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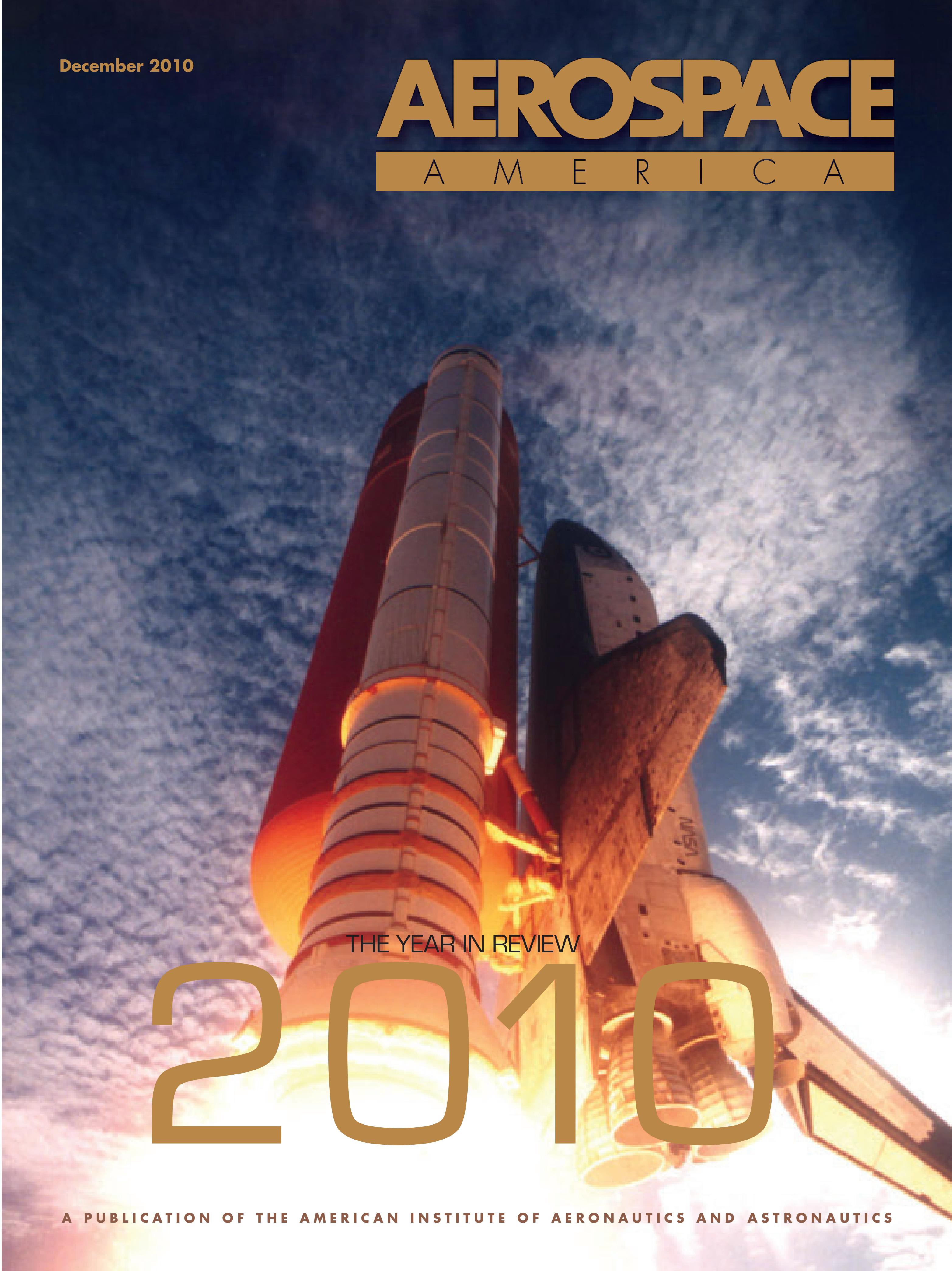

