"Packetized Propulsion" for Human and Robotic Mars Exploration

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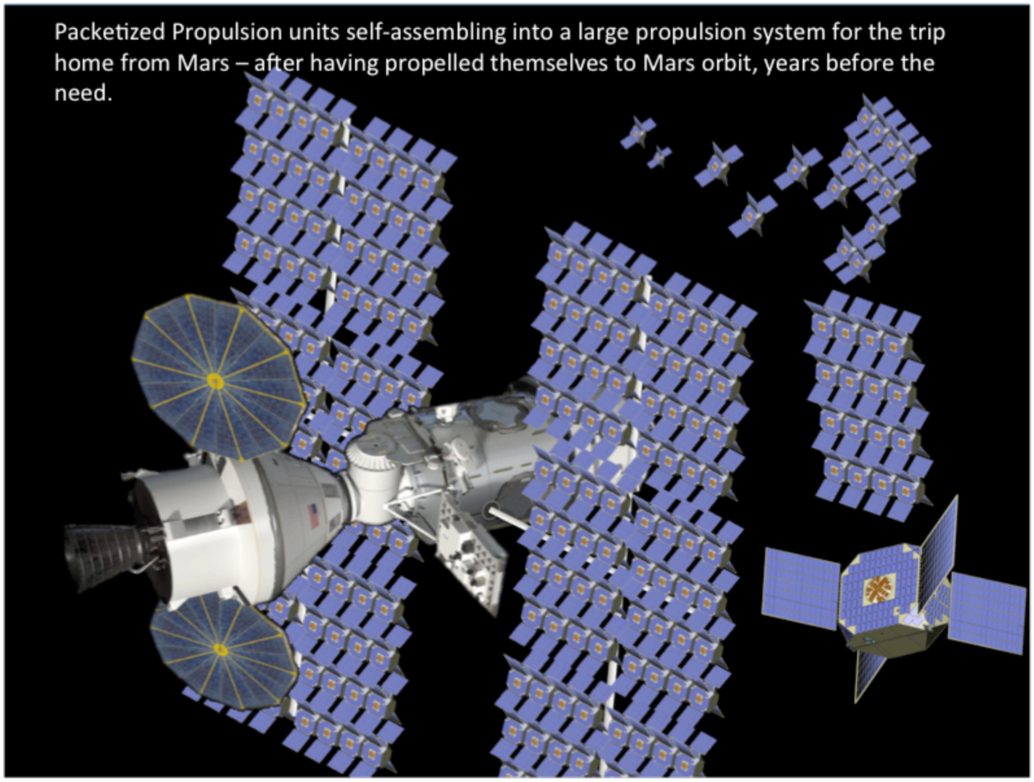

Introduction and Motivation: Perhaps the greatest challenge to future human and robotic exploration of Mars would be the delivery of large mass to Mars and return of large mass to Earth. Human exploration would require both legs of the mission to carry large payloads consisting of at least the habitat, and probably landing assets on the out-bound leg. Precursor robotic exploration would require return of samples to Earth. These are all principally challenges for propulsion, with reasonably short transits for humans (required for life-support reasons) requiring enormous propulsion capability. Even a modest sample return would require large propulsion capability to return a small, well-contained sample canister safely to Earth from Mars orbit. The requirement for large propulsion modules to be components of Mars Missions greatly increases the cost and complexity of these missions. This is a proposal to modularize the propulsion elements of Mars missions into many ~50 kg packets that could be assembled over time in Earth orbit for the outbound leg and propel themselves to Mars to self-assemble into a Mars return propulsion system years before the need.

Micro Electro-fluidic-spray Propulsion: A game-changing new JPL technology is Micro Electro-fluidic-spray Propulsion (MEP—a solid-state micro-version of Field Effect Electric Propulsion. MEP is a form of propulsion that can be implemented with thruster elements etched on silicon chips in the same process as the creation of solid-state printed integrated circuits. There are several enormous advantages of this form of propulsion:

- *Extremely high Isp (≥ 8000 sec)*
- *Widely adjustable thrust levels*
- *Safe, common metal propellant (Indium)*
- *Small, self-contained propulsion elements*

Since one of the chief advantages of MEP is that it can be self-contained in small packages (as small as a fraction of a kilogram, including thruster, power supply *and* propellant), there is an opportunity to build highly modular propulsion systems. More importantly, these modular propulsion systems could be incrementally constructed *in situ* by delivering them in small parts to Mars, years before the need. It is by design a highly redundant system because a large propulsion system can self-assemble from only the functional parts, leaving out those that might be compromised. Thus a large propulsion system on Mars orbit could be created with full verification of functionality before even launching the outbound component of the mission. Furthermore, this "*PacketizedPropulsion*" system could deliver *itself* to Mars, by being launched in small (e.g., 50 kg) autonomous elements and traveling over several years to Mars. Launches and delivery could occur as shared payload space is available, and the accumulated *"PacketProp"* elements at Mars would be a banked resource from which future return ships could draw.

