time physics-based simulation algorithms have also been developed that include models of internal forces and the forces produced when a mechanism interacts with the outside world. This capability is combined with an innovative organization for simulation algorithms, new regolith simulation methods, and a unique control and study architecture to make powerful tools with the potential to transform the way NASA verifies and compares excavator designs.

Energid's Actin software has been leveraged for this design validation. The architecture includes parametric and Monte Carlo studies tailored for validation of excavator designs and their control by remote human operators. It also includes the ability to interface with third-party software and human-input devices. Two types of simulation models have been adapted: high-fidelity discrete element models and fast analytical models. By using the first to establish parameters for the second, a system has been created that can be executed in real time, or faster than real time, on a desktop PC. This allows Monte Carlo simulations to be performed on a computer platform available to all researchers, and it allows human interaction to be included in a real-time simulation process. Metrics on excavator performance are established that work with the simulation architecture. Both static and dynamic metrics are included.

This work was done by Chalongrath Pholsiri, James English, Charles Seberino, and Yi-Je Lim of Energid Technologies for Glenn Research Center. Further information is contained in a TSP (see page 1).

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-18522-1.

Observing System Simulation Experiment (OSSE) for the HyspIRI Spectrometer Mission

NASA's Jet Propulsion Laboratory, Pasadena, California

The OSSE software provides an integrated end-to-end environment to simulate an Earth observing system by iteratively running a distributed modeling workflow based on the HyspIRI Mission, including atmospheric radiative transfer, surface albedo effects, detection, and retrieval for agile exploration of the mission design space.

The software enables an Observing System Simulation Experiment (OSSE) and can be used for design trade space exploration of science return for proposed instruments by modeling the whole ground truth, sensing, and retrieval chain and to assess retrieval accuracy for a particular instrument and algorithm design. The OSSE infrastructure is extensible to future National Research Council (NRC) Decadal Survey concept missions where integrated modeling can improve the fidelity of coupled science and engineering analyses for systematic analysis and science return studies.

This software has a distributed architecture that gives it a distinct advantage over other similar efforts. The workflow modeling components are typically legacy computer programs implemented in a variety of programming languages, including MATLAB, Excel, and FORTRAN. Integration of these diverse components is difficult and time-consuming. In order to hide this complexity, each modeling component is wrapped as a Web Service, and each component is able to pass analysis parameterizations, such as reflectance or radiance spectra, on to the next component downstream in the service workflow chain. In this way, the interface to each modeling component becomes uniform and the entire end-to-end workflow can be run using any existing or custom workflow processing engine. The architecture lets users extend workflows as new modeling components become available, chain together the components using any existing or custom workflow processing engine, and distribute them across any Internet-accessible Web Service endpoints.

The workflow components can be hosted on any Internet-accessible machine. This has the advantages that the computations can be distributed to make best use of the available computing resources, and each workflow component can be hosted and maintained by their respective domain experts.

This work was done by Michael J. Turmon, Gary L. Block, Robert O. Green, Hook Hua, Joseph C. Jacob, Harold R. Sobel, and Paul L. Springer of Caltech and Qingyuan Zhang of the University of Maryland, Baltimore County (UMBC) for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

This software is available for commercial licensing. Please contact Daniel Broderick of the California Institute of Technology at danielb@caltech.edu. Refer to NPO-47048.

Momentum Management Tool for Low-Thrust Missions

NASA's Jet Propulsion Laboratory, Pasadena, California

A momentum management tool was designed for the Dawn low-thrust interplanetary spacecraft en route to the asteroids Vesta and Ceres, in an effort to better understand the early creation of the solar system. Momentum must be managed to ensure the spacecraft has enough control authority to perform necessary turns and hold a fixed inertial attitude against external torques. Along with torques from solar pressure and gravity-gradients, ion-propulsion engines produce a torque about the thrust axis that must be countered by the four reaction wheel assemblies (RWA).

