Information Technology

Numerical Simulation of Rocket Exhaust Interaction With Lunar Soil

These simulations will help predict suitable landing sites on the Moon.

John F. Kennedy Space Center, Florida

This technology development originated from the need to assess the debris threat resulting from soil material erosion induced by landing spacecraft rocket plume impingement on extraterrestrial planetary surfaces. The impact of soil debris was observed to be highly detrimental during NASA's Apollo lunar missions and will pose a threat for any future landings on the Moon, Mars, and other exploration targets.

The innovation developed under this program provides a simulation tool that combines modeling of the diverse disciplines of rocket plume impingement gas dynamics, granular soil material liberation, and soil debris particle kinetics into one unified simulation system. The Unified Flow Solver (UFS) developed by CFDRC enabled the efficient, seamless simulation of mixed continuum and rarefied rocket plume flow utilizing a novel direct numerical simulation technique of the Boltzmann gas dynamics equation. The characteristics of the soil granular material response and modeling of the erosion and liberation processes were enabled through novel first principle-based granular mechanics models developed by the University of Florida specifically for the highly irregularly shaped and cohesive lunar regolith material. These tools were integrated into a unique simulation system that accounts for all relevant physics aspects: (1) Modeling of spacecraft rocket plume impingement flow under lunar vacuum environment resulting in a mixed continuum and rarefied flow; (2) Modeling of lunar soil characteristics to capture soil-specific effects of particle size and shape composition, soil layer cohesion and granular flow physics; and (3) Accurate tracking of soil-borne debris particles beginning with aerodynamically driven motion inside the plume to purely ballistic motion in lunar far field conditions.

In the earlier project phase of this innovation, the capabilities of the UFS for mixed continuum and rarefied flow situations were validated and demonstrated for lunar lander rocket plume flow impingement under lunar vacuum conditions. Applications and improvements to the granular flow simulation tools contributed by the University of Florida were tested against Earth environment experimental results. Requirements for developing, validating, and demonstrating this solution environment were clearly identified, and an effective second phase execution plan was devised. In this phase, the physics models were refined and fully integrated into a production-oriented simulation tool set. Three-dimensional simulations of Apollo Lunar Excursion Module (LEM) and Altair landers (including full-scale lander geometry) established the practical applicability of the UFS simulation approach and its advanced performance level for large-scale realistic problems.

The features and benefits of the developed simulation system enable the screening of landing risk scenarios through: identification of dust and debris transport footprint to protect surrounding assets; prediction of level of erosion and cratering as a function of rocket size and of local soil properties; input into the design of landing pad solidification or paving techniques; minimization of debris environment through optimization of propulsion system layout and landing approach flight path; and designing dust and debris impact mitigation measures such as berms, deflectors, and fences.

This work was done by Peter Liever and Abhijit Tosh of CFD Research Corporation and Jennifer Curtis of the University of Florida for Kennedy Space Center. Further information is contained in a TSP (see page 1). *KSC-13605*

Motion Imagery and Robotics Application (MIRA): Standards-Based Robotics

MIRA initial results have demonstrated robotic camera control that is applicable to near-Earth or distant applications.

Lyndon B. Johnson Space Center, Houston, Texas

The current Mission Control Center (MCC) is dedicated to the execution of human spaceflight missions. As the future of NASA and human space evolves, it is clear that robotic artifacts will ultimately be integrated and immersed into the human mission. In order to make the evolution and integration as technically capable at a constrained risk level and with reasonable cost, the robotic elements must adhere to standards that allow not only reuse of previous work, but keep the interfaces stable and reusable.

The MIRA project integrates several telerobotic functions into a powerful Consultative Committee for Space Data Systems (CCSDS) international standards-based telerobotic service capable of running in an International Space Station (ISS) payload computer. The MIRA goal was to mature, integrate, and demonstrate the MIRA concept (see figure), with Spacecraft Monitoring and Control (SM&C), Asynchronous Mes-