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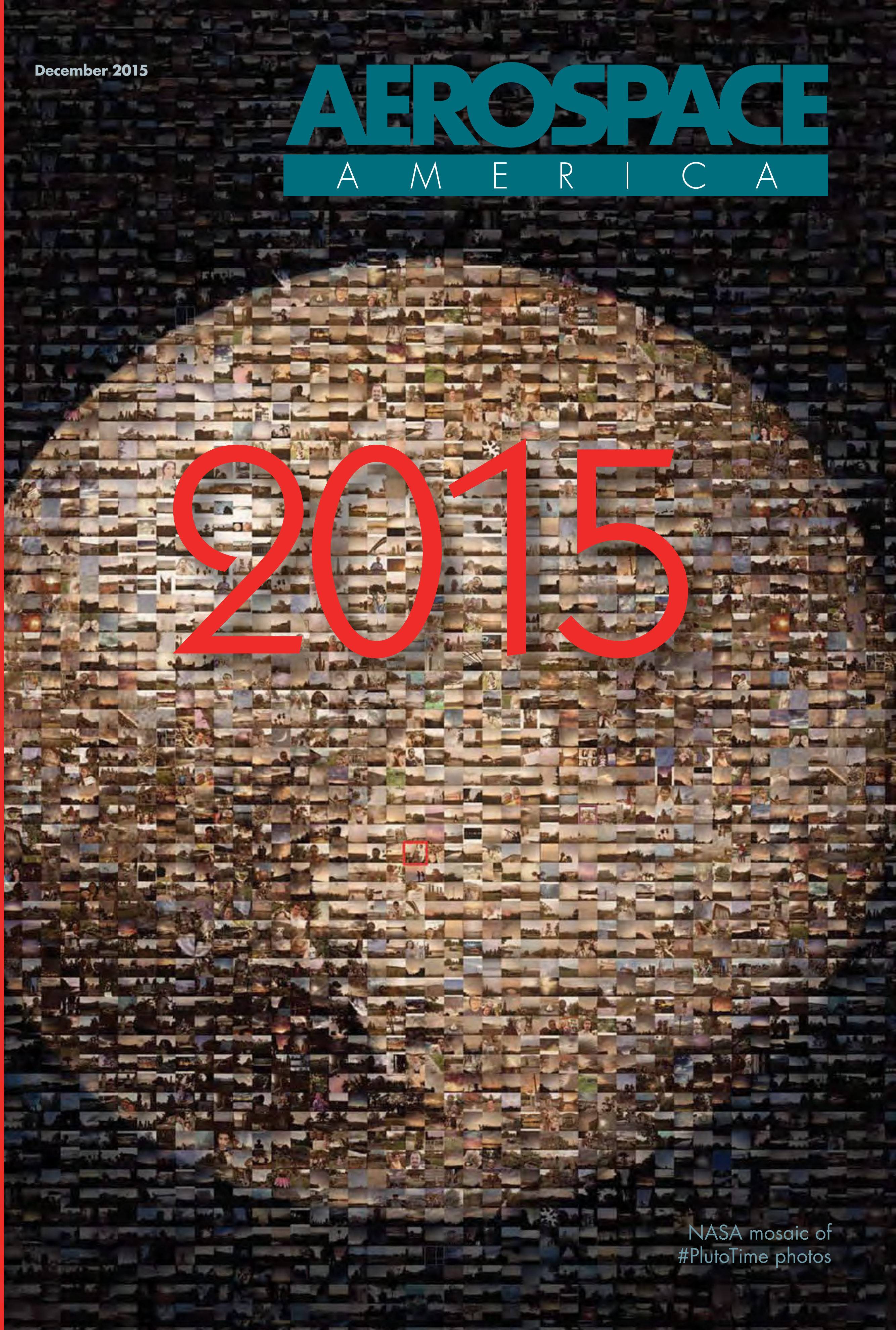

NASA mosaic of #PlutoTime photos

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Preparing thermophysics for new missions

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*The **Thermophysics Technical Committee** promotes the study and application of mechanisms involved in thermal energy transfer and storage in gases, liquids and solids, or combinations.*

In 2015, the thermophysics community developed fundamental tools at the molecular level, began preparing new technologies for future missions, and saw careful design enable scientific discovery at Pluto.

