In-Space Propulsion Technologies Minimum Demonstration Requirements for the Discovery 2010 AO

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Introduction

The purpose of this document is to describe the minimum systems and activities qualifying as a flight demonstration of a NASA-developed in-space propulsion technology. Failure to meet these requirements will result in the loss of any NASA-funded incentives.

The NEXT (NASA's Evolutionary Xenon Thruster) Ion Propulsion System

The primary goal of the NEXT project was to develop key components of an ion propulsion system (IPS) for deep space science missions. The components of a typical IPS include a thruster, power processing unit (PPU), propellant management system (PMS), digital interface control unit (DCIU), and gimbal.

The minimum required hardware set for a flight demonstration of the NEXT system is comprised of the NEXT thruster and its accompanying PPU.

1. The NEXT Prototype Model (PM) ion thruster is a 6.9 kW ion thruster design that is currently at Technology Readiness Level (TRL) 6. The NEXT Prototype Model (PM) ion thruster design baseline is a required component of any demonstration, although minor design changes of the type commonly associated with the normal evolution in transitioning a PM design to a flight design are acceptable. The NASA Glenn Research Center (GRC) developed the NEXT thruster, which was fabricated by Aerojet.
2. The NEXT Engineering Model (EM) PPU is a 7kW PPU design that operates the NEXT ion thruster and will achieve TRL 6 after successful completion of environmental testing and on-going System Integration Tests (SIT) in 2010. The NEXT EM PPU circuit design baseline is a required component of any demonstration, although NASA recognizes that substantive hardware design changes may be desired, or required, to transition NEXT EM PPU to a flight design. GRC developed the NEXT thruster, which was fabricated by L-3 Communications.

The remainder of the NEXT ion propulsion system may be used for flight demonstrations but is not required:

1. The NEXT Propellant Management System (PMS) design is a highly flexible, modular design and consists of a high-pressure assembly (HPA) and low-pressure assembly (LPA). The NEXT PMS is at TRL 6, and has been tested with the NEXT thruster and PPU in the SIT. GRC and Aerojet developed the NEXT PMS.
2. The Digital Control Interface Unit (DCIU) is the electronics interface between the spacecraft computer and the rest of the IPS components. The NEXT project developed a DCIU simulator, which will not achieve TRL 6 under existing plans. ISPT also funded a separate development task called Standard Architecture that has matured a DCIU that would work with NEXT to a breadboard-level design. This task

has also matured the associated software to operate the DCIU. The ISPT-developed DCIU breadboard design and software from this task are available upon request. However, if the ISPT-developed DCIU breadboard design and software are used, then the additional cost, schedule, and technical risks for developing the ISPT-developed DCIU design and software into a flight design would be borne by the proposal team. Aerojet developed the NEXT DCIU simulator. JPL is developing the Standard Architecture DCIU breadboard and software.

3. The gimbal is the mechanical interface between the ion thruster and the spacecraft that can articulate the thrust to maintain the thrust vector pointing through the spacecraft center-of-gravity. The NEXT project developed a gimbal design that completed vibration tests to achieve a TRL 4-5. Remaining environmental tests require spacecraft-specific definition and will not be performed under the ISPT program. The ISPT-developed gimbal design will be available upon request, but the additional cost, schedule, and technical risks for developing the ISPT gimbal into a flight design would be borne by the proposal team. JPL and ATK developed the NEXT gimbal hardware.

The (AMBR) Advanced Material Bi-propellant Rocket

A primary goal of the AMBR project was to design and test an iridium/rhenium (Ir/Re) combustion chamber in an Earth storable bipropellant apogee-class engine. The AMBR engine consists of an injector, a combustion chamber and other nozzle hardware. It is based on the RD-4 HiPAT heritage design and is at TRL 6. The AMBR was developed by Aerojet.

Since a major goal of the AMBR project was to develop the iridium/rhenium El-form fabrication process***, the minimum required hardware to be demonstrated is a combustion chamber fabricated using this process***. Alternate injector designs, which would improve performance over the existing AMBR injector design, would be considered acceptable. However, the additional development, cost, schedule, and technical risks to bring this alternate injector design to TRL 6 would be borne by the proposer. Additionally, although the AMBR engine was designed for the baseline fuel/oxidizer combination of hydrazine/nitrogen tetraoxide (N_2H_2/NTO), it would be acceptable to modify the AMBR engine to use the alternate fuel/oxidizer combination of monomethylhydrazine/nitrogen tetraoxide (MMH/NTO). However, the additional development, cost, schedule and technical risks to bring this alternate fuel/oxidizer option to TRL 6 would be borne by the proposer.

Aerocapture

The ISPT Program has developed thermal protection system (TPS) materials and structures, models for aerothermal effects, engineering atmospheric models for a number of targets, and guidance, navigation, and control (GN&C) algorithms for blunt-body rigid aeroshells. Due to the diversity of specific technologies developed, there are two different types of technology demonstrations for which incentives are offered.

