Pulsed Plasma Thruster (PPT) Summary

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The Earth Observing-1 (EO-1) Pulsed Plasma Thruster (PPT) is a new generation advanced propulsion technology that was flown to demonstrate, for the first time, the PPT technology's ability to serve as a precision attitude control actuator for spacecraft. PPTs can offer spacecraft significant mass savings by replacing the customary combinations of reaction wheels, torque rods, and chemical thrusters and have the advantage of being simple to integrate into spacecraft because of their limited mechanical mounting hardware and electrical requirements. PPTs also eliminate safety and component layout complexities associated with fluid-propellant propulsion systems.

The EO-1 PPT is a small, self-contained electromagnetic propulsion system that utilizes solid Teflon propellant. It can deliver high specific impulses (650 – 1400 sec), very fine impulse bits (90 – 860 micro N-sec) at low power levels (12 - 70 W), and an estimated total impulse of 460 N-sec. The total mass is 4.95 kg. Figure 1 shows the PPT mounted to the spacecraft while the spacecraft is attached to the launch vehicle.

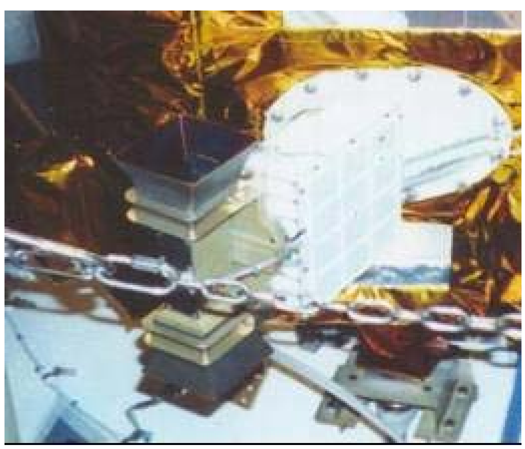

Figure 1. EO-1 spacecraft with PPT

The EO-1 PPT is the first flight PPT developed in more than 10 years and incorporates significant improvements over the previous generation of PPTs. The EO-1 PPT flight experiment was designed to validate this new generation of PPT in three key areas: 1) to demonstrate the ability of the PPT to function as a precision attitude control actuator, 2) to confirm benign interaction with other spacecraft subsystems and instruments, and 3) to verify performance parameters in flight. The flight validation of this technology was the collaborative effort of NASA Goddard Space Flight Center (GSFC), NASA Glenn

Research Center (GRC), General Dynamics Ordnance and Tactical Systems (formerly Primex Aerospace Corporation), and Swales Aerospace in partnership with the Hammers Company.

The operation of the PPT is inherently simple. Referring to Figure 2, the main capacitor is initially charged to the desired level and then discharged across the face of a Teflon fuel bar. Two fuel bars are located between separate and opposing electrode pairs to provide thrust in the positive and negative Z-axis directions (the PPT location with respect to the center of mass results in ± pitch torque). The discharge of the main capacitor occurs when the spark plug on the desired electrode pair is commanded to fire. A minute amount of charged particles is ablated into the electrode gap when the spark plug is fired. These charged particles provide a conductance path that initiates the main capacitor discharge across the gap. The main capacitor discharge ablates a small amount of Teflon. A small percentage of the Teflon is ionized to form plasma. A Lorentz force accelerates the plasma and thus produces thrust. Charged-particle to neutral-particle collisions and pressure forces from resistive heating produce additional acceleration of the neutrally charged, ablated Teflon plasma.

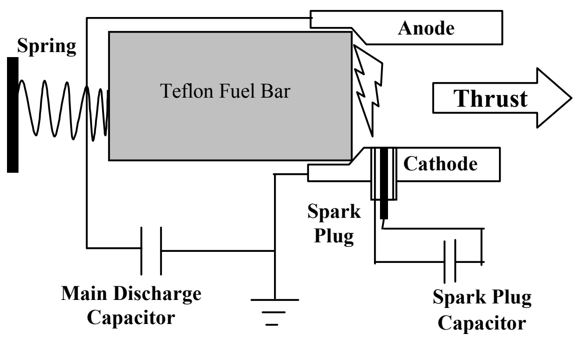

Figure 2. PPT Diagram

To modulate the thrust, the magnitude of the impulse bit is varied. Varying the charge time of the main capacitor changes the magnitude of the impulse bit. The length of time the main capacitor charges directly affects the amount of energy in the capacitor and, consequently, the amount of thrust produced during the discharge.

