Application of Solar-Electric Propulsion to Robotic and Human Missions in Near-Earth Space

ABSTRACT

Gordon Woodcock
Gray Research, Inc. Huntsville Alabama

Solar-electric propulsion (SEP) is becoming of interest for application to a wide range of missions. The benefits of SEP are strongly influenced by system element performance, especially that for the power system. Solar array performance is increasing rapidly and promises to continue to do so for another 10 to 20 years (Fig. 1). At the same time, cost per watt is decreasing. Radiation hardness is increasing. New concepts for how to design a SEP are emerging. These improvements lead to changes in the best ways to apply SEP technology to missions, and broadening of the practical uses of SEP technology compared to competing technologies.

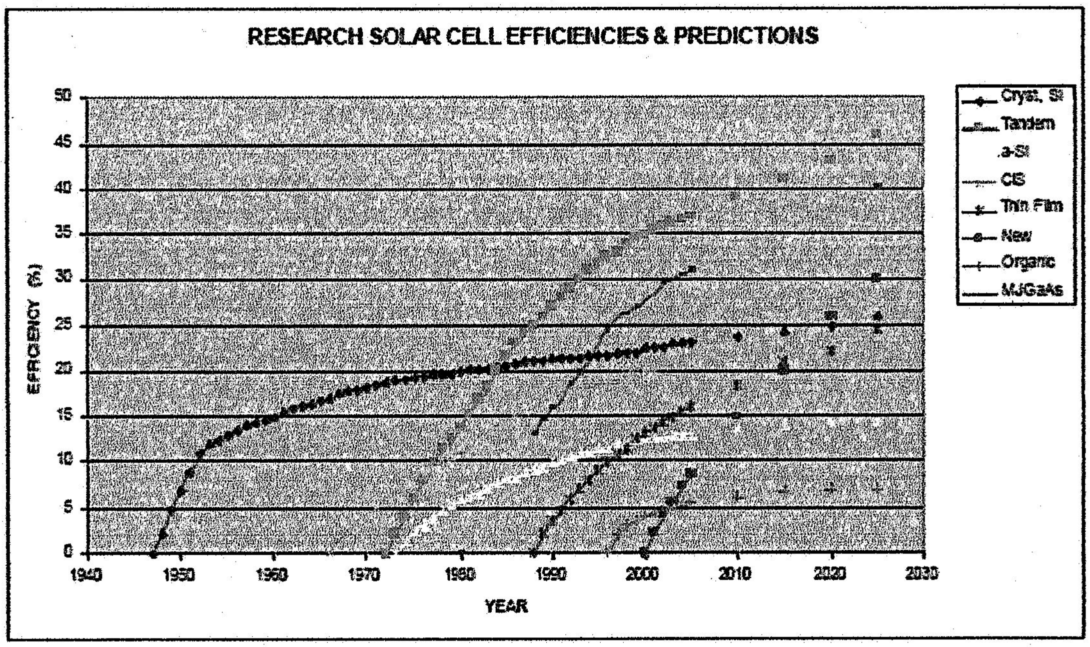

Fig. 1. History and Projection of Solar Cell Performance

This paper addresses the evolving characteristics of SEP technology from the point of view of mission design, and how mission profile characteristics can be designed to best take advantage of evolving SEP characteristics. Mission concepts include robotic lunar landers and orbiters; scientific planetary spacecraft; delivery of spacecraft to geosynchronous orbit from inclined and low-inclination launch orbits; and lunar cargo delivery from Earth orbit to lunar orbit. Expendable and re-usable SEP profiles are considered. Flight control considerations are abstracted from recent papers by the author to describe how these influence SEP design and operations.

The following mission profiles are covered:

- LEO to GEO orbit, to lunar orbit, and to positive C3 escape.
- GTO to the same target orbits. If one wishes to impart more launch energy to the vehicle than to LEO, a GTO-like orbit makes much better use of launch vehicle performance than

a circular orbit at higher altitude than LEO. Also, elliptic orbits with apogee at 10,000 km altitude or more involve much less van Allen radiation exposure than near-circular spirals (Fig. 3). Continuous thrusting is a reasonable strategy for a GTO-like starting orbit; perigee is raised rapidly to leave the high radiation environment entirely. Alternative thrusting strategies are also considered as noted below under trades.

