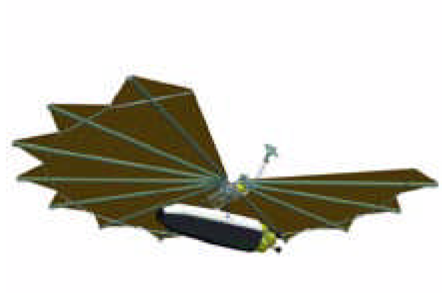
Power Systems Evaluated for Solar Electric Propulsion Vehicles



Solar electric propulsion stage for a human mission to Mars.

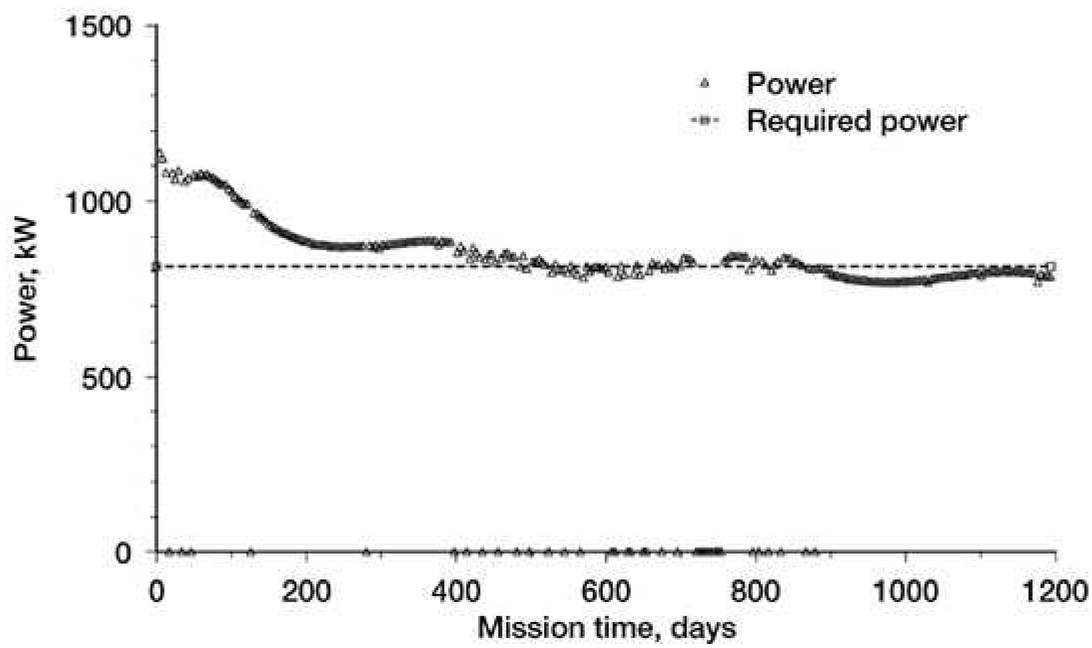
Solar electric propulsion (SEP) mission architectures are applicable to a wide range of NASA missions including the robotic exploration of the outer planets in the next decade and the human exploration of Mars (ref. 1) within the next 2 decades. SEP enables architectures that are very mass efficient with reasonable power levels (1-MW class) when aerobrake and cryogenic upper-stage transportation technologies are utilized. In this architecture, the efficient SEP stage transfers the payload from low Earth orbit (LEO) to a High Energy Elliptical Parking Orbit (HEEPO) within a period of 6 to 12 months. A high-thrust, cryogenic upper stage and payload then separate from the SEP vehicle for injection to the planetary target, allowing for fast heliocentric trip times. This mission architecture offers a potential reduction in mass to LEO in comparison to alternative all-chemical or nuclear propulsion schemes. Mass reductions may allow launch vehicle downsizing and enable missions that would have been grounded because of cost constraints.

