DEM Solutions Develops Answers to Modeling Lunar Dust and Regolith
By Carol Anne Dunn, Dr. Carlos Calle, and Dr. Richard D. LaRoche

Going back to the Moon presents many problems—one of the major problems is dealing with lunar dust. Dr. Carlos Calle, founder and director of the Electrostatics and Surface Physics Laboratory at NASA Kennedy Space Center, is very familiar with the problems of lunar dust and has carefully reviewed the Apollo Mission Reports and debriefings in order to familiarize himself with the problems the Apollo astronauts encountered during their missions. The reports indicated that the astronauts had limited visibility during descent due to dust effects and that there was even concern that blast ejecta would damage the lunar module. This was just the beginning of the problems that the Apollo astronauts had to contend with due to the highly abrasive dust. NASA was concerned for the health of the astronauts as they inhaled and ingested the dust and that the lunar module and sensitive equipment could also be contaminated by lunar dust. On one mission (Apollo 15) a camera failed due to lunar dust entering the drive mechanism.

With the proposed return to the Moon, scientists like NASA-KSC's Dr. Calle are concerned for a number of reasons. We will be staying longer on the planet's surface, future missions may include dust-raising activities, such as excavation and handling of lunar soil and rock, and we will be sending robotic instruments to do much of the work for us. Understanding more about the chemical and physical properties of lunar dust, how dust particles interact with each other and with equipment surfaces and the role of static electricity build-up on dust particles in the low-humidity lunar environment is imperative to the development of technologies for removing and preventing dust accumulation, and successfully handling lunar regolith. Dr. Calle is currently working on the problems of the electrostatic phenomena of granular and bulk materials as they apply to planetary surfaces, particularly to those of Mars and the Moon, and is heavily involved in developing instrumentation for future planetary missions.

With this end in view, the NASA Kennedy Space Center's Innovative Partnerships Program Office partnered with DEM Solutions, Inc. DEM Solutions is a global leader in particle dynamics simulation software, providing custom solutions for use in tackling tough design and process problems related to bulk solids handling. Customers in industries such as pharmaceutical, chemical, mineral, and materials processing as well as oil and gas production, agricultural and construction, and geo-technical engineering use DEM Solutions' EDEM™ software to improve the design and operation of their equipment while reducing development costs, time-to-market and operational risk. EDEM is the world's first general-purpose computer-aided engineering (CAE) tool to use state-of-the-art discrete element modeling technology for the simulation and analysis of particle handling and manufacturing operations. With EDEM you can quickly and easily create a parameterized model of your granular solids system. Computer-aided design (CAD) models of real particles can be imported to obtain an accurate representation of their shape. EDEM™ uses particle-scale behavior models to simulate bulk solids behavior. In addition to particle size and shape, the models can account for physical properties of particles along with interaction between particles and with equipment surfaces and surrounding media, as needed to define the physics of a particular process. EDEM also provides data analysis tools for

the extraction of bulk statistics and metrics from the particle-scale data, and 3D visualizations of the particle dynamics. In addition many of the physics models can be programmed externally, which enables EDEM to provide a platform for multi-physics simulation—integrating particle, machine and fluid dynamics. The flexibility and extensibility of the software literally enables the simulation of granular materials from powders to gravel; however, in order for the software to simulate lunar regolith applications, additional modeling and validation of electrostatic and surface energy adhesion forces, dynamic friction, and particle shape were required.

The partnership with DEM Solutions was in response to a NASA Innovative Partnerships Program Partnerships Seed Fund Call for Proposals – 2007. DEM Solutions was able to leverage previous work funded by NASA Kennedy Space Center's IPP where they worked closely with NASA engineers to develop custom solutions for modeling the effects of Coulombic electrostatic forces on particles. (Coulomb = a unit of electrical charge equal to the amount of charge transferred by a current of 1 ampere in 1 second.) The new proposal enhanced the existing EDEM software to provide more accurate modeling of lunar dust and regolith—with the potential to improve design quality and provide significant savings, especially in respect to field testing. "We wanted to build on an off-the-shelf software: the user-friendliness and range of capabilities in EDEM made it attractive. The experience of the staff at DEM Solutions in modeling complex particulate systems such as encountered in space applications gave us the confidence that they would be a strong partner," said Dr. Carlos Calle.

