reach high vacuum environment.

Test Rig/Sample Holder Box

The Test Rig/Sample Holder Box is an ultra-high vacuum set-up installed inside the simulator chamber and designated for sample holding, positioning, as well as for heating, cooling, and thermal cycling of the samples.

The Sample Holder Hot/Cold Platform provides a surface area of 40x40 cm² for accommodating a sample. The Sample Holder Platform can be manually pulled out of the simulator chamber using specially designed mechanism for convenient mounting/unmounting or servicing the sample tested on the rig.

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Dust Preparation System

The lunar dust simulant preparation assembly is designed as a separate vacuum chamber and is mounted on top of the testing chamber using CF 12" compatible vacuum gate valve. The apparatus consists of a housing made from stainless steel, pumping system, sample loading gate, two dust transporting conveyors, and controlled dust heating and pouring systems.

Loading of the lunar dust is carried out at atmospheric pressure through a window located on top of the device. Initially, approximately 10-15 kg of lunar dust simulant should be loaded through the loading window before starting the vacuum pumping system. After the initial load and closing the loading window, the system starts the three-stage pumping process as previously described. Once the stable vacuum of about 10^{-7} Torr is reached, the dust preparation system will start controlled heating of the lunar dust simulant. The dust preparation stage can be considered complete when the vacuum pressure drops to 10^{-7} Torr.



The dust preparation module

Once the lunar dust simulant is successfully heated, it is then loaded directly into the simulator forming the dust cloud in the testing area of the main vacuum chamber. At that point, the gate valve opens up and the vacuum pressure in the testing chamber and the device is automatically aligned.

Dust Source Operation

After successful preparation and loading of the necessary amount of the lunar dust simulant into the bunker of the dust cloud forming system, the vacuum gate is closed and the bunker, driven by a step motor, starts to spill the dust on the top diffuser. When the bunker is operated in the specific mode, the top layer of the mesh becomes covered with a uniform

layer of the lunar dust simulant, which is shaped as a line. At that time, the mesh starts to vibrate. Such shaking is achieved using a pair of cam gears and corresponding step motors.



The dust sprinkler mechanism

Effectively, the dust cloud is formed, whose uniformity can be achieved by a proper selection of the vibration parameters for both mesh diffusers. Moreover, changing the vibration parameters (frequency, amplitude) can be used to modify and adjust the shape of the dust cloud to the conditions of the experiment.

Benefits of the Technology

New practical applications, technology transfers and business opportunities related to this technology are based on many innovative capabilities that can be of very high interest for various research in simulated Lunar/Martian environments:

- Effect of dust on thermal control surfaces;
- Adhesion of dust on sensitive surfaces;
- Abrasion of space suit fabrics by dust;
- Effectiveness of dust sealing technologies;
- Wear of mechanisms by dust.

The potential uses include:

- Evaluating adherence of Lunar/Martian dust stimulants to various power-system component surfaces and coatings while at operating temperatures;
- Development of testing methodologies to conduct testing in simulated Lunar/Martian surface environments;
- Evaluating thermal performance of external thermal control coatings evaluated as function of dust coverage;
- Adding solar simulator to conduct solar cell performance tests as function of dust coverage and temperature while in vacuum environment;
- Evaluating Lunar/Martian dust mitigation, removal techniques, and special coatings;
- Studying dust-particle behavior in electrostatic fields, dust-charging mechanisms, dust-transport theories, and plasma effects.