- Lunar vicinity to GEO and return, as might be used for delivery of lunar surface payloads or products to GEO.

The following tradeoff issues are described, with typical results:

- Best Isp (more is not necessarily better).
- How much power? Evolution of design with increasing power
- Thrusting profiles ... What's the best plan? How do Isp, delta V and trip time trade off? An example is shown in Fig. 5, for two Isps, for a robotic lunar lander with part chemical and part SEP propulsion. Trip time was held constant at 180 days by increasing SEP power. As SEP takes over more of the mission profile, payload increases and cost per kg payload drops.
- Are there strategies better than simple continuous tangential thrusting? When do they work?
- Starting orbits and van Allen exposure
- Re-use vs expendable, including lifetime and refurbishment issues
- Mission cost; cost of SEP vs potential savings in launch cost
- Dealing with occultation (shadowing)
- Configuration approaches for operating in Earth-Moon space, including factors of gravity gradients and sun-tracking maneuvering in near-Earth orbits and satisfying control authority requirements (Figs 2 & 4, representative configuration approaches).
- Propellants and what's known about propellant availability issues (if we need tons & tons of xenon are we likely to be able to get it?)
- Vehicle stiffness and controllability; gravity gradients
- Targeting for lunar orbit insertion: using lunar encounters to advantage

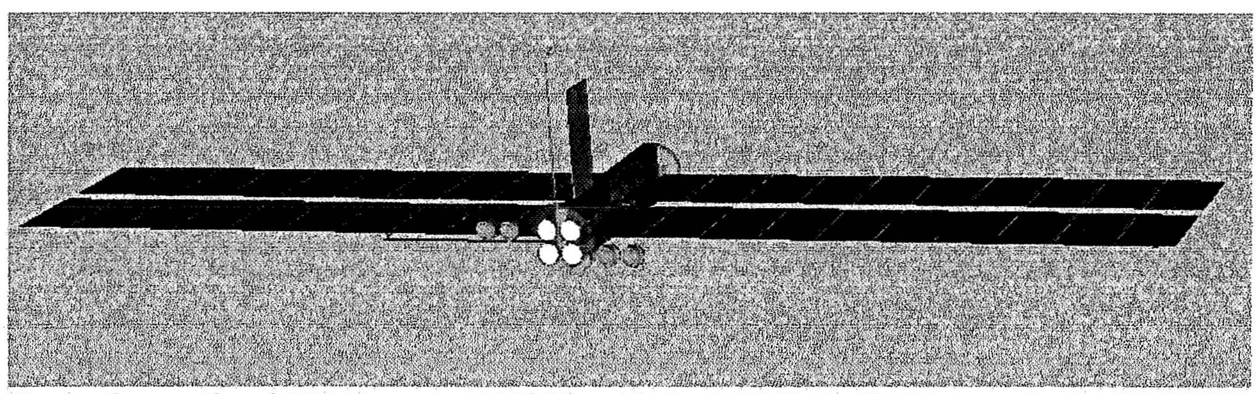

Fig. 2. Conventional SEP Concept, 500 kWe with 4 - 125 kWe Hall Thrusters, Payload Forward (not shown).

