# Solar Electric Propulsion Technologies Being Designed for Orbit Transfer Vehicle Applications

There is increasing interest in employing Solar Electric Propulsion (SEP) for new missions requiring transfer from low Earth orbit to the Earth-Moon Lagrange point, L1. Mission architecture plans place the Gateway Habitat at L1 in the 2011 to 2016 timeframe. The Gateway Habitat is envisioned to be used for Lunar exploration, space telescopes, and planetary mission staging. In these scenarios, an SEP stage, or "tug," is used to transport payloads to L1--such as the habitat module, lunar excursion and return vehicles, and chemical propellant for return crew trips. SEP tugs are attractive because they are able to efficiently transport large (>10,000 kg) payloads while minimizing propellant requirements.

To meet the needs of these missions, a preliminary conceptual design for a general-purpose SEP tug was developed that incorporates several of the advanced space power and in-space propulsion technologies (such as high-power gridded ion and Hall thrusters, high-performance thin-film photovoltaics, lithium-ion batteries, and advanced high-voltage power processing) being developed at the NASA Glenn Research Center. A spreadsheet-based vehicle system model was developed for component sizing and is currently being used for mission planning. This model incorporates a low-thrust orbit transfer algorithm to make preliminary determinations of transfer times and propellant requirements. Results from this combined tug mass estimation and orbit transfer model will be used in a higher fidelity trajectory model to refine the analysis.
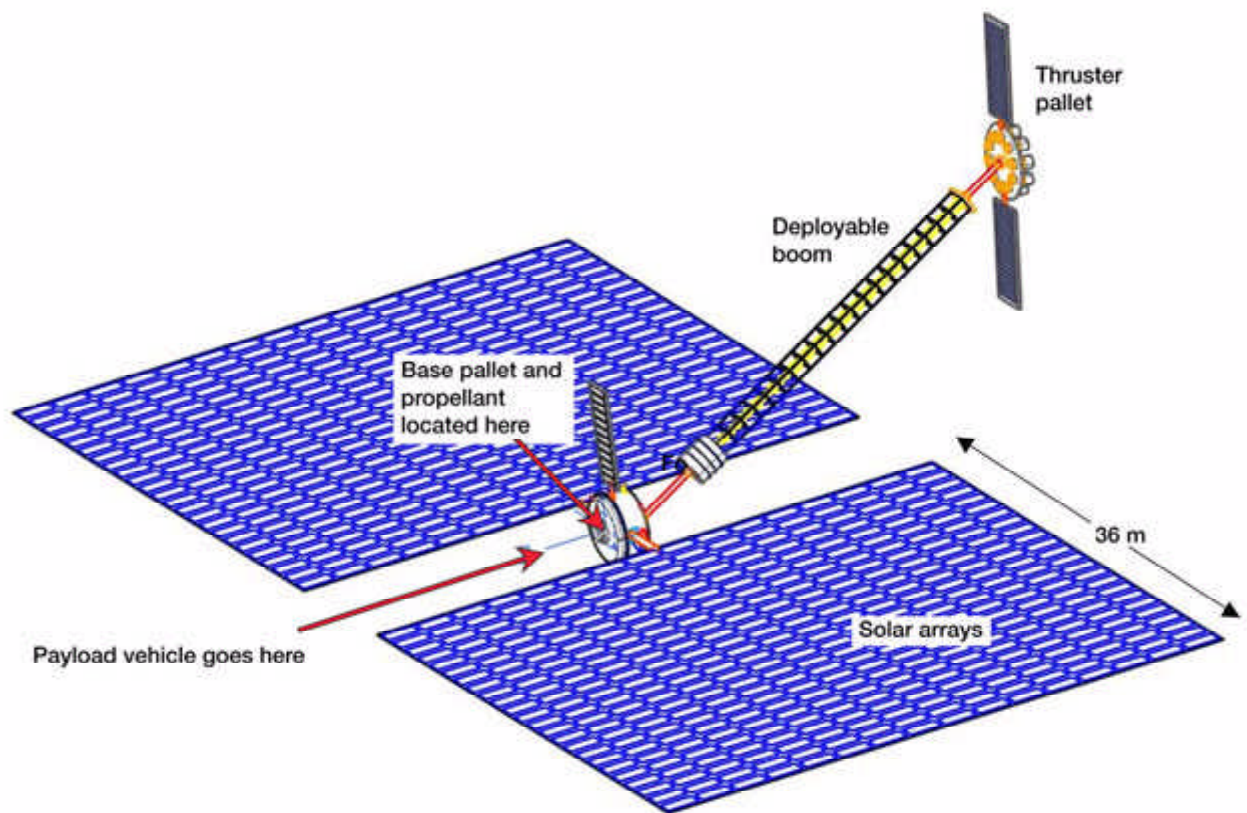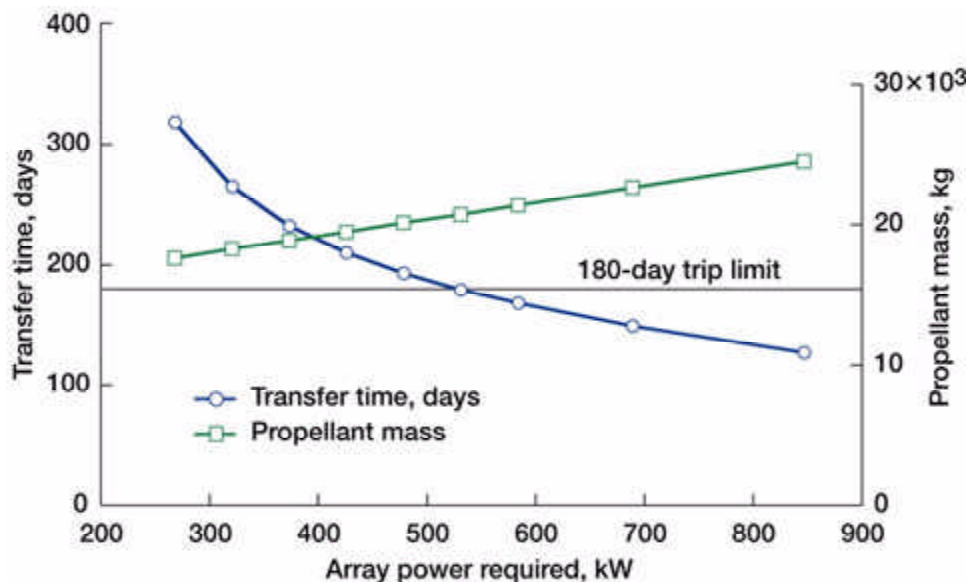
Solar Electric Propulsion (SEP) tug for the Revolutionary Aerospace Systems Concepts' Hybrid Propellant Module project. Nine 50-kW gridded ion thrusters are mounted on the deployable boom to enable the base pallet, arrays, and payload vehicle to remain in a solar inertial attitude while maintaining a constant thrust along the center of mass. The deployable boom is conformable to enable it to fit around the payload vehicle. In this case, the xenon propellant is on the payload vehicle, which is not shown. For scale, the coilable center mast section of the deployable boom (in yellow) is 20 m in length.

