National Aeronautics and
Space Administration

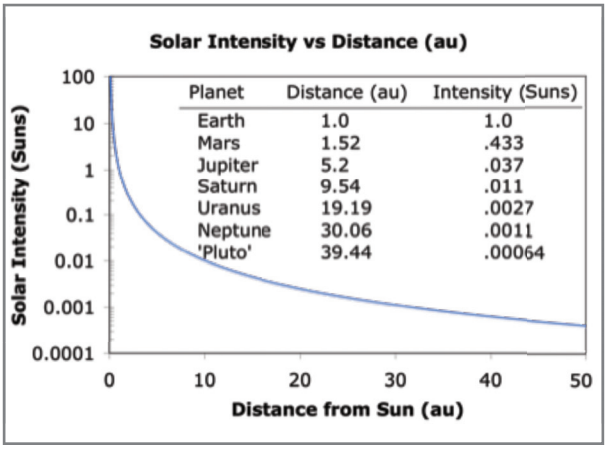
Game Changing Development Program Office

Solar Power Generation in Extreme Space Environments

NASA**facts**

Courtesy NASA/JPL-Caltech

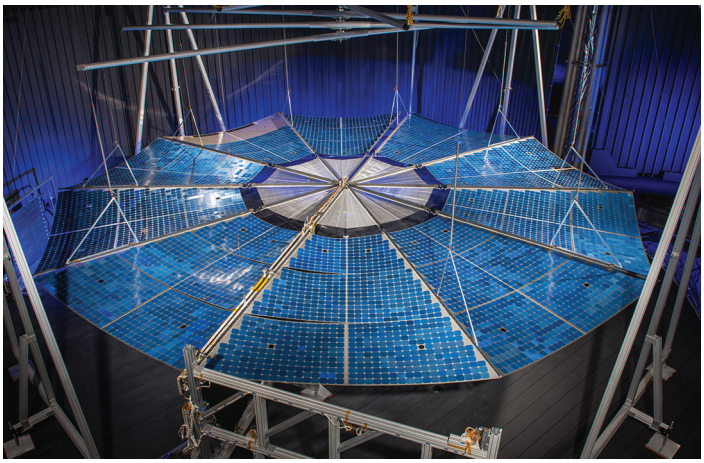
The exploration of space requires power for guidance, navigation, and control; instrumentation; thermal control; communications and data handling; and many subsystems and activities. Generating sufficient and reliable power in deep space through the use of solar arrays becomes even more challenging as solar intensity decreases and high radiation levels begin to degrade the performance of photovoltaic devices. The Extreme Environments Solar Power (EESP) project goal is to develop advanced photovoltaic technology to address these challenges.



Planet	Distance (au)	Intensity (Suns)
Earth	1.0	1.0
Mars	1.52	.433
Jupiter	5.2	.037
Saturn	9.54	.011
Uranus	19.19	.0027
Neptune	30.06	.0011
'Pluto'	39.44	.00064

LILT and Radiation Effects

The majority of NASA missions utilize solar cells that are designed and qualified for long-term operation within an Earth-orbit environment. Deep space NASA missions, however, subject solar-powered arrays to stresses well beyond those experienced by commercial space and military satellites. Spacecraft sent to explore planets and other bodies farther from the Sun will encounter reduced light intensity levels and very low temperatures. A subset of these missions may encounter low-intensity low-temperature (LILT) environments that can cause performance degradation in the power output of the solar cell. This LILT effect has been noted and verified through ground-based testing. The effect is variable from cell to cell, affecting the reliability of accurately predicting solar array performance throughout the life of a mission. The issue becomes more pronounced when one cell with this degradation characteristic is added in a series string with well-behaved, predictable cells. Under LILT conditions, the entire string will be current-limited by the output of the “bad” cell and the performance of the entire string will be degraded. Current methods of minimizing LILT effects involve screening all solar cells for the mission, adding considerable cost and schedule to the spacecraft power system.



MegaFlex Engineering Development Unit (EDU) solar array.
Alliant Technical Systems (ATK)

Space solar cells degrade over time due to exposure to the space environment, with most effects being small and predictable; however, the largest power loss is due to particulate radiation. Electrons and protons released by the Sun and trapped within various planetary orbits (such as Earth's Van Allen radiation belts) create defects within the semiconductor crystalline structure and reduce solar cell power output. The easiest way to protect the solar cell from these damaging effects is by shielding the front of the solar cell with glass. The thicker the glass, the more protection the cell receives, but this adds more mass and cost to the solar array. On typical solar arrays, a few mils of ceria-doped microsheet will protect the cell sufficiently to achieve the power output necessary at the end of the mission. Missions in very high radiation environments, such as those to Jupiter, must use novel approaches to limit these degradation effects.

EESP Technology Solutions

The EESP project aims to increase end-of-life solar array performance for those missions exposed to severe radiation environments, such as those found within Earth's Van Allen belts or the vicinity of Jupiter, and to increase overall efficiency when operating in LILT-type environments. Various methods can be used to accomplish these goals. One method involves a redesign of the solar cell. The choice of appropriate semiconductor materials, cell designs, and precise attention to cell fabrication processes could be used to develop a high-efficiency device that is both radiation tolerant and exhibits minimal LILT-type degradation effects.

Another approach would be the use of concentrator optics to shield the solar cell and minimize the amount of solar cell area needed. Concentrator concepts have been successfully used for both space and terrestrial photovoltaic systems. This approach utilizes either reflective or refractive elements to focus the sunlight onto a much smaller solar cell area. Designs vary greatly in terms of complexity and solar concentration, from simple two-Sun trough reflectors to 100+ Sun point-focus designs. Issues such as degradation/contamination of the concentrator optics and Sun-pointing requirements for the solar array exist; however, concentrator concepts do address EESP goals by providing added protection from the radiation environment for the solar cells and by operating at higher solar intensity and temperature conditions than one-Sun planar arrays.

The EESP project has recently initiated four technology development contracts that address these very NASA-unique mission requirements for solar array power systems. Johns Hopkins University Applied Physics Laboratory, The Boeing Company, Orbital ATK, and the NASA Jet Propulsion Laboratory will be working on advanced photovoltaic concepts that address radiation damage and LILT degradation effects. The array designs being considered differ, but all use varying degrees of the technology solutions summarized above: solar cell designs modified to operate under EESP mission requirements, concentrator array concepts, or combinations of both. The technology developed under these contracts is expected to extend NASA's use of solar array technology as it continues to explore the reaches of space.

MORE INFORMATION

The Game Changing Development (GCD) Program investigates ideas and approaches that could solve significant technological problems and revolutionize future space endeavors. GCD projects develop technologies through component and subsystem testing on Earth to prepare them for future use in space. GCD is part of NASA's Space Technology Mission Directorate.

For more information about GCD, please visit
http://gameon.nasa.gov/

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