The preceding figure illustrates a conceptual SEP stage design for a human Mars mission (ref. 2). Researchers at the NASA Glenn Research Center at Lewis Field designed the conceptual SEP vehicle, conceived the mission architecture to use this vehicle, and analyzed the vehicle’s performance. This SEP stage has a dry mass of 35 metric tons (MT), 40 MT of xenon propellant, and a photovoltaic array that spans 110 m, providing power to a cluster of eight 100-kW Hall thrusters. The stage can transfer an 80-MT payload and upper stage to the desired HEEPO. Preliminary packaging studies show that this space-station-class SEP vehicle meets the proposed "Magnum" launch vehicle mass and volume requirements with considerable margin. An SEP vehicle for outer planetary missions, such as the Europa Mapper Mission, would be dramatically smaller than a human Mars mission SEP stage. In this mission architecture, the SEP power system injects with the payload to provide spacecraft power throughout the mission.

Several photovoltaic array design concepts were considered for the SEP vehicle power system for the human mission to Mars. These include a space station derivative, a SCARLET (Solar Concentrator Arrays with Refractive Linear Element Technology) array derivative, and a hybrid inflatable-deployable thin polymer membrane array with thin-film solar cells (as shown in the concept illustration). This concept is based on a design developed for the Next Generation Space Telescope Sun shield. The array is divided into 16 independent electrical sections with 500-V, negative-grounded solar cell strings. The power system employs a channelized, 500-Vdc power management and distribution (PMAD) architecture with lithium ion batteries for energy storage for vehicle and payload secondary loads (the high-power Hall thrusters do not operate in eclipse periods). The 500-V PMAD voltage permits "direct-drive" thruster operation, greatly reducing the power processing unit size, complexity, and power loss. Similar power system architecture, designs, and technology are assumed for the Europa Mapper Mission SEP vehicle. The primary exceptions are that the photovoltaic array is assumed to consist of two rectangular wings and that the power system rating is 15 kW in Earth orbit and 200 W at Europa.

To size the SEP vehicle power system, a dedicated Fortran code was developed to predict detailed power system performance, mass, and thermal control requirements (ref. 2). This code also modeled all the relevant Earth orbit environments; that is, the particulate radiation, plasma, meteoroids and debris, ultraviolet radiation, contamination, and thermal conditions. Analysis results for the Human Mars Mission SEP vehicle show a power system mass of

9-MT and photovoltaic array area of 5800-m^2 for the thin-membrane design concept with $CuInS_2$ thin-film cells.



Power to Hall thruster power processing units.

Power processing unit input power for a thin-membrane array design with three-junction, amorphous SiGe solar cells is shown in the graph. Power falls off rapidly in the first weeks of the mission because of light-induced (Staebler-Wronksi) solar cell losses. During the next 200 days, power decreases steadily as the SEP stage spirals through the proton belts and sustains the bulk of the mission radiation damage. Once the vehicle apogee is above approximately four Earth radii, little additional degradation is incurred. From 400 to 800 days, a 1100-km "parking" orbit is maintained to await the next payload transfer opportunity. This orbit is below the main proton belt, and thus, little radiation dose is accumulated during this time period. During the second LEO-to-HEEPO transfer, power degrades somewhat further, but power requirements are still met. In comparison, the Europa Mapper SEP vehicle power system had a mass of 150 kg and a thin membrane array area of 100 m^2.

References

1. Gefert, L.P.; Hack, K.J.; and Kerslake, T.W.: Options for the Human Exploration of Mars Using Solar Electric Propulsion. STAIF Conference, Albuquerque, New Mexico, Jan. 1999.

2. Kerslake, T.W.; and Gefert, L.P.: Solar Power System Analyses for Electric Propulsion Missions. 34th Intersociety Energy Conversion Engineering Conference, SAE Paper 99–01–2449 (NASA/TM—1999-209289), 1999.

Glenn contact: Thomas W. Kerslake, (216) 433–5373, Thomas.W.Kerslake@grc.nasa.gov

Authors: Thomas W. Kerslake and Leon P. Gefert

Headquarters program office: OSF

Programs/Projects: HEDS