1. ***Missions performing a complete atmospheric entry must demonstrate one or more rigid heat shield materials matured by the ISPT program under conditions specified***

below. Although termed the "lander" option in the Discovery 2010 AO, a probe, penetrator, hopper, atmospheric sampler, Earth return entry vehicle, or delivery device to mid-altitudes is acceptable. These materials and the required demonstration conditions are:

a. A carbon-carbon "hot structure" with Calcarb bonded to the structure interior. This material has been designed to directly take heat up to 700W/cm^2 and is up to 30% lighter than the Genesis capsule design in cases where a backup structure is not required. This material technology is considered TRL6. *To be considered an acceptable demonstration, these materials need to be applied in a relevant heating environment (over 300 W/cm^2 heat flux) and the C-C and Calcarb construction must be employed. Using C-C as a secondary structure is not an acceptable modification.* To verify system performance, the structure will need to be instrumented with thermocouples. The incorporation of thermocouples into the structure will be funded by the ISPT Program.

b. A honeycomb "warm structure". This is a traditional honeycomb sandwich aeroshell construction, but with updated adhesives and a composite core replacing the traditional aluminum core thereby raising the maximum bondline temperature to 316 C from 250 C. This material technology is considered TRL6. This structure would need to be covered in an ablator, such as Lockheed's high-heritage SLA-561V, for heating protection although the higher permissible bondline temperature would allow for the use of a thinner ablator. *To be considered an acceptable demonstration, the ISPT-developed adhesives and core material would be employed.* To verify system performance, the structure will need to be instrumented with thermocouples at the ablator/warm structure bondline and within the ablator. The incorporation of thermocouples into the structure will be funded by the ISPT Program.

c. A honeycomb "warm structure" with an ablator. This heatshield system can be tailored to a wide range of applications. The warm structure has facesheets with enhanced resins and fibers, updated adhesives, and a light-weighted titanium honeycomb core. The warm structure can handle bondline temperatures up to 400 C. Sensitive payloads may need additional lightweight insulating blankets behind the aeroshell due to greater soakback from the higher bondline temperature. The ablator component of the system can be any one of a "family" of materials developed under ISPT, which all have the same constituents but in varying ratios to produce a range of densities. Both the SRAM (silicone-based) and PhenCarb (phenolic-based) materials have been applied to the warm structure using high-temperature adhesives. Ablators in the range of 17 to 32 lb/ft^3 have been extensively arcjet tested and have been competitively selected in the past for flight opportunities. Separately, and as a system, these materials have undergone extensive laboratory, radiative, and convective thermal testing. A 2.65-meter, 70-deg sphere-cone aeroshell is currently being manufactured, and will be complete by the end of FY2010.

Similar, 1-meter aeroshells and numerous flat panels have been manufactured and successfully tested both mechanically and thermally. The system is considered TRL6 and would be applicable for heating rates up to about 450 W/cm^2. There have been many tests above that level, but the TRL is a bit lower for the higher-density materials. It would be the responsibility of the proposer to do the additional testing necessary to bring the higher-density materials to TRL 6. *To be considered an acceptable demonstration, these materials must be used in a forebody heat shield application, although the maximum bondline temperature need not be achieved.* To verify system performance, the structure will need to be instrumented with thermocouples at the ablator/warm structure bondline and within the ablator. The incorporation of thermocouples into the structure will be funded by the ISPT Program. Note that the honeycomb "warm structure" was developed by ATK Composite Optics in San Diego, CA., with an ablator developed by Applied Research Associates, Inc. (ARA) in Centennial, CO. The ATK/ARA partnership must be preserved (*i.e.,* an ARA ablator cannot be applied to a non-ATK structure, or vice-versa).

2. For missions not performing a complete atmospheric entry — termed the "orbiter" option in the Discovery 2010 AO — ***the minimum acceptable demonstration uses the aerocapture maneuver to decelerate by at least 2km/s in the atmosphere of a planetary body and then completely exit the atmosphere after this atmospheric passage. The vehicle must also contain some minimum instrumentation suite that will validate the Aerocapture maneuver was performed within the expected parameters.*** The post-aeropass vehicle is not limited to being an orbiter; it could perform a subsequent planetary entry, or some other function.

   The ISPT Program has matured the Analytical Predictor-Corrector (APC) guidance over the past several years, by applying it in detailed systems studies to missions at Titan, Neptune, Venus, Mars, and Earth. The APC guidance performance is robust to realistic atmospheric, aerodynamic, and navigational uncertainties, and study results are documented in several publications. Most recently, a hardware-in-the-loop simulation of the Guidance, Navigation and Control system has been assembled and tested, with the APC algorithm coded in flight software. The testbed, which brings the APC algorithm to TRL 6, resides at Ball Aerospace in Boulder, CO and can be made available for simulations and trades, through ISPT.