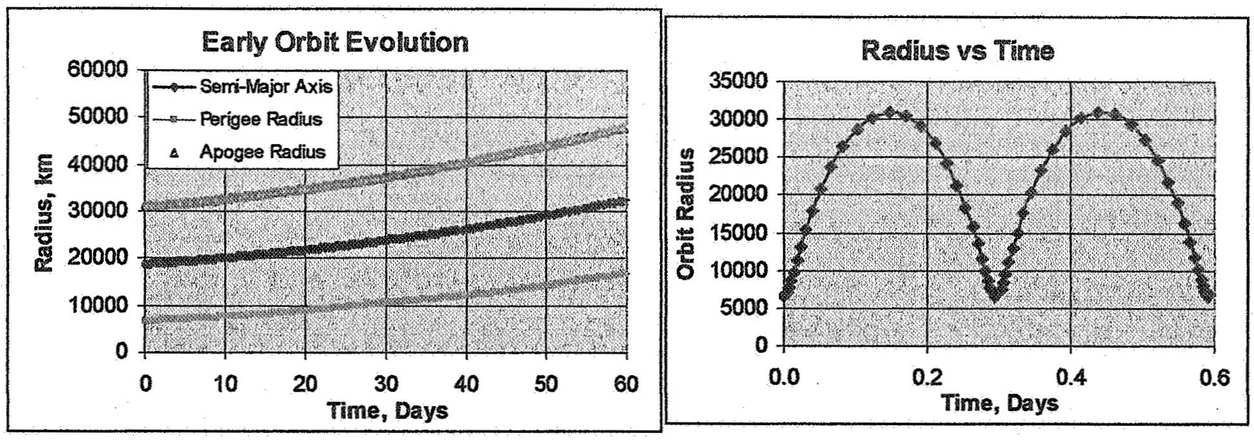

Fig. 3 Orbit Raising from GTO-Like Starting Orbit

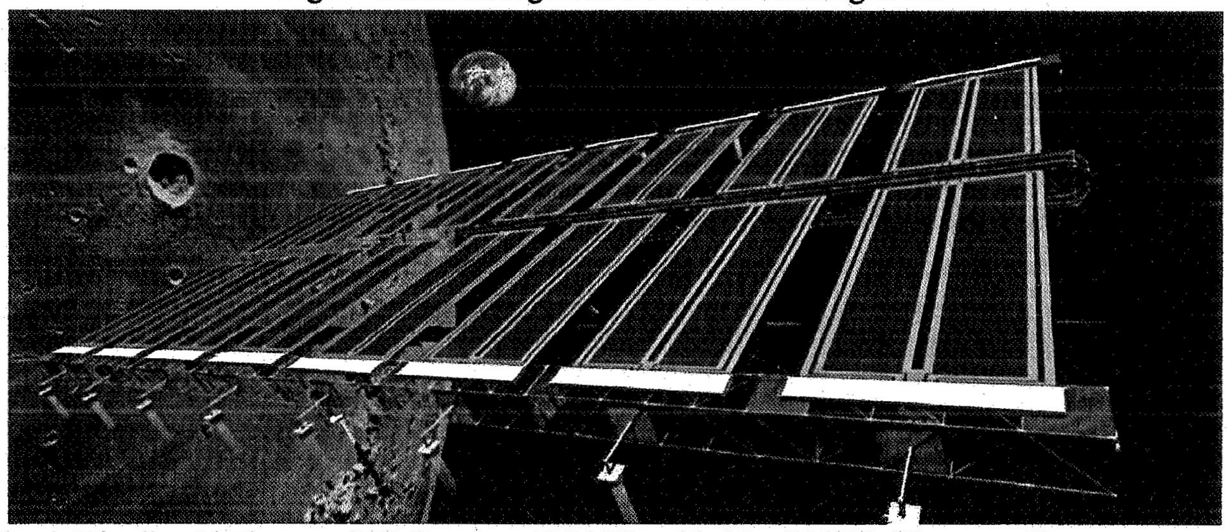

Fig. 4. Distributed Thruster SEP Concept, 500 kWe with 16 – 50 kWe Thrusters (Some Redundancy Required to Ensure Ability to Use All the Power), Payload Underslung (not shown).

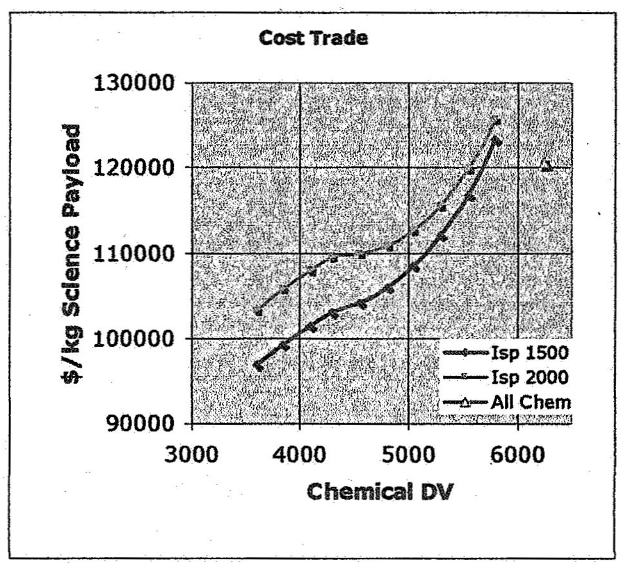

Fig. 5. Cost Trade for SEP Use On Robotic Lunar Lander