Long description Computer-generated drawing of the SEP tug. The electric thrusters are mounted on a flat pallet structure, 4 m in diameter by 0.2 m thick, at the end of the deployable boom. The thrusters, 0.7 m in diameter by 0.5 m deep, are distributed uniformly on the pallet, and all face opposite the direction of motion. Besides the thrusters, there are an equal number of power-processing boxes on the pallet, but on the opposite side. Each power-processing unit is matched to a thruster. The boom attaches to the center of the pallet on the side opposite the thrusters. The deployable boom has three elements. There are two rigid-end elements that are up to several meters long and function as standoff elements. These rigid elements are the end segments that attach to each end of the coilable mast. The coilable mast is the longest segment of the boom and extends from and collapses to a cylindrical canister at the end opposite the thruster pallet. There are mechanical wrist joints that connect each element of the boom together and attach each end of the boom to the pallets. The boom is attached to a base pallet at the center of the downstream face. The square solar arrays are mounted on short arms on each side of the pallet; these are attached on opposite sides of the base pallet. These arrays are 36 m wide

by 37.5 m long. The base pallet is 4 m in diameter by 2 m in long. The payload vehicle, along with the xenon propellant supply, will attach to the face opposite the boom.

The SEP tug system model was used in two design studies in 2001. First, the conceptual design of the Hybrid Propellant Module under the Revolutionary Aerospace Systems Concepts program at the NASA Langley Research Center required an SEP tug to transfer it to L1. This SEP tug, shown in the preceding illustration, would deliver a 36-metric-ton (MT) payload to L1 in 272 days. The second conceptual design activity was for the Lunar L1 Gateway mission architecture study at the NASA Johnson Space Flight Center. The SEP tug in this case would be able to deliver the required 30 MT payload to L1 within the time constraint of 180 days. The tug's performance is shown in the following graph, where the transfer time as a function of power on the tug is shown, along with the xenon propellant required.

Solar Electric Propulsion (SEP) tug performance for Johnson Space Center's Gateway mission. Transfer time from low Earth orbit to Earth-Moon L1 and xenon propellant mass required for transfer are shown as functions of the power generated. At 584 kW, the tug would be able to deliver the 30 MT payload in 179 days.

Long description : This graph shows the transfer time and xenon propellant mass as functions of the power generated on the SEP tug. The left axis shows the transfer time from 0 to 350 days. The right axis shows the xenon propellant mass from 0 to 30,000 kg. The x-axis shows the array power from 200 to 800 kW. The curve representing the transfer times starts in the upper left at approximately 320 days at 270 kW. It decays approximately exponentially to the lower right to a value of approximately 130 days at 850 kW. The propellant mass increases linearly from approximately 17,500 kg at 270 kW to 24,500 kg at 85 kW.

For both studies, the SEP tug performance satisfied the requirements of the respective mission designers, and the SEP concept was incorporated into the mission architectures. Further refinement of the system model, including structural and dynamic analysis and incorporation of the results of the improved orbit trajectory, is planned. The development of the SEP tug system model has been a joint effort by Glenn's Power and Propulsion Office, Power and On-Board Propulsion Technology Division, and Systems Engineering Division, through Glenn's Systems Assessment Team.

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