MomProf is a ground operations tool built to address these concerns. The momentum management tool was developed during initial checkout and early cruise, and has been refined to accommodate a

wide range of momentum-management issues. With every activity or sequence, wheel speeds and momentum state must be checked to avoid undesirable conditions and use of consumables.

MomProf was developed to operate in the MATLAB environment. All data are loaded into MATLAB as a structure to provide consistent access to all inputs by individual functions within the tool. Used in its most basic application, the Dawn momentum tool uses the basic principle of angular momentum conservation, computing momentum in the body frame, and RWA wheel speeds, for all given orientations in the input file.

MomProf was designed specifically to be able to handle the changing external torques and frequent desaturations. Incorporating significant external torques adds complexity since there are various external torques that act under different operational modes.

Mixed Real/Virtual Operator Interface for ATHLETE

NASA's Jet Propulsion Laboratory, Pasadena, California

The mixed real/virtual operator interface for ATHLETE (MSim-ATHLETE) is a new software system for operating manipulation and inspection tasks in JPL's ATHLETE (All-Terrain Hex-Legged Extra-Terrestrial Explorer). The system presents the operator with a graphical model of the robot and a palette of available joint types. Once virtual articulations are constructed for a task, the operator can move any joint or link, and the system interactively responds in real-time with a compatible motion for all joints that best satisfies all constraints.

Unique features of the software include:
• On-line topological dynamism: The key feature of MSim-ATHLETE is that it permits the kinematic structure of the operated mechanism to be changed dynamically by the operator. These changes are not (usually) meant to indicate actual changes in the physical system, but rather add/remove virtual extensions for constraining and parameterizing motions.
• Mixed reification: MSim-ATHLETE models two kinds of articulations: real articulations model the robot and virtual articulations model the virtual extensions.
• Pure kinematicity: MSim-ATHLETE is purely kinematic and thus does not require specifying any physics parameters, such as mass and friction properties.
• Useful handling of under- and over-constraint: MSim-ATHLETE allows the operator to specify both under- and over-constrained motions. In both cases, several features help organize and structure the result, including prioritized constraints, explicit hierarchical decomposition, and least-squares solving.

Antenna Controller Replacement Software

NASA's Jet Propulsion Laboratory, Pasadena, California

The Antenna Controller Replacement (ACR) software accurately points and monitors the Deep Space Network (DSN) 70-m and 34-m high-efficiency (HEF) ground-based antennas that are used to track primarily spacecraft and, periodically, celestial targets. To track a spacecraft, or other targets, the antenna must be accurately pointed at the spacecraft, which can be very far away with very weak signals. ACR's conical scanning capability collects the signal in a circular pattern around the target, calculates the location of the strongest signal, and adjusts the antenna pointing to point directly at the spacecraft. A real-time, closed-loop servo control algorithm performed every 0.02 second allows accurate positioning of the antenna in order to track these distant spacecraft. Additionally, this advanced servo control algorithm provides better antenna pointing performance in windy conditions.

The ACR software provides high-level commands that provide a very easy user interface for the DSN operator. The operator only needs to enter two commands to start the antenna and subreflector, and Master Equatorial tracking. The most accurate antenna pointing is accomplished by aligning the antenna to the Master Equatorial, which because of its small size and sheltered location, has the most stable pointing. The antenna has hundreds of digital and analog monitor points. The ACR software provides compact displays to summarize the status of the antenna, subreflector, and the Master Equatorial.

The ACR software has two major functions. First, it performs all of the steps required to accurately point the antenna (and subreflector and Master Equatorial) at the spacecraft (or celestial target). This involves controlling the antenna/subreflector/Master-Equatorial hardware, initiating and monitoring the correct sequence of operations, calculating the position of the spacecraft relative to the antenna, executing the real-time servo control algorithm to maintain the correct position, and monitoring tracking performance.

Second, the ACR software monitors the status and performance of the antenna, subreflector, and Master Equatorial for the safety of personnel and of the antenna equipment. While track-