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NRL's Forward Technology Solar Cell Experiment Flies as Part of MISSE-5 Aboard Space Shuttle *Discovery* Mission

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Introduction: The Naval Research Laboratory led the scientific team that designed, built, and launched the 5th Materials on the International Space Station Experiment (MISSE-5). The team consisted of NRL, NASA Glenn Research Center, Ohio Aerospace Institute, NASA Langley Research Center, U.S. Naval Academy, and the Air Force Space Test Program. MISSE-5 is a completely self-contained experiment system with its own power generation, storage, and communications systems. The primary MISSE-5 payload is the Forward Technology Solar Cell Experiment (FTSCE), which is currently functioning on-orbit. MISSE-5 was launched aboard the Shuttle return to flight mission (STS-114) on July 26, 2005. Astronaut Soichi Noguchi deployed MISSE-5 on the exterior of the International Space Station (ISS) during the spacewalk on August 3, 2005, just before Astronaut Steve Robinson performed the tile repair on the Shuttle *Discovery*. Figure 1 is a photograph of MISSE-5 deployed on the ISS. The experiment will remain in orbit for about one year, after which it will be returned to Earth for postflight testing and analysis.

Forward Technology Solar Cell Experiment: FTSCE was initially conceived in response to various on-orbit and ground test anomalies associated with space power systems. The Department of Defense (DoD) required a method of rapidly obtaining on-orbit validation data for new space solar cell technologies, and NRL was tasked to devise an experiment to meet this requirement. Rapid access to space was provided by the NASA Langley Research Center MISSE Program, which provides access to space for new materials and devices being considered for use in space (http://misse1.larc.nasa.gov/). Experiments are placed into a Passive Experiment Container (PEC) which is a metal box approximately 2×2 ft^2 $\times$ 4 in. thick. The experiments are mounted on custom-designed trays that mount within the PEC. When closed, the PEC provides the container for the experiments for launch on the Shuttle and transfer to the ISS. For deployment, the PEC is clamped to a handrail on the exterior of the ISS by an astronaut who then opens the PEC to expose the experiments. After a period of time, an astronaut closes the PEC, and it is returned to Earth for postflight analysis of the experiments.

While on-orbit, FTSCE is measuring a 39-point current vs voltage (IV) curve on each of 36 experimental solar cells, and the data are continuously telemetered to Earth. The experiment also measures solar cell temperature and orientation of the solar cells to the Sun. A range of solar cell technologies are included in the experiment, including state-of-the-art triple junction InGaP/GaAs/Ge solar cells from several vendors, thin film amorphous Si and $CuIn(Ga)Se_2$ cells, and next-generation technologies like single-junction GaAs cells grown on Si wafers and metamorphic InGaP/InGaAs/Ge triple-junction cells. Figure 2 shows an example of data from a triple junction solar cell measured on-orbit. Also shown are data from the same cell measured in the NRL solar cell laboratory that have been corrected to the measurement angle and temperature. The data change with time as the ISS solar angle changes. The on-orbit and laboratory data agree very well, and the data show no signs of solar cell degradation.

FIGURE 1
MISSE-5 passive experiment container attached to the exterior of the International Space Station (ISS). Visible within the container is the Forward Technology Solar Cell Experiment. This photograph was taken by the Shuttle *Discovery* crew after undocking from the ISS.

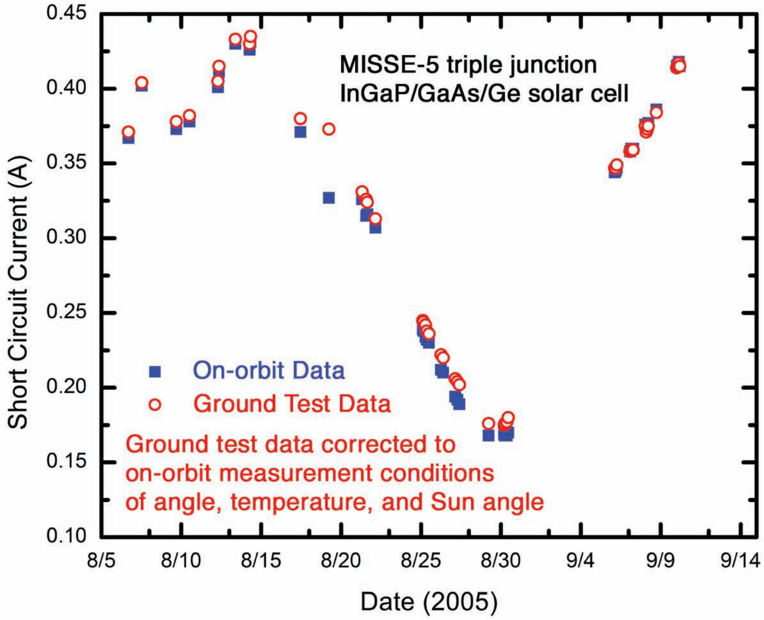

FIGURE 2
Solar cell current measured in a triple junction solar cell onboard the Forward Technology Solar Cell Experiment. The on-orbit data change with time as the ISS solar angle changes. Also plotted are data from this solar cell that were measured in the NRL solar cell laboratory prior to launch. The ground-measured data have been corrected to match the on-orbit measurement conditions, and excellent agreement can be seen.

Thin-Film Materials Experiment: In addition to FTSCE, MISSE-5 also contains a Thin-Film Materials experiment. A team led by NASA Langley Research Center has transformed the outer layer of a MISSE-5 thermal blanket into a 3 1/2-oz experiment to evaluate the in-space survivability of 200 advanced materials that are being developed to enable future U.S. space missions. The materials experiment can be seen in the photograph of MISSE-5 taken by Soichi Noguchi's helmet camera during deployment (Fig. 3). Some of the materials include DC 93-500 silicone; POSS-coated polyethylene; multiwall carbon nanotubes in polyimide; white paint on black Kapton; double aluminized Kapton, which is ISS Solar Array Blanket box material; germanium on black Kapton; silicone paint on Kapton; AZ93 White Coating; cellulose acetate; perfluoroalkoxy (Teflon PFA), high-temperature polyimide resin; and amorphous fluoropolymer (Teflon AF). The survivability of these materials will be established by comparing pre- and postflight characterization test data.

Communications System: The communications system (referred to as PCSat2), was built by the U.S. Naval Academy and transmits and receives in the Amateur Radio band, providing a node on the Amateur Radio Satellite Service (http://www.ew.usna.edu/~bruninga/pec/pc2ops.html). The PCSat2 subsystem operates in the ITU Amateur Satellite Service in cooperation with ARISS (Amateur Radio on the International Space Station) and provides a PSK-31 multiuser transponder, an FM voice repeater for possible use with ISS crew communications, and an AX.25 packet system for use as a packet digipeater and a terminal node controller. PCSat2 uses the same dual redundant AX.25 command and control system as used on PCsat (NO-44) offering eight on/off commands,

FIGURE 3
Thin-Film Materials Experiment on MISSE-5. The photograph was taken by Astronaut Soichi Noguchi's helmet camera while he was deploying MISSE-5.

five telemetry channels, and a serial port for the FTSCE telemetry. It also supports the Digital Comms Relay support of the PCsat2/APRS mission. The packet uplink is on 145.825 MHz, and the default downlinks are in the 435 MHz band to avoid any possible interference with existing ARISS missions. PCSat2 has quad redundant transmit inhibits for extravehicular activity safety issues, thus it is easy to deactivate to avoid any issues with other UHF ARISS experiments that may be activated in the future.

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