With support from the Air Force Office of Scientific Research, researchers at the University of Minnesota have developed novel, first-principles methods for studying the coupling of **chemical reactions and energy transfer collisions** to the fluid dynamics of hypersonic shock layers. New potential energy surfaces, PESs, have been constructed and used to compute rate constants for molecular dissociation, as well as nonreactive vibrational and rotational energy transfer. The new PESs were also used in the direct simulation Monte Carlo method, in which the dynamics of each collision is computed on the fly. These new techniques, coupling motion at the atomic scale to macroscopic flow and energy transfer, are being used to develop more accurate models for computational fluid dynamics simulations of hypersonic vehicles.

Future vehicle designs will be enabled not only through better flow simulations, but through new materials. NASA's **woven thermal protection system** is a new approach to produce heat-shield materials. Using precisely engineered 3D weaving techniques, NASA can customize material characteristics to meet the stringent mission requirements for protecting vehicles from the intense heat of atmospheric entry. **3D-MAT**, a fully dense quartz composite material, is engineered for the Orion capsule and is scheduled to fly on the Exploration Mission-1 in 2018.


NASA Ames Research Center

3D-MAT, a woven composite material that will be used for the heat shield of Orion, is produced from quartz yarn. Right inset: After resin infusion and machining, the 3D-MAT material (left inset) is ready.

The challenges of engineering a **spacecraft traveling at hypersonic speeds** are so extreme that the first flight of Orion, the unmanned Exploration Flight Test-1 mission in December 2014, tested the re-entry capabilities of the vehicle. EFT-1 used an extensive suite of instruments, including thermocouples, pressure transducers and radiometers, to measure the thermal response of the front heat shield and the backshell. This extensive data set will be used to validate the models used during flight and will allow engineers to understand how to use simulations and ground tests to predict flight-relevant phenomena. The European Space Agency in February launched its own flight test, the Intermediate Experimental Vehicle, on a Vega rocket. The unmanned IXV reached an altitude of 412 kilometers and re-entered the atmosphere to simulate a spaceplane returning from orbit, splashing down in the Pacific Ocean. The flight marked an important step toward efficient space access and provided researchers with flight data on the behavior of high temperature reusable thermal protection systems.

The success of the **New Horizons** flyby of Pluto and its moons in July depended on advanced thermal management over the wide range of conditions encountered by the spacecraft. This was achieved through careful integration of the spacecraft's power system, waste heat management, electronics power usage and internal heaters. The thermal management system used louvers to prevent overheating at the start of the journey. As the spacecraft approached Pluto, the challenge became keeping the spacecraft warm enough. By channeling waste heat from the spacecraft's radioisotope thermoelectric generator through the fuel tank into the main spacecraft structure, a temperature of 20 degrees Celsius was maintained inside the vehicle. This integrated approach allowed the spacecraft to operate its instruments at their design temperatures at a distance 33 times farther from the sun than Earth's orbit, with a total power budget of approximately 200 watts.

Lessons learned from the **thermophysics of spacecraft entries** have found application to a new problem: assessment of risk from atmospheric entry of asteroids. The first international workshop at NASA Ames in this area brought together experts in the areas of exoatmospheric characterization, atmospheric entry and surface damage simulations, with a view to a physics-based risk assessment framework. The simulations of large, irregularly shaped objects at entry speeds in the range of 12 to 30 kilometers per second have opened opportunities to expand the understanding of thermophysics for dense plasmas and their interactions with asteroidal materials. These analyses will aid the development of appropriate responses to these rare, but potentially catastrophic, events.