THE YEAR IN REVIEW 2010

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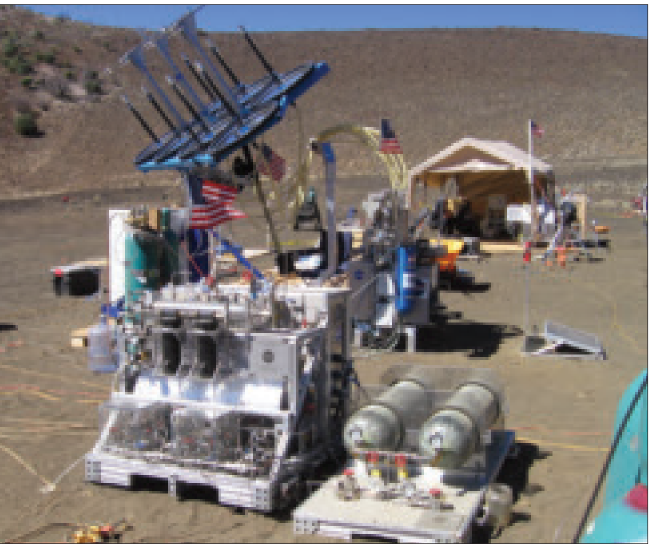
Space resources

In another exciting year for the space resource utilization community, several technologies advanced from laboratory prototype to complete operating system. Many of these technologies were integrated for the first time and tested at the 2010 International Lunar Surface Operations and ISRU (in-situ resource utilization) Analog Test. This field test took place from January 25 to February 12 at a lunar analog test site operated by PISCES (Pacific International Space Center for Exploration Systems) at an elevation of 9,000 ft on the slopes of Mauna Kea. NORCAT (Northern Center for Advanced Technology) led the test, with funding from the Canadian Space Agency. NASA's Science Mission Directorate funded resource characterization instruments.



The integrated regolith processing system located at a lunar analog test site on Mauna Kea is remotely operated from NASA Johnson.

The major participants in the field test were NASA (Kennedy, Johnson, Langley, Goddard, Ames, JPL, and Headquarters), DLR (the German space agency), ORBITEC, Honeybee Robotics, PSI, ASRC Rocket, WASK Engineering, the NORCAT-led SRCan team (Neptec, Xiphos, Ontario Drive and Gear, UTIAS, Electric Vehicle Controllers, Virgin Technologies, Natural Resources Canada, PACEAS Technologies, and YUM Culinary Academy/Cambrian College), the University of Hilo, Arizona State University, UC Davis, McMaster University, the University of Mainz, and the University of Washington.

The field test was a unique opportunity to integrate many different capabilities required for space resource utilization—active vision systems, drilling, robotic mobility, robotic manipulators, communications, and ISRU processing technologies—into a single demonstration. Several instruments characterized the geotechnical, chemical, and mineral features of the tephra at the test site. Instruments included the RESOLVE (regolith and environment science and oxygen and lunar volatile extraction) drill, a combined Mossbauer/XRF, several cone penetrometers, a heat flow probe, a multispectral microscopic imager, an X-ray diffraction instrument, a borehole X-ray fluorescence instrument, and the VAPoR (volatile analysis by pyrolysis of regolith) and RESOLVE systems for volatile analysis.

Multiagent teaming of rovers was used to autonomously prepare a landing pad at the test site. Concentrated solar energy and electric resistance heaters mounted on a rover were used to sinter the tephra surface to increase stability. The geotechnical properties of the sintered surfaces were measured before they were tested with the exhaust plume from an LCH_4/LOX thruster. Tephra was also collected with an automated rover powered by a fuel cell and delivered to a carbothermal reduction plant, where it was inserted into the reactor with a pneumatic lift system. The tephra was processed using concentrated solar energy, producing water that was electrolyzed. The hydrogen produced was stored in metal hydride canisters, while the oxygen was liquefied and later used to operate the LCH_4/LOX thruster. The stored hydrogen was used to operate a fuel cell that powered the carbothermal reduction plant and other support equipment.

The field test was very successful and met all its major objectives. Equipment from several organizations was successfully integrated at the test site to create a true end-to-end demonstration of space resource evaluation and utilization. Prototype equipment was operated in a harsh terrestrial environment for long periods as a precursor for flight hardware development. Several systems were monitored and operated remotely through a satellite communications link that provided telemetry, situational awareness, command and control, and data management. Outreach and public education events were held during the field test to share the exciting work with local residents, students, and the general public.

NASA Kennedy coordinated and hosted the inaugural Lunabotics Mining Competition. This event, sponsored in part by the AIAA Space Resources Technical Committee, included designing and building a remote-controlled or autonomous excavator (lunabot) for competition, writing a systems engineering paper, coordinating informal education outreach to K-12 students, a lunabotics mining slide presentation, and a team spirit evaluation.

Finally, an Ohio State University/NASA Marshall/NASA Kennedy/ASRC Aerospace team demonstrated the full removal of metallic and lunar oxide melts by countergravity casting from a molten regolith electrolysis furnace.

by **Robert Gustafson**