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Dawn Ion Propulsion System: Initial Checkout After Launch

John R. Brophy,* Charles E. Garner,† and Steven Mikes‡
Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California 91109

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The first 80 days after launch of the Dawn mission were dedicated to the checkout of the spacecraft with a major emphasis on the ion propulsion system. All three ion thrusters, all three thruster-gimbal assemblies, both power processor units, both digital interface and control units, and the entire xenon feed system were completely checked out, and every component was found to be in good health. Direct thrust measurements agreed well with preflight expected values for all three thrusters over the entire throttle range. Measurements of the thruster-produced roll–torque verified that each thruster produced less than the maximum allowed value of 60 μNm at full power. Thruster electrical operating parameters and power processor unit efficiencies also agreed well with preflight expected values based on acceptance test data. Two of the three ion thrusters were fully checked out within 30 days after launch. Checkout of all three thrusters was completed 64 days after launch. Deterministic thrusting with the ion propulsion system began on 17 December 2007.

Nomenclature

e	=	electronic charge, 1.6×10^{-19} C
F_T	=	thrust loss factor due to ion beam divergence
J_A	=	accelerator grid current, A
J_B	=	beam current, A
J_B^+	=	single-ion-beam current, A
J_B^{++}	=	double-ion-beam current, A
J_S	=	current measured by the beam power supply, A
m_i	=	ion mass, kg
T	=	thrust, N
V_B	=	voltage measured by the beam supply, V
V_N	=	net accelerating voltage, V
V_{NC}	=	neutralizer common voltage, V
α	=	thrust loss due to double ions

I. Introduction

THE Dawn spacecraft was launched on 27 September 2007 in the early morning shortly after dawn on an eight-year mission to explore the main-belt asteroid Vesta and the dwarf planet Ceres. The first 80 days after launch were dedicated to a thorough checkout of the spacecraft. A principal focus of this checkout activity was the ion propulsion system (IPS). Proper functioning of the IPS is critical to the success of the mission. The IPS is required to provide all of the postlaunch ΔV (aside from the Mars gravity assist), including the heliocentric transfer to Vesta, orbit capture at Vesta, transfer between science orbits at Vesta, escape from Vesta, heliocentric transfer to Ceres, orbit capture at Ceres, and transfer between science orbits at Ceres. To accomplish this, the ion propulsion system must provide a total ΔV of approximately 10.6 km/s to the spacecraft, which had an initial wet mass of 1218 kg including 425 kg of xenon and 46 kg of hydrazine. Additional details of the mission and spacecraft are given elsewhere [1–4].

A simplified block diagram of the Dawn IPS is given in Fig. 1. The ion propulsion system includes three 30-cm-diam xenon ion thrusters of the type flown on the Deep Space 1 (DS1) mission [5–8], two power processing units (PPUs), and two digital control and interface units (DCIUs). The IPS includes a lightweight, composite xenon tank developed specifically for Dawn that can store up to 425 kg of xenon. In addition to the xenon tank, the xenon feed system consists of two plenum tanks, a xenon control assembly (XCA), a high-pressure subassembly, nine service valves, the interconnecting tubing, and nine flexible propellant lines that go across the gimbal interfaces. Finally, the IPS includes three two-axis thruster-gimbal assemblies (TGAs). Each TGA provides two-axis thrust-vector control with a capability of approximately ± 8 deg in one axis and ± 12 deg in the other. Only one ion thruster is operated at a time on the Dawn spacecraft.

The xenon feed system, described in [9], controls the pressure in each plenum tank to control the xenon flow rate to each thruster. The pressure is controlled using a bang–bang regulation system that cycles high-pressure solenoid valves in response to the difference between the measured plenum pressure and the required pressure.

The Dawn ion propulsion system is designed to be single fault tolerant. To accomplish the mission, at least two ion thrusters, two TGAs, one PPU, and one DCIU must be fully functional after launch. During the 80-day checkout period, the functionality of all of the IPS hardware was tested and the results are summarized herein. A list of the key IPS-related checkout activities is given in Table 1. Operation of the IPS during normal cruise, which began on 17 December 2007, is described by Garner et al. [10].

II. IPS Preparation Activities

After launch, several activities were performed to prepare the ion propulsion system for operation. These activities began at launch plus 4 days with the bake out of the propellant lines downstream of the flow control devices in the XCA followed by cathode conditioning, pressurization of the plenum tanks, initialization of each TGA, cathode ignition, and operation of each thruster in diode mode for 2 h. The checkout plan identified FT3 as the first thruster to be tested. This thruster can be operated by either PPU, is referred to as the "shared" thruster, and is physically located in the center position as indicated in Fig. 2. Thruster FT2 is on the sun side of the spacecraft, positioned below the high-gain antenna, and FT1 is on the shade side of the spacecraft.

The plan called for FT3 to be operated from PPU-1 during the initial checkout (ICO) phase. Each PPU has relays that switch its outputs between each of two thrusters. The relays in PPU-2 can be in any state when the shared thruster FT3 is operated by PPU-1, but it is

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*Principal Engineer, 4800 Oak Grove Drive. Member AIAA.
†Senior Engineer, 4800 Oak Grove Drive. Member AIAA.
‡Senior Engineer, 4800 Oak Grove Drive.