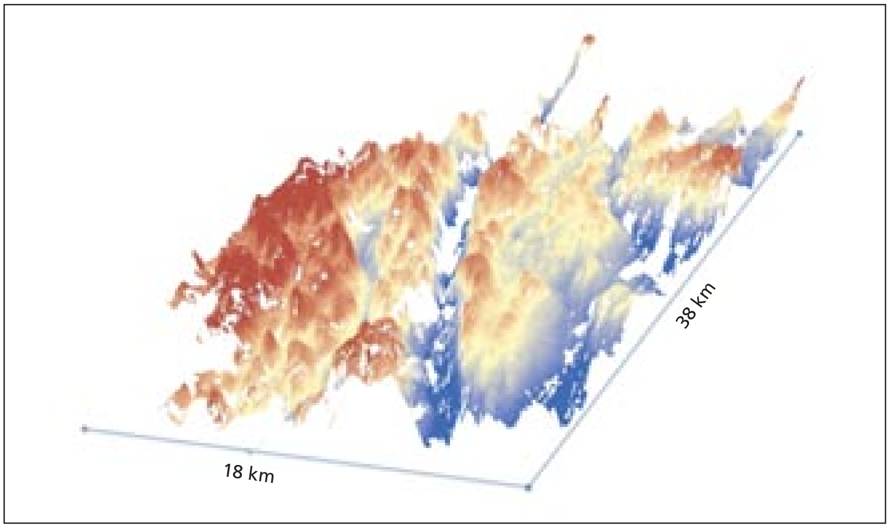

A 3D perspective of the Russell Glacier bed in Greenland produced from the 2011 Ice Bridge mission data using the **Tomographic Processor**.

In this innovative development supported in part by NASA ESTO, airborne tomographic ice sounding technology was used to successfully image the reflectivity and topography of the surface as well as the reflectivity of the ice sheet base and ice sheet thickness. From the surface topography and ice thickness measurements, the 3D basal topography can be computed. For the first time, one is able to "see" through kilometers-thick ice sheets and measure the 3D bottom topography and its scattering properties, across a several-kilometers-wide swath. Validation with independent measurements indicates that this technique provides accurate topographic measurement of ice sheet surface and bed, and can be used for local ice sheet bed mapping.

The tomographic sounding processing system is composed of several major modules: a sub-aperture, back-projection azimuth compression with ray-bending correction; a MUSIC/ML arrival angle estimation to estimate surface/bed return arrival angles; and post-processing modules including data regrid and DEM (digital elevation model) mosaic. It produces the ice thickness map and the bedmap as the final product.

This work was done by Xiaoqing Wu, Ernesto Rodriguez, and Anthony Freeman of Caltech; and Ken Jezek of Ohio State University for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). **NPO-48638**

flexplan: Mission Planning System for the Lunar Reconnaissance Orbiter

The tool can be configured for any mission without the need to modify or re-compile code.

Goddard Space Flight Center, Greenbelt, Maryland

flexplan is a mission planning and scheduling (MPS) tool that uses soft algorithms to define mission scheduling rules and constraints. This allows the operator to configure the tool for any mission without the need to modify or re-compile code. In addition, flexplan uses an ID system to track every output on the schedule to the input from which it was generated. This allows flexplan to receive feedback as the schedules are executed, and update the status of all activities in a Web-based client. flexplan outputs include various planning reports, stored command loads for the Lunar Reconnaissance Orbiter (LRO), ephemeris loads, and pass scripts for automation.

flexplan covers the end-to-end loop of MPS and allows users to adapt the system to their requirements quickly and easily. At the core of flexplan's scheduling process is a soft algorithm generation engine that requires no recompiling of the tool whenever flight rules change. This engine is largely responsible for the ease of adaptability of flexplan to the different mission phases, requirements, and styles of planning and scheduling operations. flexplan's modular architecture allows its components to interact with each other via the database. This allows different components to be run at different times or concurrently by different operators. This architecture also allows flexplan to be easily extended with additional modules to support specific mission requirements or needs. The LRO MPS uses flexplan's core modules plus additional modules developed using existing flexplan capabilities to support LRO's flight software memory loads generation and modeling, a slew maneuver planning tool, and Web-based mission status reporting.

