Digital MicroPropulsion

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This paper describes the concept and reports current test results of the “Digital microPropulsion” concept. A new micro-thruster configuration has been fabricated and tested, and a flight-test module has been constructed and tested. Initial space-flight tests of the micro-thrusters are planned for March, 2000.

Propulsion, station-keeping, and attitude control for ≤ 1 kg micro-spacecraft will require a compact and light-weight integrated system for controllably generating tiny amounts of impulse. To accomplish these goals, we adopted a novel approach to micro-propulsion that avoids tanks, fuel lines, and valves. In this concept, an array of small sealed plenums are constructed each with a rupturable diaphragm on one side. The plenums are loaded with a fuel or an inert substance in gas, liquid or solid form. In the case of a fuel, it is ignited and reacts to typically form a high-pressure, high-temperature fluid. In the case of an inert substance, it is heated to raise its pressure. Once the pressure exceeds the burst pressure of the diaphragm, the diaphragm ruptures, and an impulse is imparted as the fluid is expelled from the plenum. Thus, each plenum can deliver one “bit” of impulse. The size of the impulse is determined during fabrication by the size of the plenum and the fuel that is loaded into it. This approach eliminates valves (and therefore consumable) individual thrusters for a multi-use conventional thruster and fuel tank (with a consumable fuel supply).

There are several advantages to this design. These micro-thrusters have no moving parts, each engine has a low parts count, no valves or lines or external tankage. The propulsion function can be combined with the satellite structure. The array of micro-thrusters is highly redundant. The array can be programmed to fire individual thrusters, several thrusters at once, or in controlled sequences. Since the dimensions of the individual rocket engines are under the designers’ control, the creation of smaller and smaller “impulse bits” is straightforward. ≈ 10^6 thrusters can be fabricated on a wafer.

The current Digital Propulsion configuration is shown in Figure . As shown, it consists of a 3-layer sandwich. The top layer contains an array of thin diaphragms (0.5 micron thick silicon nitride, 190 or 290 or 390 microns square). The middle layer contains an array of through-holes (FOTURAN photosensitive glass, 1.5 mm thick, 300, 500, or 700 micron diameter holes) which are loaded with propellant. The bottom layer contains a matching array of polysilicon micro-resistors. The bottom two layers are bonded together, then fueled, then the top layer is bonded to complete the assembly. With a series of different sizes of plenum holes, diaphragms, and resistors, we have 90 different configurations that can be assembled. An assembled and mounted chip and is shown in Figure .

Initial testing, using lead styphnate as the propellant, has produced 10^{-4} Newton-seconds of impulse and about 100 Watts (shown in Figure ), with the expectation that this can be increased by nearly a factor of 10 with more complete combustion of the fuel.

A cylindrical space-flight test module has been fabricated and tested, incorporating a microprocessor to sequentially initiate 28 micro-thrusters and optical devices to sense the firing of the thrusters. Data from the optical sensors will be telemetered to a ground station during the 260 second flight to an altitude of 25 km aboard a commercial sounding rocket.

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Figure 1. Configuration of the Digital MicroPropulsion Chip. (DPconfig)

Figure 2. Digital MicroPropulsion Chip.
Figure 3. FIRING THE MICRO-THRUSTER produces, in this early prototype, 0.1 mN of impulse and 100 W of power. The thrust plume is visible to the right of the chip. This series of images was acquired at 4,500 frames per second.

References