THE EXTRATERRESTRIAL MATERIALS SIMULATION LABORATORY

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Challenges of In Situ Exploration in the Outer Solar System: In contrast to fly-by and orbital missions, in situ missions face an incredible array of challenges in near-target navigation, landing site selection, descent, landing, science operations, sample collection and handling, drilling, anchoring, sub-surface descent, communications, contamination. The wide range of materials characteristics and environments threaten mission safety and success. For example, many physical properties are poorly characterized, including strength, composition, heterogeneity, phase change, texture, thermal properties, terrain features, atmospheric interaction, and stratigraphy. Examples of the range of materials properties include, for example: (1) Comets, with a possible compressive strength ranging from a light fluff to harder than concrete: $10^2 – 10^8$ Pa; (2) Europa, including a possible phase change at the surface, unknown strength and terrain roughness; and (3) Titan, with an completely unknown surface and possible liquid ocean.

The Extraterrestrial Materials Simulation Laboratory: A new laboratory for the physical simulation of extraterrestrial surface materials has been developed to support the development of upcoming in situ missions. In the Extraterrestrial Materials Simulation Laboratory (EMSiL) we develop new formulations, methodologies, and technologies to create ambient and cryogenic simulant materials for use in testing and validation of in situ surface systems and vehicles, such as In Situ Explorers, Subsurface Systems, Cryobots, Hydrobots, Moles, Anchoring Systems, and Drilling Systems for environments, such as the Galilean satellites (Europa, Ganymede, Callisto, and Io), Titan, comets, and asteroids, as well as Antarctica, Mars polar regions. The design and costs of in situ missions are significantly affected by the large uncertainties in our knowledge of the working environments and surface materials properties. In situ missions in the Outer Solar System will require realistic test materials and environments in which to test new technologies and systems as part of an active design and test cycle. The unknowns of the in situ environment can drive up costs and mass in order to reduce risks. A well-planned test program in relevant materials and conditions can reduce risk and foster Mission Safety. The importance of realistic testing and simulation capabilities was emphasized in the *Report on Project Management in NASA by the Mars Climate Orbiter Mishap Investigation Board* (Stephenson et al) which states "Conduct extensive testing and simulation in conditions as similar to actual flight conditions as possible." JPL's Extraterrestrial Materials Simulation Laboratory serves three functions: (1) Perform research to understand better the in situ surface environments and to predict expected physical properties; (2) Develop, formulate, and test terrestrial analog materials that will match the properties expected in the in situ environment; (3) Develop and deliver small- and large-scale test articles and materials to the test programs for in situ missions and associated technology programs to aid in the design and test cycle to reduce mission risk and cost.

Description: Over the past few years we have developed a variety of laboratory hardware and methodologies to: create cryogenic ice-dust mixtures, contain and process the materials in a specially designed cryogenic high vacuum chamber, and study the effects of insolation from measurements of the changing physical properties of a variety of ice/dusty mixtures. In particular, we create suspensions of water, minerals, and other relevant components with a composition similar to those expected of extraterrestrial environments, based on telescopic and spacecraft observations. We can finely specify the particle size range of the minerals through the use of an air jet sieve system that allows us to grade particles to sizes less than 5 microns. After a mixing procedure that includes the ultrasonic break-up of flocculated particles, the suspension is atomized and sprayed into a liquid nitrogen bath contained in a LN2-cooled, instrumented sample canister (cylinder: diameter = 0.20 m; depth = 0.25 m), which is adaptable enough to provide cooling for the back-plate only, sides only, or for the entire canister. Upon completion of the formation of the analog materials, we transfer the sample canister to the cryogenic vacuum chamber (10e-9 Torr). Once in the vacuum chamber, the canister can be oriented from 0-45 degrees with respect to the incoming insolation. The solar simulator output covers 0.1-2.1 Solar Constant. Temperatures are measured with 10 sensors in the mixture inside the canister. The gas release is monitored as a function of time with two mass spectrometers: one for the lower pressures and one for the higher pressures that may develop during an outburst. Dust release is recorded on videotape. A mechanical penetrator-scratcher measures penetrability and disturbs the surface for assessment of surface changes. At the end of the experiment, the sample is removed and core samples are taken for tests of compression strength, penetrability, porosity, density, and thin section analysis. Methods allowing detailed microscopic examination of the samples are under development. A freezing microtome for cutting thin sections of the sample and a freezing stage on a microscope are to be used for examination of the pore and grain structure of the icy mixtures. With all elements in place for the laboratory simulation of extraterrestrial materials, we are now performing our first experiments to simulate relevant in situ materials. The next steps in the process to support the test programs for upcoming in situ missions in the Outer Solar System is the development of low cost ambient, as well as cryogenic, test materials and the ability to produce the desired volumes of simulants, which can be very large. We have begun these steps and are currently supporting test and validation programs for advanced technologies, advanced mission studies, and flight projects.

Conclusion: The Extraterrestrial Materials Simulation Laboratory will play an important role in reducing risk and aiding mission success for upcoming in situ missions in the Outer Solar System. An active design and test cycle with tests in well-calibrated, reproducible, well-documented simulant materials will ensure optimized designs and reliability of spacecraft components and systems.