When the waiting, on-orbit, PacketProp elements' need-time arrives, they could activate their GN&C/Autonomous Rendezvous and Docking (AR&D) systems and assemble to form a high-thrust solar electric propulsion system. These elements would come with their own solar arrays, so as the PacketProps rendezvous *en masse*, the ensemble resembles a large lattice of solar-arrays and engine-housings. Inter-PacketProp attachments could be modest because their indiviusal thrust is relatively low (e.g., 5 mN); meaning that attachments between bus-elements of approximately 50 cm x 50 cm x 50 cm in size could readily be made sufficiently robust. For the case of a large crewed return vehicle, empty outriggers on which the free-flying PacketProps would "roost" and plug in to provide both power and thrust for the trip home could be used. The empty (and light-weight) return proplusion module carrier could be sent to Mars before the out-bound ship leaves Earth, along with hundreds of the PacketProps (over several years). This would allow the return-ship propulsion system to assemble and be thoroughly tested before sending the humans.

Using PacketProp Architecture for MSR: Mars Sample Return (MSR) could be a first application of PacketizedPropulsion, with self-assembly of both the outbound and return propulsion elements on Earth and Mars orbit respectively. Several dozen PacketProp modules would be accumulated in Earth orbit (perhaps several on every ISS re-supply mission) and the ISS crew can supervise as they assemble themselves on the scaffold of the empty outbound MSR propulsion system. Then the ISS crew could direct the assembly of the other MSR elements into the complete MSR stack, which could be dispatched to Mars. In the meantime, dozens of PacketProps would have been dispatched to Mars and begin self-assembling into a propulsion module to provide thrust for the return mission component. This approach has the advantage of linking SMD and HEOMD in the MSR development and paving the way for bigger but cheaper robotic and human missions.

Using PacketProp Architecture for ISS: A PacketProp approach could also be applied to the proposed ISS "tug." A small spacecraft with outrigger roosts could be sent to the ISS followed by a number of PacketProps lofted to roost in the rigging, providing the ISS with both propulsion and additional power (when the engines aren't running). ISS uses 7000 kg/year of propellant for attitude and trajectory control. If this work were done with 8000 sec Isp PacketProps instead of 200 sec Isp hydrazine engines, the propellant consumption would be approximately 175 kg/year—a substantial savings of up-mass cost. Each PacketProp unit could carry 20 kg of Indium propellant, so only ten 50 kg PacketProp units per year would be required. When individual PacketProp units are nearly out of Indium, they could detach from the roost and propel themselves into the atmosphere for disposal – or transit to the station where a crew member can install a new Indium slug and send the PacketProp back to its roost.

Concluding remarks: This is a technology with almost limitless applications. The reconfigurability aspects of deploying "swarms" of propulsion microsats is a key feature that could be efficiently applied to many missions, with the flexibility to be applied as a primary propulsion capability for essentially any deep space mission. The low cost of a single PacketProp module could enable universities and small businesses to participate by contributing and operating their own microsats. These could be dual-purposed for some initial science or technology demonstration objectives and then later repurposed (with sufficient remaining propellant) to join other on-orbit PacketProps, providing a new capability for a completely new deep space mission.

This combination of features raises the tantalizing possibility of establishing a mass production line of PacketProps. PacketProps could be inexpensively produced by the hundreds or thousands and placed in orbit as available excess payload capacity allowed, providing a bank of propulsion capability that would stay viable for years. Science institutions (including NASA) could draw on the module production line to build small planetary micro-missions as well as drawing on the propulsion bank for large flagship missions such as the proposed MSR mission. The PacketProp propulsion bank concept is a viable solution to the difficult problem of having sufficient propulsion mass/capability at Earth and at Mars to enable a quick and reliable transit of humans beyond Earth and Moon and insure their safe and speedy return home.