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Products from NASA's in-space propulsion technology program applicable to low-cost planetary missions

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ABSTRACT

Since September 2001, NASA's In-Space Propulsion Technology (ISPT) program has been developing technologies for lowering the cost of planetary science missions. Recently completed is the high-temperature Advanced Material Bipropellant Rocket (AMBR) engine providing higher performance for lower cost. Two other cost saving technologies nearing completion are the NEXT ion thruster and the Aerocapture technology project. Under development are several technologies for low-cost sample return missions. These include a low-cost Hall-effect thruster (HIVHAC) which will be completed in 2011, light-weight propellant tanks, and a Multi-Mission Earth Entry Vehicle (MMEEV). This paper will discuss the status of the technology development, the cost savings or performance benefits, and applicability of these in-space propulsion technologies to NASA's future Discovery, and New Frontiers missions, as well as their relevance for sample return missions.

1. Introduction

NASA's Science Mission Directorate (SMD) missions seek to answer important science questions about our planet, the Solar System and beyond. To meet NASA's future mission needs, the goal of the ISPT program is the development of new enabling propulsion technologies that cannot be reasonably achieved within the cost or schedule constraints of mission development timelines. Since 2001, the In-Space Propulsion Technology (ISPT) program has been developing in-space propulsion technologies that will enable and/or benefit near and mid-term NASA robotic science missions by significantly reducing cost, mass, and/or travel times. ISPTs will help deliver spacecraft to SMD's destinations of interest.

An objective of ISPT is to develop products that realize near-term and mid-term benefits. The program primarily focuses on technologies in the mid TRL range (TRL 3 to 6+ range) that have a reasonable chance of reaching maturity in 4–6 years. The objective is to achieve technology readiness level (TRL) 6 and reduce risk sufficiently for mission infusion. The project strongly emphasizes developing propulsion products for NASA flight missions that will be ultimately manufactured by industry and made equally available to all potential users for missions and proposals.

The ISPT program is currently developing technology in four areas. These include Advanced Chemical and Electric Propulsion, Entry Vehicle Technologies, Sample Return

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Propulsion, and Systems/Mission Analysis. These in-space propulsion technologies are applicable, and potentially enabling for future NASA Discovery, New Frontiers, and sample return missions currently under consideration, as well as having broad applicability to potential Flagship missions. For more background on ISPT, please see Refs. [1] and [2].

2. Technology relevance

The ISPT priorities and products are tied closely to the science roadmaps, the SMD's science plan, and the decadal surveys. ISPT emphasizes technology development with mission pull. In 2006, the Solar System Exploration (SSE) Roadmap [3] identified technology development needs for Solar System exploration, and described transportation technologies as highest priority, with the highest priority propulsion technologies being electric propulsion and aerocapture. Excerpts from the science community are discussed in Ref. [4]. Initially, ISPT's responsibility was to develop technologies for Flagship missions, but in 2006 the focus evolved to technology investments that would be applicable to New Frontiers and Discovery competed missions. Aerocapture (the use of aerodynamic drag for orbit capture) and electric propulsion continued to be a priority, but the refocus activity also recommended a long-life lower-power Hall system.

Looking towards ISPT's future, the 2011 Planetary Science Decadal Survey [5] was released March 2011 and provides guidance for ISPT's future technology investments. The Decadal Survey made many references to ISPTs such as aerocapture, NEXT, AMBR, astrodynamics, mission trajectory and planning tools. This Decadal Survey is validating the technology investments ISPT has made over the last 10 years, but also provides ISPT with a new focus for the next 10–20 years.

The Decadal Survey supported NASA developing a multi-mission technology investment program that will "preserve its focus on fundamental system capabilities rather than solely on individual technology tasks." The Decadal Survey highlighted the NEXT system development as an example of this "integrated approach" of "advancement of solar electric propulsion systems to enable wide variety of new missions throughout the solar system." The Decadal Survey recommends "making similar equivalent systems investments" in the advanced Ultraflex solar array technology and aerocapture. The Decadal Survey discussed the importance of developing those system technologies to TRL 6.

One recommendation in the Decadal Survey was for "a balanced mix of Discovery, New Frontiers, and Flagship missions, enabling both a steady stream of new discoveries and the capability to address larger challenges like sample return missions and outer planet exploration." These broad mission needs would require a balanced set of multi-mission technologies and integrated system capabilities. The Survey acknowledges that a "robust Discovery and New Frontiers program would be substantially enhanced by such a commitment to multi-mission technologies."

3. Results and discussion

3.1. Aerocapture

Aerocapture is the process of entering the atmosphere of a target body to practically eliminate the chemical propulsion requirements of orbit capture. Aerocapture is the next step beyond aerobraking, which relies on multiple passes high in the atmosphere using the spacecraft's drag to reduce orbital energy. Aerobraking has been used at Mars on multiple orbiter missions. Aerocapture, illustrated in Fig. 1, maximizes the benefit from the atmosphere by capturing into orbit in a single pass. Aerocapture represents a major advance over aerobraking techniques, by flying at a lower altitude where the atmosphere is more dense. Key to successful aerocapture is accurate arrival state knowledge, validated atmospheric models, sufficient vehicle control authority (i.e. lift-to-drag ratio), and robust guidance during the maneuver. A lightweight thermal protection system and structure maximizes the aerocapture mass benefits.

Executing the aerocapture maneuver itself enables the great mass savings over other orbital insertion methods. If the hardware subsystems are not mass efficient, or if performance is so poor that additional propellant is needed to adjust the final orbit, the benefits can be significantly reduced. ISPT efforts in aerocapture subsystem technologies are focused on improving the efficiency and number of suitable alternatives for aeroshell structures and ablative thermal protection systems (TPS). These include development of families of low and medium density (14–36 lbs/ft^3) TPS and the related sensors, development of a carbon–carbon rib-stiffened rigid aeroshell, and high temperature honeycomb structures and adhesives. Development occurred on inflatable decelerators through concept definition and initial design and testing of several inflatable decelerator candidates. Finally, progress was made through improvement of models for atmospheres, aerothermal effects, and algorithms and testing of a flight-like guidance, navigation and control (GN and C) system.

Aerocapture has shown repeatedly in detailed analyses to be an enabling or strongly enhancing technology for

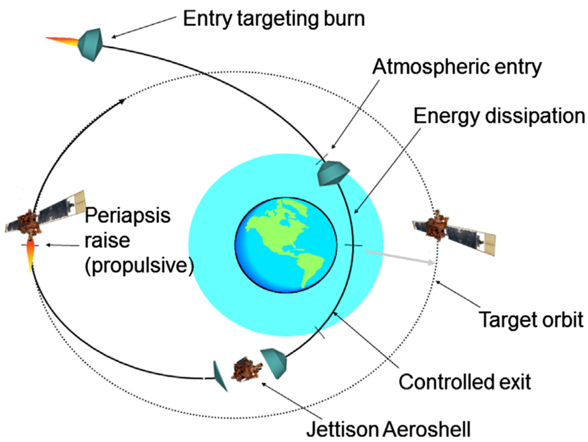

Fig. 1. Illustration of the aerocapture maneuver.