NASA isn't the only organization looking to benefit from this technology. Dr. Carol Plouffe, P.E., engineering manager working for John Deere, said, "The goals of the project are of great interest to John Deere since we have similar objectives as NASA in terms of being able to build reliable models of bulk particulate behavior and are users of EDEM software. Most of the agricultural and construction machinery developed by Deere involves the movement of bulk material and Deere has long recognized that DEM is one of the most promising approaches to simulation of such systems." Dr. Plouffe went on to say, "by developing the capability to model lunar regolith, which is a fine cohesive material with angular particles and cohesive properties, the project is likely to solve some of the modeling challenges we face on Earth with cohesive or sandy soils."

The DEM Solutions Seed Fund proposal provided NASA with the needed expertise in particle dynamics simulation and a custom CAE tool that supported already funded ESMD Exploration Technology Development Program (ETDP) initiatives in Dust Mitigation and In situ Resource Utilization (ISRU). NASA's use of EDEM as a platform for multi-physics simulation of lunar dust particles helped mitigate the ETDP technology risk of qualifying dust/coating interaction by virtually modeling the behavior of the dust in contact with coatings of the KSC electrodynamics screen. EDEM simulations now augment the development of NASA surface systems dust mitigation technologies that are designed for dust removal and cleaning of optical and thermal radiator surfaces, connectors, and seals. EDEM virtual prototyping capabilities also streamline the design process for development of systems for ISRU excavation, traction, material flow, and the electrostatic separation of ilmenite.

This was done by incorporating dust algorithms into existing DEM software by the addition of dielectrophoretic force calculation to the code for dust screen and regolith beneficiation simulations for ISRU; importing the electrodynamics' screen simulations from previous software into EDEM; addition of Van der Waals forces for small particles adhesion to surfaces; and addition of dynamic and rotational friction forces. In physical chemistry, Van der Waals forces (named after Dutch scientist Johannes Direrik van der Waals) are the attractive or repulsive force between molecules (or between parts of the same molecule) other than those due to covalent bonds or to the electrostatic interaction of ions with one another or with neutral molecules. Both the NASA KSC Electrostatics and Surface Physics laboratory and the NASA Glenn Research Center's ISRU Lunar Regolith Characterization Laboratory participated in this partnership. Both centers' team members helped to identify the correct physics for addition to the EDEM code. DEM Solutions provided eight perpetual licenses (4 to NASA-KSC and 4 to NASA-GRC) for the new EDEM software resulting from this work. NASA matched the DEM Solutions contribution by providing labor funding for DEM Solutions and associated NASA personnel.

NASA's IPP Seed fund has been highly successful in leveraging its funds with partners and infusing the resulting technology back into the program. EDEM software was successfully developed in the areas of particle electrostatics and tribocharging, interaction between charged particles and a varying electric field, and surface energy based particle cohesion to support preliminary simulations for Dust Mitigation and ISRU. In addition, according to Dr. Richard D. LaRoche, Vice President of Engineering and US General Manager, DEM Solutions, these new EDEM capabilities can be applied in many industries unrelated to space exploration and have been adopted by several prominent US companies including John Deere, Pfizer, Xerox and Procter & Gamble. The honest conclusion is that this project was definitely a win-win situation for all involved and once again proves that NASA's Innovative Partnerships Program's Seed Fund is an innovative way to not only help the space program but to provide an additional resource for U.S. industry that not only stimulates the economy but provides hardcore answers to difficult problems.

Much of the information on DEM Solutions can be found on their website at http://www.dem-solutions.com. Thanks should be given to DEM Solutions for help in writing this article. Please contact DEM Solutions (USA) Inc., 24 Hanover Street, Suite 10, Lebanon, NH 03766 or Dr. Richard LaRoche (richard.laroche@dem-solutions.com); For NASA Innovative Partnerships Program Seed Fund questions, please contact Alexis Hongamen NASA-KSC Partnership Program Manager; and for questions regarding the Electrostatics and Surface Physics Laboratory at NASA Kennedy Space Center, please contact Dr. Carlos Calle, Senior Research Scientist, NASA, Kennedy Space Center (carlos.i.calle@nasa.gov).