To achieve the minimum objective associated with flight validating the advanced PPT technology for performing the attitude control function within the cost and schedule constraints of the EO-1 mission, the impacts to the baseline attitude control system were minimized. This approach led to the fundamental experiment design choices of using a single PPT unit to replace the function of the pitch axis momentum wheel for a limited time during the mission and operating the PPT at a fixed firing frequency (1 Hz) while varying the PPT power level to achieve thrust variability. During PPT control mode, the roll and yaw axes continued to be controlled by their associated reaction wheels and torquer bars.

The EO-1 PPT component flight unit underwent extensive ground protoflight hardware validation and development testing. Functionality tests were performed at the bench top and vacuum chamber level to verify and map the electrical characteristics of the unit. The PPT was throttled through the range of charge durations (160 - 920 msec). Performance tests measured thrust and impulse bit as a function of PPT charge time before and after life testing. Off-axis thrust components were evaluated and shot-to-shot repeatability was characterized. The spacecraft-level tests included sending discrete fire commands to the PPT as well as closed-loop autonomous commanding of the PPT by the EO-1 attitude control system. Hundreds of shots were accumulated over the entire range of PPT charge levels. The results of all of the

PPT spacecraft-level tests confirmed proper command and telemetry to and from the PPT and PPT electrical functionality.

The initial on-orbit tests consisted of incrementally verifying PPT functionality as well as spacecraft and instrument health. The test firings and short duration closed-loop control activities culminated in four-hours (2.4 orbits) of continuous PPT pitch axis control. During this time period, the attitude commanding was nadir pointing with yaw steering enabled. Three Data Collection Events (DCEs) were performed with the Advanced Land Imager (ALI) under PPT control to validate pointing performance for science observations and to evaluate whether there were any adverse effects on the instrument.

During the second test period, the pitch axis of the spacecraft was under PPT control for a total of 10 hours over a 12-hour period. Four science DCEs were performed with the ALI as well as additional ALI calibration events with PPT firings. The second PPT tests enabled evaluation of PPT pointing performance over a longer duration.

During the third test period of operations with the PPT, the pitch axis of the spacecraft was under continuous PPT control for over 9 hours. During this period, five science-instrument DCEs were performed with the Atmospheric Corrector.

All spacecraft subsystems and the ALI instrument operated nominally during and after all PPT operations. The PPT operated for more than 23 hours, accumulating over 84,000 pulses from the three PPT test periods. During PPT operation, there were no processor or other error flags generated on the spacecraft that could be linked to PPT operations. All telemetry and telemetry links appeared nominal. There was no evidence of electromagnetic interference (EMI) or plume effects on other subsystems or instruments.

During all PPT operations to date, the Hyperion instrument was powered off and in a “warm” outgas mode. At the end of the first PPT validation sequence, the Hyperion was powered on. All Hyperion data looked nominal and there were no indications of any harm to the instrument from PPT operations. Hyperion operation after all additional PPT testing also confirmed that the instrument operated nominally and was not affected by PPT operation. Plans exist for imaging with the Hyperion during PPT control in future testing.

The PPT has been successfully validated as a precision attitude control thruster on the EO-1 spacecraft and has been demonstrated to be compatible with all spacecraft subsystems and all instruments’ modes of operations. All PPT performance parameters appear nominal and correspond with ground measurements. Additional testing of the PPT is scheduled to complete performance evaluation and give insight into life issues. The success of the EO-1 PPT Flight Validation Experiment enables this new generation PPT technology to be considered for future missions with negligible risk.