The flexplan components are divided into two categories: core components that are modules responsible for the generation of conflict-free schedules, and supporting components that are modules supporting additional requirements for the LRO and for the status awareness of planned activities.

flexplan offers three advantages over existing systems:

1. Use of soft algorithms to define mission scheduling rules and constraints. This allows the operators to define how planning and scheduling is accomplished, without the need for manufacturer modification to the software. All scheduling rules and constraints can be placed under configuration management, allowing the operation team to easily create and use rules for different phases of the mission.
2. Tracking ID. All inputs and outputs into and from flexplan are assigned a unique ID. This allows the operations team to identify the source of scheduled activities. It also allows flexplan to receive execution feedback for all schedule activities and update the activities status on a Web-based client for improved mission awareness.
3. Open XML format for all scheduling inputs. A single XML structure is used to ingest all scheduling inputs, regard-

less of the nature or source of the input. This allows new scheduling inputs to be processed without the need to configure the external interface to a specific input format.

flexplan is also used in the scheduling operations of the LDCM (Landsat Data Continuity Mission) spacecraft, also at GSFC, which is currently undergoing final mission and ground readiness testing to prepare for upcoming launch in January of 2013, and undergoing customization for operational use in the TDRS (Tracking and Data Relay Satellites) Space Network upgrade project, SGSS, a joint venture between NASA GSFC and WSC.

This work was done by Assaf Barnoy and Theresa Beech of GMV USA for Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-15558-1

Estimating Torque Imparted on Spacecraft Using Telemetry

Methodology is straightforward and does not involve the use of any complex supporting ground software.

NASA's Jet Propulsion Laboratory, Pasadena, California

There have been a number of missions with spacecraft flying by planetary moons with atmospheres; there will be future missions with similar flybys. When a spacecraft such as Cassini flies by a moon with an atmosphere, the spacecraft will experience an atmospheric torque. This torque could be used to determine the density of the atmosphere. This is because the relation between the atmospheric torque vector and the atmosphere density could be established analytically using the mass properties of the spacecraft, known drag coefficient of objects in free-molecular flow, and the spacecraft velocity relative to the moon. The density estimated in this way could be used to check results measured by science instruments. Since the proposed methodology could estimate disturbance torque as small as 0.02 N-m, it could also be used to estimate disturbance torque imparted on the spacecraft during high-altitude flybys.

When the expected value of torque imparted on the spacecraft is low and within the control authority of the reaction wheel assemblies (RWAs), mission design engineers will use these RWAs to control the spacecraft attitude. Relative to thrusters, RWA can produce better pointing control and stability performance. To estimate the disturbance torque imparted on the Cassini spacecraft, the proposed methodology exploits the unique and known relation between the disturbance torque and the RWA-based attitude control error during an Enceladus or Titan flyby.

To estimate the disturbance torque imparted on the Cassini spacecraft, the unique and known relation between the disturbance torque and the attitude and attitude rate control errors during an Enceladus flyby (or a Titan flyby) on reaction wheels was used. The effectiveness of this methodology is illustrated using telemetry data obtained from the 50-km Enceladus-3 flyby. Results determined using this approach were compared with those determined using the "time rate of change of spacecraft angular momentum" approach. Results of this flyby determined that using this new approach compared very well with that estimated using the angular momentum approach. In effect, density estimates made using these two independent engineering methodologies could cross check each other. Moreover, density estimates determined using these methods could also be used to cross check science-based density estimates.

This method could be used to estimate very small torque imparted on the spacecraft. The methodology is straightforward and does not involve the use of any complex supporting ground software. This methodology uses telemetry data that are available at high telemetry frequency, and the telemetry data involved (per-axis attitude control errors and per-axis attitude rate control errors) are floating-point data with high accuracy.

This work was done by Allan Y. Lee, Eric K. Wang, and Glenn A. Macala of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-47545

PowderSim: Lagrangian Discrete and Mesh-Free Continuum Simulation Code for Cohesive Soils

John H. Glenn Research Center, Cleveland, Ohio

PowderSim is a calculation tool that combines a discrete-element method (DEM) module, including calibrated interparticle-interaction relationships, with a mesh-free, continuum, SPH (smoothed-particle hydrodynamics) based module that utilizes enhanced, calibrated, constitutive models capable of mimicking both large deformations and the flow behavior of regolith simulants and lunar regolith under conditions anticipated during in situ resource utilization (ISRU) operations.

The major innovation introduced in PowderSim is to use a mesh-free method (SPH-based) with a calibrated and slightly modified critical-state soil mechanics constitutive model to extend the ability of the simulation tool to also address full-scale engineering systems in the continuum sense. The PowderSim software maintains the ability to address particle-scale problems, like size segregation, in selected regions with a traditional DEM module, which has improved contact physics and electrostatic interaction models.

PowderSim provides answers with comprehensive cohesive-contact models and a new charge-spot model for electrostatic forces arising from localized charge patches on the surfaces and in the interiors of individual particles. For